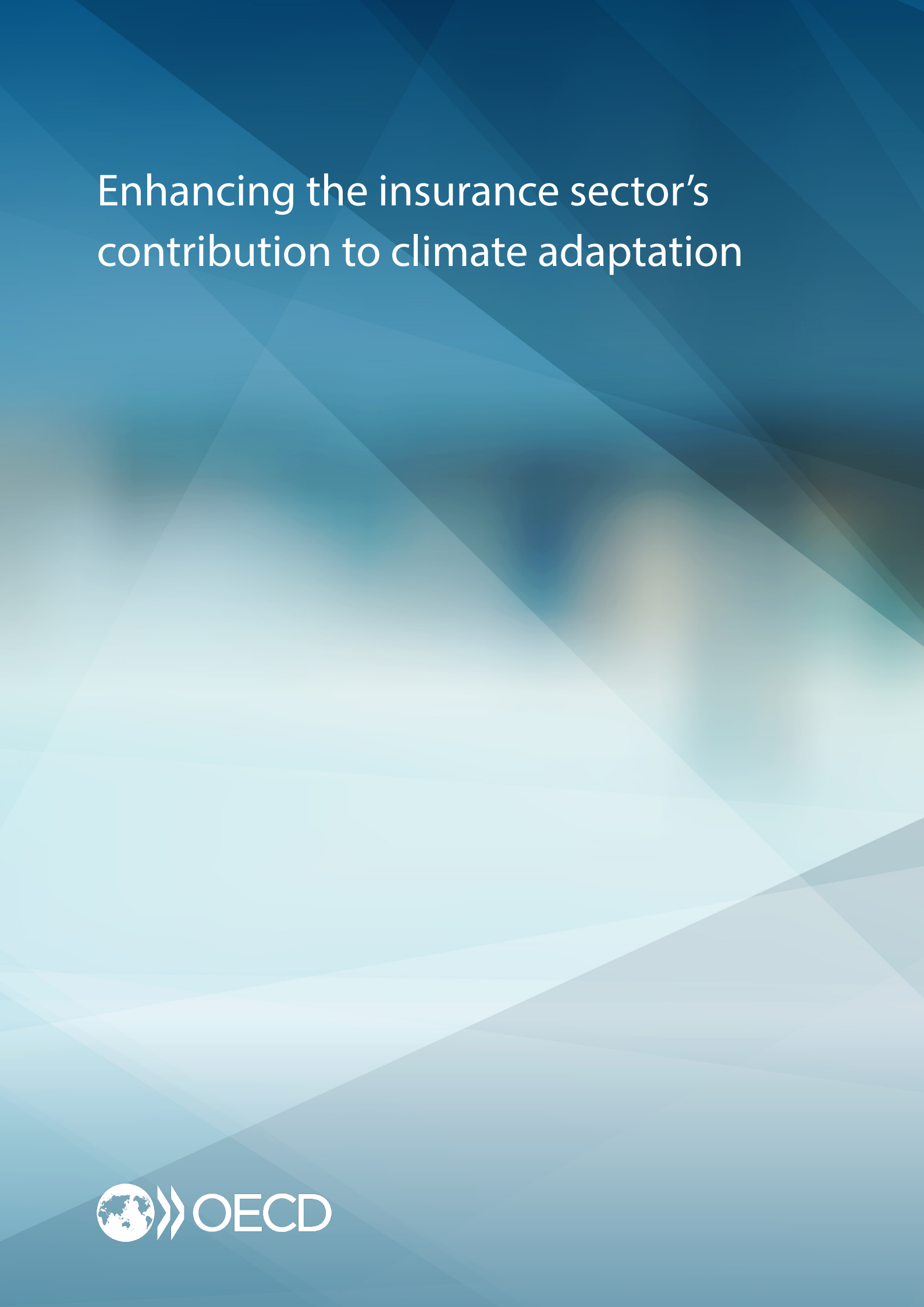
Enhancing the insurance sector's contribution to climate adaptation



OECD

Please cite as: OECD (2023), *Enhancing the insurance sector's contribution to climate adaptation*, OECD Business and Finance Policy Papers, OECD Publishing, Paris, https://doi.org/10.1787/0951dfcd-en.

Insurance coverage plays an important role in protecting households, businesses and governments from the financial impacts of climate-related disasters. However, climate change is expected to increase the frequency and/or intensity of a range of climate-related (weather) perils and could potentially limit the availability of affordable insurance in the future. Risk reduction through adaptation to climate change will be the only sustainable means to limit the increase in future climate damages and losses and potential disruptions to insurance markets. This paper examines the contribution of the insurance sector to climate adaptation. It outlines some of the challenges to assessing future climate risks, encouraging policyholder risk reduction and supporting resilient reinstatement. The paper also identifies potential approaches that policy makers, regulators and supervisors could consider to support a greater contribution of the insurance sector to climate adaptation.

Foreword

Insurance coverage plays an important role in protecting households, businesses and governments from the financial impacts of climate-related disasters. However, climate change is expected to increase the frequency and/or intensity of a range of climate-related (weather) perils, including floods, storms and cyclones, wildfires and droughts and could potentially limit the availability of affordable insurance in the future. Risk reduction through adaptation to climate change will be the only sustainable means to limit the increase in future climate damages and losses, and the potential disruptions to insurance markets that could result.

This paper examines the contribution of the insurance sector to climate adaptation through: (i) developing risk analytical tools; (ii) providing risk information and expertise on adaptation and risk reduction measures; (iii) providing incentives for risk reduction and adaptation; and (iv) supporting more resilient post-event reconstruction. It outlines some of the challenges to assessing future climate risks, encouraging policyholder risk reduction and supporting resilient reinstatement. It also identifies potential approaches that policy makers, regulators and supervisors could consider to support a greater contribution of insurance to climate adaptation.

This paper was prepared by Leigh Wolfrom under the supervision of Timothy Bishop and the oversight of Flore-Anne Messy within the OECD Directorate for Financial and Enterprise Affairs. It benefitted from comments and input from delegates to the OECD Insurance and Private Pensions Committee (IPPC), members of the OECD High-Level Advisory Board on the Financial Management of Catastrophe Risks, members of the Insurance Development Forum and from a number of colleagues from the OECD Environment Directorate, including Andrew Prag, Stephanie Venuti and Simon Touboul. Liv Gudmundson and Eva Abbott (OECD Directorate for Financial and Enterprise Affairs) provided editorial and communication support. This paper was discussed and approved by the Insurance and Private Pensions Committee (IPPC) and prepared for publication by the OECD Secretariat as an IPPC contribution to the OECD Horizontal Project on Climate and Economic Resilience.

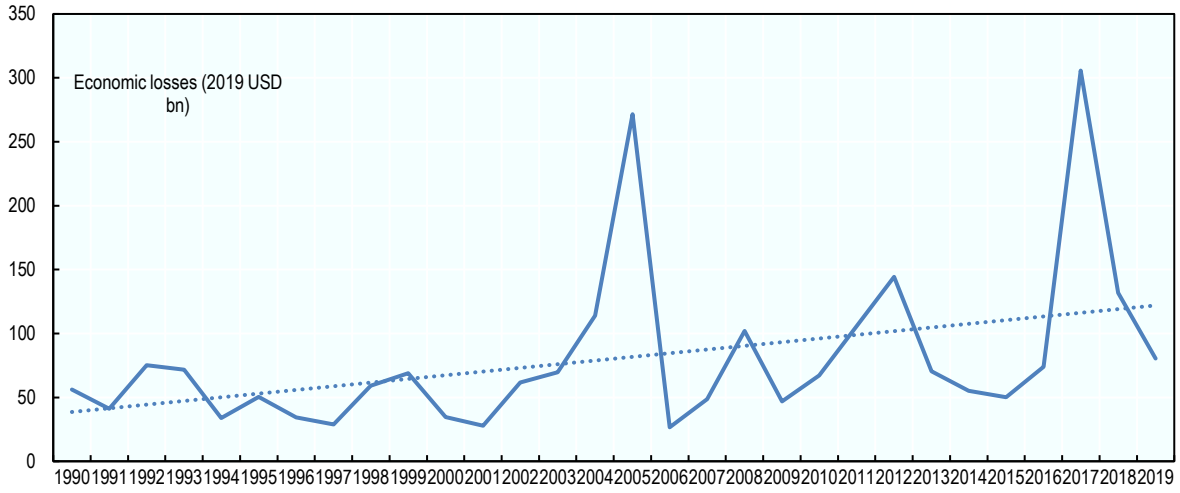
Table of contents

FIGURES

Introduction

A changing climate is expected to increase the frequency and/or intensity of a range of climate change-related weather perils (or "climate perils"[1]), including floods, storms and cyclones, wildfires and droughts. More frequent or more intense climate-related disasters – as well as continued development in hazard-prone locations – will lead to increasing damages to homes, businesses and public assets and losses as a result of disrupted livelihoods and business interruption. There is already some evidence that damages and losses from climate-related disasters are increasing (see Figure 1) This increase is likely driven by a number of factors, including an increase in hazard and growth in exposure (i.e. increasing value at risk for instance due to urbanisation) – along with improvements in reporting and data collection on economic losses from climate events.

Figure 1. Climate-related economic losses in OECD members and accession candidates



Note: Includes all events categorised (primarily) as "Drought, bush fires, heat waves", "Flood", "Hail" or "Storms" in OECD member countries and six OECD accession candidates (Argentina, Brazil, Bulgaria, Croatia, Peru and Romania).
Source: OECD calculations based on data provided by (Swiss Re sigma, 2020[1]).

Insurance coverage for climate perils can play a critical role in absorbing the costs of future climate damages and losses and supporting economic recovery in the aftermath of these disasters. There is some evidence that higher levels of insurance coverage for damages and losses from disasters is linked to

[1] Hazards such as flooding, wildfires and storms are (short-term) weather events whose frequency and/or severity will change as a result of changes in longer-term climate. In this paper, "climate hazards", "climate risks", "climate perils", "climate disasters" and "climate events" refer to the weather-related hazards, risks, perils, disasters or events, respectively whose frequency and/or severity will be impacted by climate change.

quicker recovery and more limited economic disruption.[2] However, in many countries (developed and developing), the level of insurance coverage for climate (and other disaster damages and losses) is relatively low, meaning that households, businesses and governments ultimately absorb a significant share of these damages and losses. For example, in 2021, close to 60% of economic losses from catastrophe events were uninsured (and more than 80% in Latin America and the Caribbean, Africa and Asia) (Swiss Re sigma, 2022[2]). While not the focus of the paper, increasing damages and losses from more frequent and/or more severe climate disasters could limit the availability of affordable insurance in the future if the amount of premiums that needs to be collected to cover higher losses leads to a cost of coverage that is beyond the willingness (or capacity) of households and businesses to pay (EIOPA, 2021[3]).

Mitigating anthropogenic climate change through a rapid and comprehensive transition to a net-zero economy will be critical for avoiding the most severe impacts of climate change. However, some level of global warming will occur (and has already occurred), necessitating investment in adaptation[3] to protect homes, businesses and public assets against the more frequent and more severe climate disasters that are expected no matter the speed of the climate transition. Risk reduction through adaptation to climate change will be the only sustainable means to limit the increase in future damages and losses and the potential disruptions to insurance markets that could result. It is critical for the insurance sector to contribute to this effort in order to: (i) manage the exposure to climate risks assumed through the insurance coverage it provides to households, businesses and governments; and (ii) ensure that insurance coverage for these risks remains available (and affordable) in the future[4] (EIOPA, 2023[4]).

Beyond providing financial protection, insurance can play an important role in identifying assets at risk and encouraging risk reduction and adaptation[5] (as a complement to government investment in risk reduction and adaptation):

- The insurance sector is at the forefront of developing sophisticated risk analytical tools, such as catastrophe models, that can provide probabilistic estimates of the level of risk to homes, buildings and public assets in specific locations, taking into account the structural characteristics of individual buildings as well as any existing protections at the community level (e.g. flood barriers);

[2] A number of examinations of the impact of broad insurance coverage on post-event economic recovery have shown that countries with high-levels of insurance (and reinsurance) coverage usually recover more quickly (Melecky and Raddatz, 2011[81]; Von Peter, Von Dahlen and Saxena, 2012[82]; OECD, 2018[83]; Cambridge Centre for Risk Studies and AXA XL, 2020[84]; Fache Rousová et al., 2021[85]).

[3] Adaptation refers to “adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts” including “changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change” (UNFCCC, n.d.[79]).The focus of this paper is on changes that moderate potential damages and losses (i.e. risk reduction).

[4] For example, it has been argued that some insurance sector characteristics, such as indemnification to pre-event standards, could enshrine existing levels of risk (if homes and businesses are rebuilt in the same place without any measures to reduce risk) (O’Hare, White and Connelly, 2016[51]).

[5] Subject to standards of prudent investment, the insurance sector can also make a potential contribution to adaptation through its investment decisions by allocating investments towards assets that support resilience or adaptation. For example, (re)insurance companies could invest directly in financial instruments that fund resilience or adaptation investments (such as green bonds used to finance adaptation investments or infrastructure projects that contribute to adaptation) or by investing in the debt or equity of businesses or governments that better integrate climate resilience or adaptation into their activities. Many insurers are investing directly in community resilience in partnership with local community groups or other non-governmental organisations (a number of examples are included in (Bouchard et al., 2022[86])). That said, while the insurance sector (and financial sector more broadly) can contribute to climate adaptation, resilience to climate risks will not be achievable without effective contributions from all stakeholders, including policy interventions targeted across the real economy. A discussion of this potential contribution is not included within the scope of this paper.

- Leveraging its claims experience and risk analytics, the insurance sector can provide expertise to individual policyholders or wider communities on adaptation and risk reduction measures that can provide effective protection against climate perils;
- In applying premium pricing that reflects the level of risk at the level of individual policyholders, the insurance sector can provide an important risk signal and incentives for adaptation and risk reduction; and
- Through its role in funding (and sometimes managing) post-event reconstruction, the insurance sector can make an important contribution to supporting resilient reinstatement (or building back better – i.e. rebuilding damaged building to a higher standard of resilience).

The purpose of this paper is to examine existing contributions of the insurance sector to adaptation and ways in which that contribution could be enhanced, with a specific focus on the actions that policy makers, regulators and supervisors can take to support that contribution. In that regard, the findings may support the aims of the *Sharm-El-Sheikh Adaptation Agenda* related to enhancing the property and casualty insurance sector's role in actively supporting project implementation and institutionalising a longer-term industry approach to climate adaptation (COP 27 Presidency, 2022[5]).

Insurance sector contributions to climate adaptation

This section provides an overview of the existing contributions of the insurance sector to risk reduction and adaptation, with a focus on whether: (i) insurance sector risk analytics capture the impact of climate change; (ii) the insurance sector provides expertise to support climate adaptation; (iii) the insurance sector provides incentives to support climate adaptation; and (iv) the insurance sector supports adaptation during post event reinstatement.

Do insurance sector risk analytics capture the impacts of climate change?

The role of insurance companies in assuming risk from policyholders requires that they have the ability to quantify the potential losses they could face as a result of assuming that risk. The ability to quantify potential losses is critical for establishing the premium amounts that they need to collect in order to ensure sufficient financial capacity to pay claims (and remain profitable), establish sufficient levels of reserves and capital and also for transferring risks that they assume to reinsurance (or retrocession) markets. For high-frequency (low-severity) risks, such as motor vehicle accidents or health expenses, insurance companies can generally depend on historical experience, with adjustments to account for changes in behaviour or exogenous factors over time. However, for low-frequency/high-severity events, such as climate-related disasters, historical experience is often insufficient – particularly in the context of changes in climate conditions that affect the frequency and intensity of climate hazards (IAA, 2022[6])

To assess risk, price coverage and manage exposures to climate and other natural hazards, the insurance sector (insurance and reinsurance companies, intermediaries as well as specialised modelling firms) has developed catastrophe models that apply catalogues of hazard events to inventories of exposure (built environment), measures of vulnerability and coverage terms and conditions to estimate the potential financial losses for a given property or portfolio of properties. Catastrophe models can provide estimates of average annual losses (which can be used to inform pricing) as well as exceedance probability (the probability that a given loss will be exceeded – which is often used for establishing reserves and capital) (PRA, 2019[7]). While not all perils or regions of the world are covered by catastrophe models, one of the major modelling companies has estimated that its current suite of models captured approximately 92% of global insured losses between 2000 and 2020 (AIR Worldwide, 2021[8]).

The catalogue of hazard events that is applied in catastrophe models to estimate probable loss distributions is based on a mix of past and simulated catastrophe events. The catalogue of events is updated on a regular basis to integrate more recent events and new simulations although, given the infrequency of these types of events, a significant proportion of the catalogue encompasses events that occurred (or could have plausibly occurred) under past climate conditions (EIOPA, 2021[9]; PRA, 2019[7]). Through its impact on a number of climate variables such as temperature (land and sea), sea-levels and precipitation (amongst others), climate change will lead (and has led) to changes in the frequency and intensity of floods, wildfires, storms, droughts and other climate-related events. These changes are accounted for to the extent that they have already led to a change in frequency or intensity in recent years (through more recent updates

to event catalogues) (EIOPA, 2021[3]) although models are arguably not completely accounting for these changes in the future based on their calibration to past climatic conditions (PRA, 2019[7]; Sclafane, 2022[10]).

Event catalogues that are used to generate loss distributions can be adjusted to account for changes in climatic conditions through "climate conditioning" (Insurance Development Forum, 2020[11]). Climate conditioning of catastrophe models can be accomplished by adjusting the catalogue of events either by selecting events that are more likely under future climate conditions or by adjusting the attributes of the events (e.g. in terms of frequency or severity) to reflect future climate conditions (IAA, 2020[12]; PRA, 2019[7]).

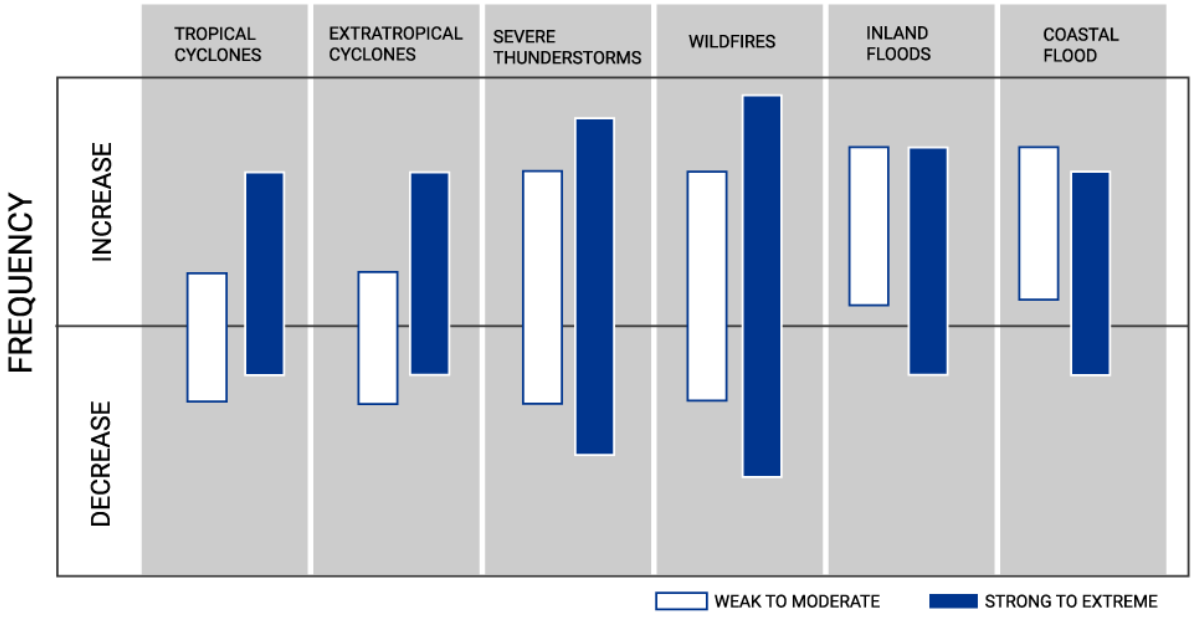
However, there are a number of uncertainties related to future emissions, hazard frequency and severity and exposure and vulnerability that increase the level of uncertainty in loss distributions generated through climate-conditioned catastrophe models – especially for the more distant future:

- *Uncertainty related to the level of future emissions (and the resulting impacts on climate conditions):* The level of future greenhouse gas emissions is unknown and will depend on efforts to mitigate climate change through behavioural changes and new technologies (PRA, 2019[7]). The Intergovernmental Panel on Climate Change aims to account for different future emissions scenarios by providing estimates of future climate variables based on a number of Shared Socioeconomic Pathways (SSPs)[6] describing a future that ranges from a gradual but pervasive transition to a more sustainable path to a scenario involving continued exploitation of fossil fuels.
- *Uncertainty related to the impact of climate change on hazard frequency and intensity:* While future emissions scenarios can provide relatively reliable ranges for some key climate variables, such as increases in sea-levels or temperature, the drivers of extreme events are much more complex to model and involve further uncertainties, including as a result of natural climate variability.[7] For many types of climate perils, the assessment of future climate change impacts involves levels of uncertainty that make it unclear whether frequency will increase or decrease in the future (see Figure 2 for one catastrophe modelling firm's assessment of the level of uncertainty).
- *Uncertainty related to future exposure and vulnerability:* Loss distributions provided by catastrophe models depend on the interaction of hazard with exposure (assets at risk) and vulnerability (the ability (or inability) of assets-at-risk to withstand impacts) although climate conditioning normally only takes into account changes in hazard. Increases in economic development in areas exposed to climate risks has been a significant driver of increases in damages and losses (Grenier, 2022[13]). Increased investment in risk reduction and adaptation to protect communities exposed to climate risks can also have a significant impact on reducing future losses (PRA, 2019[7]).

[6] Shared Socioeconomic Pathways (SSPs) are a set of different pathways to describe alternative futures of socio-economic development based on different levels of climate mitigation and adaptation, ranging from sustainability (SSP1) to fossil-fueled development (SSP5).

[7] Natural climate variability, as a result of climate phenomena such as the El Niño-Southern Oscillation, La Niña or Atlantic Multi-decadal Oscillation, can have significant impacts on annual variation in the frequency and severity of a number of climate perils, such as wildfires, droughts, cyclones and extreme participation (Grenier, 2022[13]; IAA, 2022[6]). There is some uncertainty related to the impact of a changing climate on the frequency and duration of these types of phenomena. For example, there is some evidence that the frequency of La Nina episodes has increased (from occurring in 28% of years between 1950 and 1999 to occurring in approximately 50% of years in the last 25 years), despite climate models predicting the opposite effect in terms of frequency (Borensteinm Seth, 2022[72]).

Figure 2. Uncertainty in the impact of climate change on the frequency of climate events of different magnitudes (for 2100): A catastrophe modeller's assessment



Note: The length of the bars illustrates the level of uncertainty related to expected changes in frequency (by year 2100). The white bars refer to events of weak-to-moderate severity. The blue bars refer to events of strong-to-extreme severity.
Source: (Sousounis and Little, 2017[14])

Catastrophe model providers are managing some of these uncertainties by providing model outputs that incorporate climate change for specific perils and regions, usually incorporating different emissions scenarios. For example, RMS applied predictions of future precipitation patterns under four emissions scenarios to its inland flood model for Europe to estimate potential annual losses in European countries in 2050 and 2090 (Babovic, Sassi and Castéran, 2020[15]). AIR Worldwide applied the Representative Concentration Pathway (RCP)[8] 8.5 (high warming) scenario to its US hurricane model to estimate the potential impact of changes in hurricane frequency and severity and sea-level rise on loss distributions for major US cities in 2050 (Grenier et al., 2020[16]). More recently, the company has released climate projections for its US Hurricane and Caribbean Tropical Cyclone models that provide a probabilistic view of future risk to 2100 under four SSP and RCP scenarios (Verisk Extreme Event Solutions, 2022[17]). Karen Clark and Company has integrated climate change scenarios for five SSPs into its US hurricane model (Karen Clark & Company, 2021[18]). Fathom has integrated future climate into its US and UK flood risk models (Fathom, n.d.[19]). First Street Foundation, a non-profit research group, has incorporated forward (30-year) climate projections into models that provide property-level risk assessment for flood, wildfire, and extreme heat risk for US properties (First Street Foundation, n.d.[20]). Aon, an insurance broker, is integrating climate change-related flood and wildfire risks into its European flood models and US wildfire models through partnerships with academic institutions (Aon, 2022[21]; Carrier Management, 2022[22]).

In some cases, these models are incorporating both changes in hazard and exposure. For example, JBA Risk Management developed a project-specific flood model for European countries that provided loss distributions for both a baseline (2020) and future climate scenario (2050) that accounted for potential

[8] Representative Concentration Pathways (RCPs) are a set of different pathways to describe future levels of greenhouse gas concentrations, ranging from very low future emissions (RCP2.6) to very high future emission (RPC 8.5).

changes in fluvial flooding as well as changes in population at risk (Ludlam, 2021[23]). The specialised modelling firms are also increasingly offering climate conditioned event catalogues, consulting and specific analyses of climate impacts that apply future climate conditions to current models as a service.

Emerging technologies and innovation – and particularly new analytical capacities provided by artificial intelligence and machine learning – are offering new capacities to integrate future climate into existing models. For example, one traditional modelling firm is using machine learning to identify the "rules of atmospheric behaviour that produces extreme events" in order to increase the value of global circulation models for modelling catastrophe loss distributions (Guin, 2020[24]). In addition, a number of new entrants are applying artificial intelligence and machine learning techniques to develop risk scores and models under future climate conditions for a variety of climate-related perils.[9] However, the integration of these types of tools into insurance pricing and exposure management may be impeded by a number of business challenges and some regulatory and supervisory restrictions (see Box 1).

Box 1. Are there impediments to assessing climate risks using catastrophe models or emerging technologies and innovations?

The use of climate-conditioned catastrophe models or analyses and emerging data sources and analytical tools in risk assessment and pricing of insurance coverage for climate-related perils may be impeded by business considerations/challenges and/or by regulatory or supervisory requirements that may restrict the use of these tools.

Business case impediments

The integration of climate-conditioned catastrophe models and analyses and emerging data sources and analytical tools may be limited by a lack of necessary resources or expertise, consumer acceptance or challenges related to tool availability (for example, limited access to climate-conditioned catastrophe models for certain perils or regions). One survey examining the application of data analytical tools to climate risk assessment and pricing found that only 35% of companies had actually adopted advanced data analysis tools such as machine learning in pricing and risk models (Capgemini Research Institute, 2022[25]). However, there appears to be significant interest among (re)insurance companies in applying these types of data sources and analytical tools. Of the 166 industry respondents to a survey for the development of a (forthcoming) report on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector* (from OECD and non-OECD jurisdictions), just under 65% indicated that they had either examined or applied innovative data sources (e.g. data from connected devices, social media or Application Programming Interfaces [APIs]) and just under 50% had either examined or applied advanced data analytical technologies such as artificial intelligence to underwriting assessment (for different lines of business).

[9] Some examples include: (i) Cervest which is using artificial intelligence to create asset-level climate hazard exposure estimates to 2100 (Cervest, n.d.[73]); (ii) Reask which is using machine learning to develop climate-adjusted tropical cyclone models (Reask, n.d.[74]); (iii) Gamma Location Intelligence, which is working with Sust Global to provide property-level climate risk assessments using artificial intelligence (Gamma LI, 2022[77]); and (iv) Jupiter, which uses machine learning to downscale global climate models to derive local climate risk assessments for a number of climate perils (Jupiter Intelligence, 2022[61]).

Regulatory/supervisory impediments

Regulatory requirements could impede the use of catastrophe models (with or without climate change incorporated) or emerging technologies and innovations for the pricing of property insurance coverage offered to households or businesses (or both). For example, in some jurisdictions, pricing of insurance coverage for climate or other catastrophe perils is fixed (e.g. as a fixed share of sum insured) or must be based solely on specified criteria such as location within a hazard zone or construction characteristics – which would limit (if not eliminate) the benefits of using innovative data sources or advanced analytical techniques (including climate-conditioned catastrophe models). Some jurisdictions require that pricing be based solely on historical loss experience (e.g. US state of California (CDI, 2021[26])) or prohibit the use of models, innovative data sources or advanced data analytical tools in insurance coverage pricing.

The 2022 review of implementation of the *OECD Recommendation on Disaster Risk Financing Strategies* found that most OECD respondents do not impose any requirements that could impede the use of catastrophe models and/or the use of new data sources or analytical techniques for underwriting insurance coverage (20 of 24 respondents) (OECD, 2022[27]). Of the 25 (OECD and non-OECD) respondents to a 2022 survey for the development of a report on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector*, approximately 55% did not impose any type of restriction on pricing (fixed pricing or pricing criteria or prior review of pricing) or on the use of new data sources or analytical techniques for underwriting property insurance coverage. That said, approximately 17% of the 166 (re)insurance companies that responded to an industry survey for the same project indicated that they faced challenges in receiving regulatory or supervisory approval for the use of emerging technologies and innovations for risk assessment, underwriting or pricing/rating (although the challenges may have been encountered for approvals in other lines of business).

The short-term nature of insurance coverage for climate (and other) risks to property – with annual renewals (and potentially re-pricing) – has also likely impacted the demand for risk assessment and pricing tools that integrate a longer-term horizon that accounts for the impacts of a changing climate (Surminski, Barnes and Vincent, 2022[28]; EIOPA, 2021[3]). While model providers have integrated longer-term climate risk into some models – or have published analyses on the impact of integrating longer-term climate conditions – catastrophe models for most perils and regions remain focused on current and near-term climate (i.e. 0 – 10 year timeframe) (AIR Worldwide, 2021[8]).

Does the insurance sector provide expertise to support climate adaptation?

The risk assessment and risk management expertise that the insurance sector has developed to manage its own exposures can be leveraged to support risk reduction and adaptation: (i) by making climate risk information available in order to build awareness about exposure to climate risk; and (ii) by providing advice on potential risk reduction and adaptation investments (Jarzabkowski et al., 2019[29]).

The insurance sector recognises the contribution that they can make in providing climate risk information to governments to inform development planning, building codes and public risk reduction and adaptation investments (Surminski, Barnes and Vincent, 2022[28]; Insurance Development Forum, 2020[11]). Insurance companies (or associations) in Austria, Germany, Switzerland and the United Kingdom have supported the development of national risk maps with the aim of supporting risk awareness and improved land-use planning (Warner et al., 2009[30]; Seifert-Dähnn, 2018[31]). In Norway, the insurance association has aggregated and shared information on flood insurance claims with municipalities in order to support risk reduction (Ebeltoft, 2016[32]). The Insurance Development Forum, which involves industry and representatives from international organisations and development co-operation agencies, has established

a Global Risk Modelling Alliance to support the availability of risk analytics and catastrophe models in developing countries vulnerable to a changing climate (Insurance Development Forum, 2021[33]).

Risk analytical tools developed by the insurance sector can help governments identify areas facing high exposure to climate risks where future development should be limited (Insurance Development Forum, 2020[11]). These tools can be used to assess the benefits of strengthening building codes or increasing building code enforcement (Jarzabkowski et al., 2019[29]). Catastrophe models (and other risk analytical tools) can also help assess the benefits of risk reduction and adaptation investments in terms of avoided losses. For example, JBA's UK flood model allows estimation of the benefits (reduced losses) from investing in flood defences to protect against, river, surface and coastal flooding (JBA Risk Management, 2022[34]). RMS worked with the American Forest Foundation to apply modifications to its US wildfire model in order to estimate the potential benefits of applying different forest management practices (as the net present value benefit of investing in treatment options relative to the cost of those treatment approaches) (Young, 2022[35]). In the United States, the National Association of Insurance Commissioners is establishing a Catastrophe (CAT) Modeling "Center of Excellence" that will, among other functions, support the use of catastrophe models to identify high-risk areas where risk reduction measures will be critical for enhancing resilience and for demonstrating the economic value of risk reduction measures (NAIC Center for Insurance Policy and Research, 2021[36]).

The insurance sector also recognises the contribution that they can make to adaptation by providing risk information and expertise on risk reduction and adaptation to policyholders. In many countries, the insurance sector has established research institutes aimed at identifying effective protection measures against natural hazards (such as the Institute of Business and Home Safety (IBHS) in the United States). In a recent white paper on climate transition and resilience, the French insurance association proposed the establishment of a research programme to identify effective prevention measures (France Assureurs, 2022[37]).

Many insurance associations provide information to policyholders on risk reduction and adaptation measures that they can take (Seifert-Dähnn, 2018[31]; Suykens et al., 2016[38]). The 2022 review of implementation of the *OECD Recommendation on Disaster Risk Financing Strategies* found that risk awareness initiatives implemented by the insurance sector (or government) included information on potential risk reduction measures that households or businesses could undertake in most OECD country respondents (15 of 18 respondents) (OECD, 2022[27]). One European insurance company that participated in EIOPA's *pilot exercise on the implementation of climate-related adaptation measures in non-life insurance products* offers risk assessment visits to residential policyholders (without additional charge) to provide information on climate change-related weather hazards and recommendations on risk reduction options (EIOPA, 2023[4]). The sector's risk analytical tools can also be used to quantify the potential benefits of risk reduction and adaptation benefits at the level of specific properties. For example, RMS' US wildfire model can reportedly account for property-level risk factors, such as the types of roofing materials, property vegetation density and distance between homes and vegetation (Young, 2022[35]).

However, there is limited (and sometimes contradictory) evidence on whether building awareness of risk reduction and adaptation options leads to increased policyholder investment in risk reduction and adaptation. Some examinations of this question in France, Germany and the United States have found evidence that those that sought or were provided with information on flood protection measures were more likely to make investments in flood protection (Poussin, Botzen and Aerts, 2014[39]; Sims and Baumann, 1987[40]; Thieken et al., 2010[41]). In Austria, England and Romania, one survey found that households that received information on potential flood risk reduction measures (as well as premium discounts – see below) were more likely to invest in such measures (Hanger et al., 2018[42]). However, a study focused on households in Italy found no evidence that communications on potential risk reduction measures influenced household willingness to make such investments (Miceli, Sotgiu and Settanni, 2008[43]).

Despite industry (and government) efforts to provide information on potential risk reduction and adaptation measures, there is some evidence that many residential policyholders are not receiving such information. A survey of insured households in Austria, England and Romania found that only 30% of Romanian households, 20% of Austrian households and 5% of English households reported receiving information on potential risk reduction measures from their insurance companies (Hanger et al., 2018[42]). EIOPA's *pilot exercise on the implementation of climate-related adaptation measures in non-life insurance products* found that only 25% of the 31 participating insurance companies provided climate-related risk information to policyholders and only some provide specific information on practical risk reduction measures that policyholders could take (EIOPA, 2023[4]).

Digitalisation and innovation might have both advantages and disadvantages for the provision of risk reduction and adaptation information and advice to policyholders. Digital distribution of insurance coverage could limit the interaction with a knowledgeable intermediary that can provide information on risk and risk reduction options (EIOPA, 2021[3]) although new technologies might also provide new mechanisms for communicating this type of information to policyholders. Among the 166 insurance companies that responded to a 2022 survey for the development of a report on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector*, 44% indicated that they had examined the potential for – or had developed – dedicated smartphone applications to support risk reduction by policyholders (although for various lines of business).

Providing tailored (rather than general) advice to individual (particularly residential) policyholders is likely more challenging for the insurance sector given the high transaction costs that would be involved in assessing risk and identifying potential risk reduction investments at the level of individual buildings (Seifert-Dähnn, 2018[31]). As a result, tailored risk reduction advice is usually only available to larger (corporate) policyholders (EIOPA, 2021[3]).[10]

In some jurisdictions, the inclusion of risk mitigation services could have an impact on insurance product approval (e.g. Mexico, Philippines) and could potentially create an impediment to the insurance sector's ability to provide such advice. In Poland, the *Insurance and Reinsurance Activity Act* prohibits insurers from involvement in any activity other than insurance (which would prevent them from providing risk mitigation services). In the United States, risk mitigation services that are provided to policyholders at no cost (e.g. a water detection device) would need to comply with anti-rebate laws applied at US state-level in some states. Approximately 15% of the 166 insurance companies that responded to the survey for the project on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector* indicated that they had faced challenges in receiving regulatory or supervisory approval for the use of emerging technologies and innovations for offering risk prevention or mitigation services or products to policyholders (although, some of these challenges may have been related to services offered under other lines of business).

[10] There are many examples of insurance companies providing risk information and risk reduction advice to corporate policyholders. For example, FM Global provides "Climate Risk Reports" that provide risk information on specific locations by peril as well as information on potential mitigation actions (along with a resilience credit (premium offset) equivalent to 5% of paid premiums to fund identified adaptation measures) (FM Global, n.d.[76]). Similarly, AXA Climate Consulting Services provides asset-by-asset climate risk assessment and adaptation advice to businesses on a consulting basis (author's personal communication with AXA Climate). Zurich Insurance has a business unit (Zurich Resilience Solutions) that supports corporate policyholders in reducing risk and has recently announced a partnership with South Pole to provide an assessment of both carbon emissions and climate risk with the aim of developing longer-term strategies for both reducing emissions and building climate resilience (Zurich Resilience Solutions and South Pole, n.d.[80]).

Does the insurance sector provide incentives to support climate adaptation?

Premium pricing (or deductibles) for residential or commercial property insurance coverage that reflects the level of risk for individual policyholders can provide an incentive for policyholder adaptation (EIOPA, 2021[3]). If a high-risk policyholder is faced with a high premium for coverage (or a high deductible) – and can benefit from a lower premium (or deductible) by investing in adaptation measures, the potential cost savings will provide an incentive for making that investment (as the reduction in premium will absorb some of the cost of the adaptation measure).

One recent survey of US residential policyholders found that the vast majority of respondents (77%)[11] indicated a willingness to make risk reduction investments in order to benefit from a premium reduction, indicating that many policyholders are aware of the relationship between risk reduction (or adaptation) and the cost of insurance (Center for Insurance Policy and Research, 2021[44]). A survey of flood-exposed households in the Netherlands found a similar level of willingness to make investments in risk reduction in order to benefit from reduced premiums (68% were willing to make such investments) (Warner et al., 2009[30]). An analysis of survey responses from insured households in Austria, England and Romania found that households that were able to benefit from a premium discount for risk reduction investments were more likely to invest in structural risk reduction measures (Hanger et al., 2018[42]).

However, despite the potential for risk-based pricing and premium discounts to incentivise policyholder risk reduction and adaptation investments (and few regulatory or supervisory restrictions, as discussed in Box 2), there is limited evidence that demonstrates whether risk-based pricing has actually led to significant policyholder investment in risk reduction or adaptation (Hanger et al., 2018[42]; Priest, Penning-Rowsell and Suykens, 2016[45]; Surminski and Thieken, 2017[46]).

There are a number of examples where insurance companies provide premium discounts for risk reduction and adaptation investments:

- In the United States, a number of insurance companies, particularly in hurricane-exposed states, offer discounts to households that make investments to meet a set of “FORTIFIED” construction standards for homes (or roofs) – and many US states require insurers to offer these discounts (Smart Home America, n.d.[47]) (see discussion on Potential approaches to enhancing the insurance sector contribution to adaptation).
- In Germany, insurance companies have worked with some households that are highly exposed to flood risk to identify tailored risk reduction measures that can be implemented and have offered premium reductions for those that have implemented these measures (Seifert-Dähnn, 2018[31]).
- In Barbados, one insurance company offered significant premium discounts (25%-40%) to households and businesses that made investments in retrofitting buildings to protect against hurricane-force winds (Warner et al., 2009[30]).
- In the Netherlands, a provider of catastrophe insurance coverage has reportedly offered premium discounts to policyholders that take specific measures to reduce potential losses from flooding, including installing electrical and heating equipment above the ground floor, ensuring the availability of flood shields and installing a water-resistant floor on the ground level (Surminski et al., 2015[48]).

However, it has been suggested that premium discounts are not commonly provided (EIOPA, 2021[3]; Hanger et al., 2018[42]; Suykens et al., 2016[38]) and applied inconsistently by insurance companies (University of Cambridge Institute for Sustainability Leadership (CISL), 2021[49]). One survey of

[11] The same survey found that 42% of respondents indicated a willingness to invest a given amount into risk reduction investments (USD 501 to USD 2 500) if that investment will lead to a premium reduction of 1% to 10% (Center for Insurance Policy and Research, 2021[44]).

policyholders in Austria, England and Romania found that very few of the respondents in any of the three countries were aware of the availability of premium discounts from their insurers for risk reduction measures (Hanger et al., 2018[42]) (which may be due either to a lack of awareness or limited availability of premium discounts from insurers).

There are a number of potential impediments to providing effective incentives for risk reduction through premium pricing (or deductibles):

- As outlined in the previous section, policyholders may not be aware of the adaptation measures that can be taken to reduce premiums or deductibles (or the availability of premium discounts), may underestimate their exposure to climate perils, the costs that they could face if affected and/or the benefits of risk reduction and adaptation measures (EIOPA, 2021[3]; Hanger et al., 2018[42]; Priest, Penning-Rowsell and Suykens, 2016[45]; Seifert-Dähnn, 2018[31]).
- Policyholders may not have access to (the potentially substantial) funding or financing needed to implement the risk reduction and adaptation measures that could lead to lower premiums (Seifert-Dähnn, 2018[31]; Warner et al., 2009[30]).
- The most effective risk reduction or adaptation investments might be outside the control of the individual policyholder (e.g. the construction of a flood barrier that protects a broader community).[12]
- Insurance companies may not be sufficiently confident that some risk reduction or adaptation investments will effectively reduce future losses (and therefore unwilling to provide premium discounts for such investments)[13] or may only make discounts available for properties at high risk where the level of potential loss reduction is more substantial (EIOPA, 2023[4]; Suykens et al., 2016[38]).
- Premium pricing (or deductibles) applied by insurance companies may not be sufficiently reflective of (longer-term) climate risk to provide the necessary price signal. The price signal may be dampened if: (i) the coverage for climate perils is bundled with coverage for other perils without a clear allocation of premium cost for climate perils (which is a common practice in many countries) (EIOPA, 2021[3]; Seifert-Dähnn, 2018[31]); (ii) there is a reliance on the possibility for frequent re-pricing to account for changes in climate conditions or excessive uncertainty about future climate conditions; or (iii) other factors are incorporated into pricing (e.g. competition, reputational or other business considerations (EIOPA, 2021[3]; Seifert-Dähnn, 2018[31]).
- Risk-based premiums or deductibles or premium discounts for risk reduction or adaptation measures may not be permitted in some countries (see Box 2).

[12] One approach that has been proposed is the establishment of community-based catastrophe insurance whereby a local government or other community-based authority acquires insurance coverage on a collective basis on behalf of members of the community. This approach can provide benefits in terms of ensuring broad affordable coverage of covered risks. It could also support community-level risk reduction efforts (and capture the benefits of reduced premiums on behalf of community members) which may be the most effective approach to reducing risk in some cases (i.e. in cases where protecting a community is more effective than protecting each individual property (Bernhardt et al., 2021[71])).

[13] Insurance companies may have more confidence in the risk reduction benefits of public investments relative to investments by individual households (based on the perception that public investments are more likely to be properly installed and maintained), permanent property-level measures (such as floor elevation to protect against flood) (Priest, Penning-Rowsell and Suykens, 2016[45]) and measures that do not require a specific action by policyholders in the hours before a potential impact (such as closing of storm shutters) (Suykens et al., 2016[38]). In addition, for policyholders to benefit from a reduced premium as a result of a risk reduction investment, that investment would need to be accounted for in the insurer's risk assessment – which may depend on the nature (level of detail) of the insurer's risk assessment process for establishing premiums.

In addition to providing incentives through risk-based pricing, insurance companies could also impose requirements or conditions on policyholders to undertake risk reduction or adaptation measures in order to benefit from coverage. The requirement could be imposed as a prerequisite (i.e., the measures must be implemented prior to receiving coverage) or as a condition included when providing coverage (i.e., a requirement for the measures to be implemented during the period of coverage in order for the policyholder to be eligible for reimbursement of damages or losses). For example, in Germany, increasing numbers of insurers are reportedly requiring property-level flood risk reduction measures as a condition of insurance for policyholders at high-risk of flooding (Seifert-Dähnn, 2018[31]). This type of requirement would likely be difficult to impose in a competitive market, except in the case of policyholders facing an extremely high-level of risk and with few options in terms of coverage providers. It could also lead to reduced access to insurance for those unable to take such measures if they are costly.

Box 2. Policy, regulatory or supervisory restrictions on risk-based pricing

Government policies, regulation or supervisory requirements may restrict the ability of insurance companies (or catastrophe risk insurance programmes) to set premiums or deductibles that reflect the level of risk faced by individual households or businesses.

Simplified pricing frameworks applied by catastrophe risk insurance programmes

In many countries where catastrophe risk insurance programmes provide coverage for some or all climate-related risks, simplified approaches to pricing insurance coverage are in place. In Iceland, France, New Zealand, Norway, Switzerland (some cantons) and Spain – coverage for some climate-related perils is priced based on sum insured (and type of occupancy in some cases) without regard to the location or construction characteristics of the insured property. In the United States, National Flood Insurance Program premiums are generally risk-based although with various provisions that limit the cost of insurance for high-risk properties. In the United Kingdom, the reinsurance coverage provided by Flood Re for policyholders facing high flood risks is priced based on a measure of wealth rather than risk. As a result, coverage provided by these programmes do not provide a full price signal reflecting levels of risk.

Mandated pricing frameworks

Some countries (mostly developing countries) impose specific requirements related to the pricing of property insurance coverage for climate-related (and other catastrophe) perils, either as a fixed cost based on sum insured or based on a pricing framework that accounts for some specific property characteristics (occupancy, construction type, location in a hazard zone). Among the 25 insurance regulators that responded to a 2022 survey for the development of a report on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector*, approximately 14% imposed requirements on premium-setting for residential and commercial property insurance coverage (i.e., premiums must be established based on sum insured or specific rating criteria). Pricing based on sum insured or only a few specific rating criteria could dampen the price signal in premium pricing. In addition, approximately 27% of responding jurisdictions require insurers to submit information on pricing approaches for supervisory approval which – depending on the approach to supervisory review – could also dampen price signals if some relevant rating criteria are not permitted.

Restrictions on premium discounts

In a small number of countries, insurers may not be allowed to provide discounts (or lower deductibles) for risk reduction or adaptation investments made by policyholders. Three of the 25 jurisdictions that responded to the 2022 survey for the development of a report on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector* indicated that there were regulatory or supervisory requirements that could impede insurance companies' ability to provide premium discounts to residential property insurance policyholders for investments that might reduce risk.

Does the insurance sector support climate adaptation during reinstatement?

The insurance sector has an opportunity to support risk reduction and adaptation through the payments that they make to policyholders that have incurred damage from a climate event. Enhancing the resilience of structures against climate risks has been demonstrated to be more cost efficient (and less disruptive) than making risk reduction investments to a non-damaged building (Lamond et al., 2019[50]; O'Hare, White and Connelly, 2016[51]). The standards to which damaged homes and businesses are rebuilt can have a significant impact on future exposure to losses from climate-related events (Priest, Penning-Rowsell and Suykens, 2016[45]) and can benefit from the expertise of the insurance sector in assessing effective measures for risk reduction. The strengthening of building codes to account for future climate risk can help ensure that reinstated structures are more resilient.

The insurance sector recognises the potential benefits of leveraging the reinstatement process for reducing future risk and adapting to a changing climate. For example, the Global Federation of Insurance Association released a set of "key principles for more resilient and sustainable construction" that recommends that – in order to avoid recurring disasters "identical reconstruction after a natural disaster should not be the default" (GFIA, 2021[52]). In a white paper on climate transition and resilience, the French insurance association proposed the establishment of a research programme to identify effective risk reduction measures that could be implemented before or after a climate event (France Assureurs, 2022[37]). In Canada, the Institute of Catastrophic Loss Reduction (an insurance sector-funded research institute) established an "'Insurers Rebuild Better Homes" programme that sets out specific elements that should be incorporated by insurers (and policyholders) during reinstatement (Canadian Underwriter, 2016[53]). Similarly, in the United States, the FORTIFIED construction standards provide a set of principles for resilient reinstatement that has been examined by number of insurers (Jarzabkowski et al., 2019[29]).

However, most residential and commercial property insurance coverage only requires insurance companies to reinstate damaged property to the same (or a materially equivalent) condition as prior to incurring the loss (Rosenfield, 2022[54]). Policyholders may have some flexibility to receive a cash settlement and may not have a specific obligation to reinstate their existing home or reinstate the home in the same location, although the obligations of the insurer are generally limited to providing sufficient funds to rebuild only to the same standard (Rosenfield, 2022[54]). As a result, communities rebuilt after catastrophe events will generally face the same level of exposure to similar events in the future. For example, after the 2007 summer flooding in England, approximately 82% of damaged homes were returned to their pre-event condition with no increase in their resilience to future flooding (Joseph, Proverbs and Lamond, 2014[55]).

Most jurisdictions do not impose regulatory or supervisory measures that could impede the ability of insurance companies to support resilient reinstatement. Among the 25 insurance regulators that responded to a 2022 survey for the development of a report on *Leveraging digitalisation for risk prevention and mitigation in the insurance sector*, only three jurisdictions indicated that existing regulatory or supervisory requirements could impede an insurance company from supporting or funding policyholder risk prevention

or mitigation measures after a claim is incurred.[14] Among the 166 insurance companies that responded to a survey for this project, approximately 8% indicated that they had faced challenges in receiving regulatory or supervisory approval for supporting (or funding) policyholder risk mitigation measures after a property insurance claim.

The main impediment to resilient reinstatement is the additional cost involved for the insurer as insurance companies are not obligated to pay for any form of betterment (and will often discount the cost of betterment repairs from the claims payments they make to policyholders (Rosenfield, 2022[54])). For private (profit-motivated) insurers, there is little incentive to help policyholders implement more resilient reinstatement if it leads to greater costs as policyholders may choose to purchase future coverage from another insurance company who will then capture the benefits of reduced future losses (Seifert-Dähnn, 2018[31]; Warner et al., 2009[30]). For example, in Germany, some insurers have reportedly permitted repairs that improve flood resilience for policyholders with damaged property although only where such improvements do not lead to higher costs relative to standard reconstruction (Seifert-Dähnn, 2018[31]).

Resilient reinstatement (or other post-event risk reduction measures) have more commonly been implemented in countries where the insurance coverage for climate risks is supported by a catastrophe risk insurance programme. For example, in France, insurers have (indirectly) supported post-event relocation of impacted policyholders through funding provided by a prevention fund financed by premiums (Poussin, Botzen and Aerts, 2014[39]). In the United Kingdom, Flood Re has worked with a group of direct insurers to launch a Build Back Better scheme that will offer up to GBP 10 000 in additional payments to policyholders (i.e. additional to repair costs) for flood resilience measures (Hay, 2022[56]).

[14] In Colombia and Costa Rica, respondents pointed to legal requirements that limit insurance companies' activities to core insurance functions as a possible impediment. In Poland, the respondent noted a legal requirement that claims paid by insurers could not be higher than the amount of damage incurred by the policyholder.

Potential approaches to enhancing the insurance sector contribution to adaptation

The section above identified a number of potential areas where the insurance sector contributes to climate adaptation, by: (i) developing risk analytics and catastrophe models that account for climate change; (ii) providing climate risk information and advice on risk reduction and adaptation to governments and policyholders; (iii) incentivising policyholder risk reduction and adaptation through premium pricing; and (iv) supporting risk reduction and adaptation through resilient reinstatement. However, a number of challenges were identified that likely impede the contribution that the insurance sector is making to climate adaptation, including: (i) a focus on near-term climate in risk assessment due to uncertainties related to future climate and socio-economic developments and limited demand for longer-term climate risk assessment; (ii) limited policyholder appetite for investment in risk reduction and adaptation, likely due to a lack of awareness of risks and risk reduction options and benefits as well as the cost of such measures; and (iii) competitive dynamics that limit the incentives for insurance companies to invest significantly in tailored risk reduction advice and resilient reinstatement. The following section outlines some possible approaches to responding to some of these challenges.

Encouraging climate-conditioned risk analytics and a longer-term outlook in climate risk assessment

As noted, the insurance sector's capacity to assess and quantify climate risk, through catastrophe models and other risk analytical tools, can provide a critical contribution to climate risk management. An accurate assessment of climate risk and the effectiveness of risk reduction and adaptation investments for mitigating climate risk forms the basis of the insurance sector's ability to provide risk management expertise to governments, households and businesses and incentivise risk reduction and adaptation through risk-based pricing. However, uncertainties related to future emissions, socio-economic developments, adaptation investments as well as how future changes in temperatures, sea levels and other climate parameters will impact hazard frequency and intensity impede the ability of risk analytical tools to confidently provide estimations of future loss distributions.

That said, the availability of climate-conditioned event sets and modelling outcomes is increasing. The insurance sector has the risk analytical capacity to provide estimates of future losses under different emissions and socio-economic development scenarios (subject to a certain level of uncertainty) – although this expertise has (thus far) not been broadly applied across countries and perils. The short-term nature of property insurance policies and the ability of insurers to re-price coverage on an annual basis likely impedes the demand (to some extent) for longer-term climate risk analytics.

As commercial (for-profit) entities, the specialised catastrophe modelling firms – as well as the many new entrants that are applying emerging technologies to climate risk assessment – are motivated by demand

for their analytical tools from the insurance and reinsurance companies that use these tools for pricing and exposure management. This is demonstrated by the country and peril coverage of existing commercial catastrophe models, which is generally focused on countries and perils where private insurers have assumed significant catastrophe risk (OECD, 2021[57]).

While not the main objective of insurance supervision, regulatory and supervisory efforts to ensure that insurance companies are appropriately monitoring climate risks are creating incentives for the development of longer-term climate risk assessments. For example, the Bank of England's 2021 Climate Biennial Exploratory Scenario exercise, which required certain insurers to provide a quantitative assessment of the impact of climate on average annual losses and 1-in-100 year exceedance probability, led modelling companies to release specific tools or provide expertise to help insurers meet this requirement (Clarke and Latchman, 2021[58]; Ellison, 2022[59]). The European Commission is proposing amendments to the Solvency II directive, including (i) a requirement for (re)insurers with material exposure to climate change to include long-term scenario analysis in future own risk and solvency assessments (ORSA); and (ii) a requirement for EIOPA to review the calibration of the standard parameters of the non-life catastrophe sub-module of the Solvency Capital Requirement to ensure that the latest climate science is taken into account (European Commission, 2021[60]). If implemented, these proposals will likely increase demand for risk analytics that incorporate longer-term climate risk.

Similarly, regulatory or supervisory impediments to the use of new data sources and emerging data analytical capacity (such as artificial intelligence and machine learning) in insurance pricing (see Box 1) could also limit the demand for these tools and the incentives for innovators to develop and commercialise such tools. While the use of non-traditional data and pricing approaches needs to be closely monitored to protect consumers[15] and also ensure the accuracy of their results (including through appropriate scientific oversight of their use in climate risk assessment (Jupiter Intelligence, 2022[61])), broad impediments without any ability for insurers to experiment with these approaches could stifle the innovation that is likely needed to overcome the challenges in improving future climate risk assessment and making such assessment more broadly available.

Addressing barriers to insurance sector risk management services, risk-based pricing and resilient reinstatement

As noted, the risk assessment capacity and risk management expertise of the insurance sector (particularly where longer-term climate risk can be confidently incorporated) can be shared to support risk reduction and adaptation decisions by households, businesses and governments and incentivise risk reduction and adaptation through risk-based premiums (or deductibles) and premium discounts for implemented measures. However, as discussed above, there are a number of policy, regulatory, supervisory and commercial impediments to the provision by insurance companies of risk management advice and services and the application of risk-based pricing and premium discounts – as well as significant barriers to policyholder investment in risk reduction and adaptation, including risk awareness as well as financial constraints (see section on Public funding or guarantees for resilience measures (*ex ante and ex post*) to complement insurance).

Governments, regulators and supervisors should consider whether the benefits of these policy, regulatory or supervisory impediments (which may be aimed at consumer protection, broad affordable coverage or competitive markets) outweigh the costs in terms of restricting the insurance sector role in advising on and

[15] The use of artificial intelligence for underwriting insurance coverage can lead to a number of risks for consumers, including the potential for biased or discriminatory outcomes (including the use of prohibited rating factors) as well as the potential for financial exclusion.

incentivising risk reduction and adaptation – or whether other (or adapted) approaches might be able to achieve these objectives while still contributing to climate adaptation:

- As noted, a small number of jurisdictions have regulatory or supervisory requirements that could impede the provision of risk expertise and mitigation services by insurance companies. Where these requirements exist, they appear to be linked to either: (i) efforts to limit the scope of business activities that licensed insurance companies engage in, potentially as a means to ensure that the primary activity of a licensed insurance company is providing insurance coverage (i.e. instead of other commercial activities); or (ii) as a means to ensure that insurance companies do not circumvent pricing regulation by offering benefits to policyholders without charge. Regulators that impose these types of restrictions may wish to consider whether these objectives could be achieved without restricting the provision of risk management services, which ideally should be considered a critical and beneficial activity that is core to the delivery of insurance. For example, in the United States, the National Association of Insurance Commissioners made amendments to its model *Unfair Trade Practices Act* in 2021 in order to allow insurance companies to offer value-added products and services in connection with the sale of insurance, including risk expertise and management services (Holahan, Lee and Roehl, 2021[62]).
- In the (more significant) number of jurisdictions where risk-based pricing is limited by rating approval requirements or the presence of catastrophe risk insurance programmes that apply flat (or relatively flat) pricing frameworks, policyholders could be provided with information on what the risk-based (actuarial-based) premium would be if there were no impediments to risk-based pricing. This would at least provide a price signal to the policyholder related to the level of risk that they face, even if the actual premium paid may not provide a significant incentive for risk reduction (a shift towards greater risk-based pricing would be more effective in creating such incentives). It could also provide a signal to governments on where risk reduction or adaptation investments should be made (for example, if households in a specific community are facing unsustainable levels of current of future risk) (Jarzabkowski et al., 2019[29]).

If desirable, there may be opportunities for insurance companies to provide better information on climate risk and potential adaptation investments that policyholders can make – potentially encouraged by regulators and supervisors although, for some insurance supervisors, this role may not be considered consistent with a mandate focused on policyholder protection and enforcement of legal requirements. Such approaches could include, for example:

- Insurers could potentially provide policyholders with information on how their premium might be impacted in the future by a changing climate (which could also increase the demand for longer-term climate-conditioned risk analytics). Given the level of uncertainty related to future climate risk, any such disclosures would clearly need to be provided as indicative while highlighting the inherent uncertainties.
- Insurers could potentially provide policyholders with information on risk reduction and adaptation measures that they could take to reduce their risk (and premiums), based on current as well as future climate conditions. Ideally, such disclosures would provide quantitative estimates of the potential reduction in future loss (and potentially future premium costs) in order to provide policyholders with the information that they need to make informed decisions on the costs and benefits of such investments. Any such disclosures could also include information on potential sources of funding or financing for risk reduction and adaptation investments (see section on Public funding or guarantees for resilience measures (*ex ante and ex post*) to complement insurance).
- Insurers could potentially provide policyholders with specific information on available premium discounts for risk reduction and adaptation measures, including any conditions that must be met in order to receive that discount. For example, insurance companies in the US state of Florida are legally required to provide policyholders with information on available premium discounts (Warner

et al., 2009[30]). Insurers could provide policyholders with information on trusted contractors to implement such investments, which could also provide insurers with some confidence that the measures are correctly installed. Providers of risk analytics could be encouraged to support the availability of evidence on the effectiveness of various types of property-level risk reduction and adaptation measures in order to help insurers and policyholders assess the relative benefits and effectiveness of different approaches (and the reduction in premiums that should follow).

Regulators and supervisors could also assess whether it would be helpful to encourage (or possibly require) insurance companies to provide premium discounts for specific (and effective) risk reduction and adaptation measures. A number of US states, for example, require insurers to provide premium discounts to households that implement specific strengthening measures.[16] In October 2022, the California Insurance Department issued regulations requiring insurance companies to provide discounts for a specific set of community and property-level wildfire risk mitigation actions as well as information on the individual property's "wildfire risk score" and on mitigation measures to reduce (improve) that risk score (CDI, 2022[63]). However, these types of requirements should be applied carefully to ensure that the mandated discounts do not put insurer solvency at risk. In the US state of Florida, for example, it has been suggested that legislative requirements to provide a broad range of premium discounts for risk mitigation measures may have contributed to private insurer exits from the market after large losses in 2004-05 (Medders and Nicholson, 2018[64]).

The process of repairing and reinstating damaged properties – particularly after more severe damages – provides a (likely cost-effective) opportunity to implement risk reduction and adaptation measures to reduce risk in the future. Regulators and supervisors could assess whether it may be helpful to encourage insurance companies to support resilient reinstatement in the aftermath of damaging events (Priest, Penning-Rowsell and Suykens, 2016[45]; Seifert-Dähnn, 2018[31]) (and should examine the potential benefits (and risks) of eliminating any regulatory or supervisory measures that could impede resilient reinstatement). In order to account for the additional cost of more resilient reinstatement, insurance companies could potentially be encouraged to offer policyholders a coverage that would provide additional payments for the implementation of post-event risk reduction or adaptation measures[17] (while governments could potentially offer complementary funding, as outlined in the section on Public funding or guarantees for resilience measures (*ex ante and ex post*) to complement insurance). Insurance companies could also be required to provide sufficient funding for resilient reinstatement in response to severe damage claims (and allowed to account for this increased cost in their premium pricing) (Jarzabkowski et al., 2019[29]). Enabling insurance companies to extend the duration of insurance contracts in exchange for investments in resilient reinstatement could reduce some of the disincentives for insurers to support resilient reinstatement.

A commonly cited impediment to greater insurance sector involvement in supporting policyholder risk reduction and adaptation to longer-term climate risk is the short-term renewal cycle of most residential and commercial property insurance coverage. In response, some have suggested that longer-term (or multi-year) property insurance contracts could help overcome some of the challenges in incentivising policyholders to invest in risk reduction and adaptation (see Box 1).

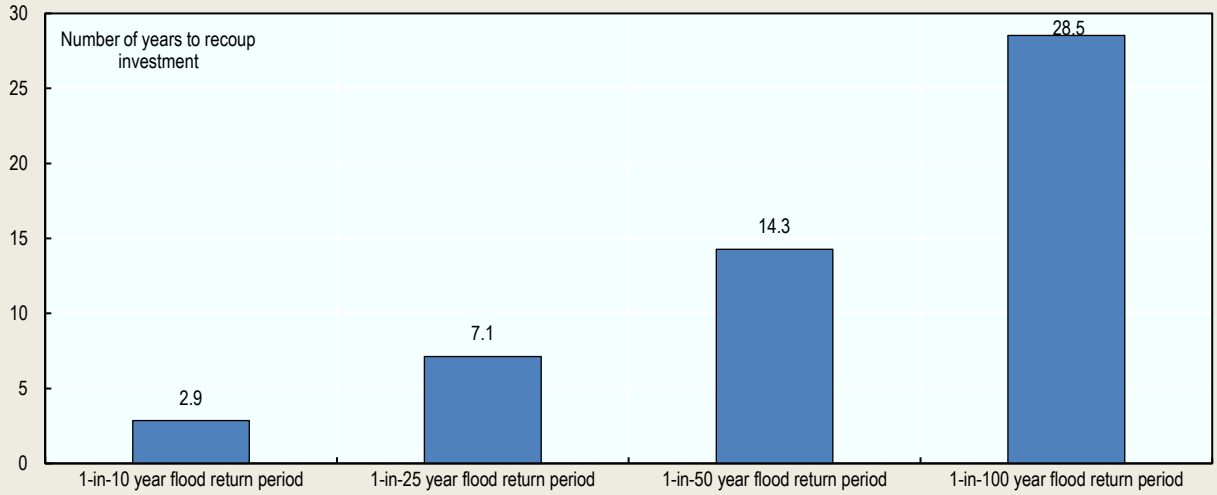
[16] For example, Connecticut (permanent storm shutters, impact resistant glass), Florida (various measures, including fixtures and construction techniques), Maryland (various measures), New York (storm shutters, laminated glass windows/doors) and South Carolina (EIOPA, 2021[3]; Smart Home America, n.d.[47]).

[17] For example, one Canadian insurance company is offering a *Stronger Home* coverage that will provide additional payments to cover the cost of replacing a roof or exterior siding with more resilient materials (Wawanesa Insurance, 2022[75]).

Box 3. Long-term (multi-year) property insurance coverage

A multi-year property insurance policy would provide policyholders with a stable premium price (or in some variations, a guaranteed price range) for their coverage over multiple years (Jaffee, Kunreuther and Michel-Kerjan, 2008[65]). A longer-term guaranteed price for coverage would reduce the potential for significant re-pricing in the aftermath of large insured losses[1] and could also provide a more visible incentive for policyholder investment in risk reduction if a guaranteed reduction in premium costs is provided for multiple years through a long-term property insurance contract (and for insurers if a decrease in assumed risk over multiple years is possible by investing in risk reduction) (EIOPA, 2021[3]; Jaffee, Kunreuther and Michel-Kerjan, 2008[65]; Maynard and Ranger, 2012[66]). A multi-year coverage might also encourage the integration of longer-term climate risk into insurance sector risk analytics.

Figure 3. Illustrative payback period for investment in dry flood-proofing



Note: The estimated cost of dry-proofing measures is from (Hudson, 2020[67]) (median cost for larger homes (scheme 2), or EUR 14 650 (2015)) and is assumed to be effective in reducing 85% of losses (high-estimate from (Hudson, 2020[67])). The average flood claim cost is an estimate (median, USD 55 000) for Germany, United Kingdom and the United States (as reported in (Evans, 2021[68])).
Source: OECD calculations based on (Evans, 2021[68]; Hudson, 2020[67])

However, there are some important challenges (and costs) to multi-year property insurance coverage:

- *Premium cost*: the premium that insurers would need to charge for multi-year coverage would likely be higher than for single-year coverage as insurers would need to set aside a larger amount of capital to account for the possibility of multiple losses within the contract period and for the greater uncertainty inherent in longer-term pricing (Maynard and Ranger, 2012[66]). Insurers might also need to set aside more capital to replace the "pressure valve" offered by annual pricing (EIOPA, 2021[3]; Maynard and Ranger, 2012[66]).
- *Potential for reduced policyholder choice*: a multi-year contract could impede policyholders from seeking an alternative coverage provider or re-negotiating insurance costs during annual renewal and might reduce the overall competitiveness of the market if policyholders are locked into contracts for longer periods (EIOPA, 2021[3]). EIOPA's *pilot exercise on the implementation of climate-related adaptation measures in non-life insurance products* found that some multi-year

insurance contracts mitigate this risk by allowing policyholders to withdraw and seek coverage from another provider during the multi-year contract period (EIOPA, 2023[4]).

- *Prolonged payback periods*: while multi-year insurance coverage should make the benefit of risk reduction and adaptation more visible – for many types of risk reduction measures, it could still take many years for the premium discounts that would result to account for the initial cost (i.e. for policyholders to recoup their initial investment). Figure 3 provides an illustration of "payback periods" for dry flood-proofing for different levels of exposure to flood risk – which would likely be beyond five years for all but the most highly-exposed properties.

Notes:
[1] There are a number of examples where insurance companies have significantly increased premiums or withdrawn coverage in the aftermath of large events, including after the major flooding in Germany in 2002, after two significant hurricane loss years in the United States in 2004/2005 and in the aftermath of recent wildfires in the US state of California (EIOPA, 2021[3]) (amongst many other examples).
[2] Without the ability to re-price, insurance companies would basically be providing a guarantee that climate risk as well as other factors that are integrated into property insurance pricing (cost of repair, capital requirements, taxation, etc.) will not change during the contract period (or not change from the insurance company's initial assessment of those factors over the contract period).

Public funding or guarantees for resilience measures (*ex ante and ex post*) to complement insurance

For policyholders, a key barrier to investing in risk reduction and adaptation measures is the investment cost (Jaffee, Kunreuther and Michel-Kerjan, 2008[65]; Maynard and Ranger, 2012[66]; Priest, Penning-Rowsell and Suykens, 2016[45]; Seifert-Dähnn, 2018[31]). This cost can be funded by premium discounts provided by insurers (although subject to the challenges related to payback periods as noted above), grants provided by governments,[18] loans provided by governments or the financial sector (including insurers, potentially with the support of a government guarantee) – or through a mix of these funding sources. One survey of risk reduction measures implemented by policyholders in Austria, England and Romania found that the Austrian households that have greater access to financial incentives for risk reduction were more likely to make such investments (Hanger et al., 2018[42]).

Government support for risk reduction is likely a more cost-effective approach to managing the financial impacts of climate risks than providing compensation for damages and losses after an event or even supporting the availability of insurance coverage for climate risks through catastrophe risk insurance programmes, as investments in risk reduction provide a permanent reduction in losses – not just a mechanism for absorbing losses after a single event (which may reoccur).

Governments could support policyholder risk reduction by: (i) providing grants (including tax credits) or loans directly to households and businesses facing increased climate risk to implement risk reduction and adaptation measures, potentially with a means-tested application of any grant element to that support; or (ii) providing guarantees to support lending by banks (or even insurance companies) to support risk reduction or adaptation measures, with the aim of reducing credit risk for lenders and the cost of financing for households and businesses. Given the high cost of many types of risk reduction and adaptation

[18] Many governments provide financial support to households for risk reduction and adaptation. For example, in the United States, programmes such as *Strengthen Alabama Homes*, *South Carolina Safe Home* and *My Safe Florida Home* provide grants of varying amounts to policyholders to implement risk reduction measures to protect against hurricane damages.

programmes, lending programmes are likely more feasible than grant programmes as loans (which involve less government outlays) would allow for broader reach.

The provision of government funding for risk reduction and adaptation could potentially be co-ordinated (or even integrated) with the acquisition of insurance coverage and the payment of claims after an event. Policyholders facing high premiums could automatically be offered financing for risk reduction (from governments, banks or even insurance companies, potentially with government credit guarantees) with insurance companies required to offer premium discounts for the implemented measures (therefore reducing the debt burden on policyholders that access that financing). Governments could also provide complementary funding to policyholders that have suffered severe damage to allow more resilient reinstatement. For example, in the United Kingdom, a Repair and Renew Grant offered up to GBP 5 000 for resilient reinstatement to households who were impacted by flooding in 2013-14 and 2015-16 (Priest, Penning-Rowsell and Suykens, 2016[45]; Suykens et al., 2016[38]). Similarly, the Canadian federal government is providing up to CAD 6 million (in aggregate) to allow homeowners in a wildfire-devastated community with basic insurance to rebuild their homes with fire-resistant materials (Williams, 2022[69]). Such an approach has been recommended as part of the Global Federation of Insurance Associations' "key principles for more resilient and sustainable construction" (GFIA, 2021[52]).

Conclusion

It is clear that the insurance sector has substantial expertise in assessing climate risks and adaptation options and various tools for encouraging risk reduction and adaptation investments by households, businesses and governments. However, commercial considerations as well as technical and some regulatory constraints (including limitations on pricing flexibility) may be limiting: (i) the development of climate-conditioned risk analytics; (ii) the delivery of information on climate risks to policyholders and governments; and (iii) incentives and support for adaptation and risk reduction in the form of premium discounts and funding for resilient reinstatement.

This paper provided some possible approaches to enhancing the insurance sector's contribution to climate change adaptation, including:

- incentivising and facilitating the development of climate risk analytics by, for example, requiring further assessment by insurers of their longer-term exposure to climate risks and reviewing any impediments to the use of innovative data sources and analytical techniques for climate risk assessment;
- encouraging insurers to communicate longer-term climate risk information to policyholders along with potential adaptation options to policyholders and potential benefits in terms of premium reductions or discounts; and
- supporting resilient reinstatement in the aftermath of climate disasters by encouraging insurers to provide coverage for resilience improvements and seeking opportunities to complement insurance claims payments with public funding or guarantees for such improvements.

While achieving climate resilience will only be possible through effective contributions of all stakeholders across the economy, enhancing the insurance sector's contribution to adaptation can be critical for limiting some of the increase in future climate damages and losses and the potential disruptions to insurance markets that could result.

References

AIR Worldwide (2021), *Global Modeled Catastrophe Losses*, AIR Worldwide. [8]

Aon (2022), *Aon Collaborates With The University Of California System To Enhance Wildfire Modeling By Leveraging The Latest Climate Science*, Aon (website), https://aon.mediaroom.com/news-releases?item=138166 (accessed on 24 October 2022). [21]

Babovic, F., M. Sassi and A. Castéran (2020), *European Flood and Climate Change: Examining the Potential Impact on Insured Losses*, RMS, https://www.rms.com/blog/2020/12/11/european-flood-and-climate-change-examining-the-potential-impact-on-insured-losses (accessed on 6 June 2022). [15]

Bernhardt, A. et al. (2021), *Community-Based Catastrophe Insurance: A model for closing the disaster protection gap*, Marsh & McLennan Companies and Wharton Risk Management and Decision Processes Center. [71]

Borensteinm Seth (2022), "More La Ninas Confounding Computer Models and Fueling Western Drought", *Carrier Management*, https://www.carriermanagement.com/news/2022/05/30/236614.htm (accessed on 6 June 2022). [72]

Bouchard, F. et al. (2022), *Fulfilling a Legacy of Societal Risk Management: Mobilizing Insurance Sector Capabilities to Advance Community-Level Climate Risk Reduction and Adaptation*, Marsh McLennan. [86]

Cambridge Centre for Risk Studies and AXA XL (2020), *Optimising Disaster Recovery: The Role of Insurance Capital in Improving Economic Resilience.*, Cambridge Centre for Risk Studies at the University of Cambridge Judge Business School, https://axaxl.com/-/media/axaxl/files/optimizing-disaster-recovery.pdf (accessed on 20 October 2020). [84]

Canadian Underwriter (2016), "ICLR launches 'Insurers Rebuild Better Homes' program to help reduce risk of loss and damage from natural hazards, including wildfire", *Canadian Underwriter*, https://www.canadianunderwriter.ca/insurance/iclr-launches-insurers-rebuild-better-homes-program-help-reduce-risk-loss-damage-natural-hazards-including-wildfire-1004091577/ (accessed on 9 June 2022). [53]

Capgemini Research Institute (2022), *Walking the Talk: How Insurers can lead Climate Change Resiliency*, Capgemini Research Institute. [25]

Carrier Management (2022), "Markets/Coverages: Aon Incorporates Climate Science Into European Flood Models", *Carrier Management*, https://www.carriermanagement.com/news/2022/07/01/237838.htm (accessed on 17 October 2022). [22]

CDI (2022), *Mitigation in Rating Plans and Wildfire Risk Models (Final Text of Regulation)*, State of California Office of Administrative Law. [63]

CDI (2021), *Protecting Communities, Preserving Nature and Building Resiliency: How First-of-its-Kind Climate Insurance Will Help Combat the Costs of Wildfires, Extreme Heat, and Floods*, California Department of Insurance. [26]

Center for Insurance Policy and Research (2021), *Extreme Weather and Property Insurance: Consumer Views*, National Association of Insurance Commissioners. [44]

Cervest (n.d.), *Earth Science AI*, Cervest, https://cervest.earth/earth-science-ai (accessed on 6 June 2022). [73]

Clarke, A. and S. Latchman (2021), *Helping Clients Respond to the Bank of England*, AIR Worldwide, https://www.air-worldwide.com/blog/posts/2021/8/helping-clients-respond-to-the-bank-of-englands-2021-climate-biennial-exploratory-scenario/ (accessed on 11 June 2022). [58]

ClimateCheck (n.d.), *Our Methodologies*, ClimateCheck (website), https://climatecheck.com/our-methodologies (accessed on 24 October 2022). [78]

COP 27 Presidency (2022), *Sharm-El-Sheikh Adaptation Agenda: The global transformations towards adaptive and resilient development*, COP 27 Presidency. [5]

Ebeltoft, M. (2016), *Private-Public-Project: - sharing insurance loss data to local and national authorities, (and scientists) in DRR and resilience work*, Finance Norway. [32]

EIOPA (2023), *Impact underwriting: Report on the Implementation of Climate-Related Adaptation Measures in Non-Life Underwriting Practices*, European Insurance and Occupational Pensions Authority, https://www.eiopa.europa.eu/document-library/report/impact-underwriting-report-implementation-of-climate-related-adaptation_en (accessed on 10 February 2023). [4]

EIOPA (2021), *Methodological paper on potential inclusion of climate change in the Nat Cat standard formula*, European Insurance and Occupational Pensions Authority. [9]

EIOPA (2021), *Report on non-life underwriting and pricing in light of climate change*, European Insurance and Occupational Pensions Authority. [3]

Ellison, J. (2022), *Judith Ellison: Climate Commercial Lead, JBA Risk Management: Assessing future flood risk globally (podcast)*, InsTech, https://www.instech.co/podcast/judith-ellison-climate-commercial-lead-jba-risk-assessing-flood-risk (accessed on 24 October 2022). [59]

European Commission (2021), *Proposal for a Directive of the European Parliament and of the Council amending Directive 2009/138/EC as regards proportionality, quality of supervision, reporting, long-term guarantee measures, macro-prudential tools, sustainability risks, group and cross-border supervision*, EUR-Lex, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0581 (accessed on 24 October 2022). [60]

Evans, S. (2021), *Minimum 43,400 buildings impacted by European floods: ICEYE*, Artemis.bm, https://www.artemis.bm/news/minimum-43400-buildings-impacted-by-european-floods-iceye/ (accessed on 15 June 2022). [68]

Fache Rousová, L. et al. (2021), *Climate Change, Catastrophe and the Macroeconomic Benefits of Insurance*, European Insurance and Occupational Pensions Authority. [85]

Fathom (n.d.), *About us*, Fathom (website), https://www.fathom.global/who-we-are/ (accessed on 24 October 2022). [19]

First Street Foundation (n.d.), *Mission*, First Street Foundation (website), https://firststreet.org/mission/ (accessed on 25 October 2022). [20]

FM Global (n.d.), *Climate Resilience Products*, FM Global (website), https://www.fmglobal.com/products-and-services/products/climate (accessed on 24 October 2022). [76]

France Assureurs (2022), *Réussir la transition écologique et renforcer la résilience face aux défis climatiques*, France Assureurs. [37]

Gamma LI (2022), *Gamma LI maps out international expansion through latest data partnership with Sust Global*, Gamma Location Intelligence (website), https://gammali.co.uk/2022/08/31/gamma-location-intelligence-maps-out-international-expansion-through-latest-data-partnership-with-sust-global/ (accessed on 24 October 2022). [77]

GFIA (2021), *Key Principles for more Resilient and Sustainable Construction*. [52]

Grenier, R. (2022), *Climate Change Is Not the Only Driver of Rising Natural Disaster Losses—and That's Good News*, AIR Worldwide, https://www.air-worldwide.com/publications/perspectives/climate-change-not-only-driver-of-rising-natural-disaster-losses/ (accessed on 6 June 2022). [13]

Grenier, R. et al. (2020), *Quantifying the Impact from Climate Change on U.S. Hurricane Risk*, AIR Worldwide. [16]

Guin, J. (2020), *Climate Change: A Reckoning and a New Approach to Modeling Risk*, AIR Worldwide, https://www.air-worldwide.com/publications/air-currents/2020/climate-change-a-reckoning-and-a-new-approach-to-modeling-risk/ (accessed on 6 June 2022). [24]

Hanger, S. et al. (2018), "Insurance, Public Assistance, and Household Flood Risk Reduction: A Comparative Study of Austria, England, and Romania", *Risk Analysis*, Vol. 38/4, pp. 680-693, https://doi.org/10.1111/RISA.12881. [42]

Hay, B. (2022), "Flood Re launches world first 'Build Back Better' scheme to help householders after a flood", *The Intermediary*, https://theintermediary.co.uk/2022/04/flood-re-launches-world-first-build-back-better-scheme-to-help-householders-after-a-flood/ (accessed on 9 June 2022). [56]

Holahan, J., J. Lee and T. Roehl (2021), *NAIC Approves Changes to the Anti-Rebating Laws to Usher in a New Era of Insurance Marketing*, Morris, Manning & Martin LLP, https://www.mmmlaw.com/media/naic-approves-changes-to-the-anti-rebating-laws-to-usher-in-a-new-era-of-insurance-marketing/ (accessed on 11 June 2022). [62]

Hudson, P. (2020), "The Affordability of Flood Risk Property-Level Adaptation Measures", *Risk Analysis*, Vol. 40/6, pp. 1151-1167, https://doi.org/10.1111/RISA.13465. [67]

IAA (2022), *Climate Science: A Summary for Actuaries - What the IPCC Climate Change Report 2021 Means for the Actuarial Profession*, International Actuarial Association. [6]

IAA (2020), *Importance of Climate-Related Risks for Actuaries*, International Association of Actuaries. [12]

Insurance Council of Australia (2022), *ICA Opening statement Senate Economics Legislation committee hearing into the Northern Australia Cyclone Reinsurance scheme*, Insurance Council of Australia (website), https://insurancecouncil.com.au/resource/ica-opening-statement-senate-economics-legislation-committee-hearing-into-the-northern-australia-cyclone-reinsurance-scheme/ (accessed on 19 May 2022). [70]

Insurance Development Forum (2021), *COP26: IDF and V20 Announce Partnership in Risk Understanding to Build Global Resilience to Climate Risk; IDF Announces other Multi-Partner Resilience Actions*, Insurance Development Forum, https://www.insdevforum.org/press-release-cop26-idf-and-v20-announce-partnership-in-risk-understanding-to-build-global-resilience-to-climate-risk-idf-announces-other-multi-partner-resilience-actions/ (accessed on 9 June 2022). [33]

Insurance Development Forum (2020), *The Development Impact of Risk Analytics*, Insurance Development Forum, https://www.insdevforum.org/knowledge/idf-reports-publications/development-impact-of-risk-analytics/ (accessed on 6 June 2022). [11]

Jaffee, D., H. Kunreuther and E. Michel-Kerjan (2008), "Long Term Insurance (LTI) for Addressing Catastrophe Risk", https://doi.org/10.3386/W14210. [65]

Jarzabkowski, P. et al. (2019), *Insurance for climate adaptation: Opportunities and limitations*, Global Commission on Adaptation. [29]

JBA Risk Management (2022), *New JBA model reveals 1 in 4 UK properties at risk to flood*, JBA Risk Management, https://www.jbarisk.com/news-blogs/new-jba-model-reveals-1-in-4-uk-properties-at-risk-to-flood/ (accessed on 8 June 2022). [34]

Joseph, R., D. Proverbs and J. Lamond (2014), "Resilient Reinstatement: What Can We Learn From The 2007 Flooding In England?", *WIT Transactions on Ecology and the Environment*, Vol. 184, pp. 175-186, https://doi.org/10.2495/FRIAR140151. [55]

Jupiter Intelligence (2022), *Climate Data Matters (webinar)*, Jupiter Intelligence, https://www2.jupiterintel.com/On-Demand-TYP (accessed on 24 October 2022). [61]

Karen Clark & Company (2021), *Climate Change Impacts on Hurricanes and Insured Wind Losses*, Karen Clark & Company. [18]

Lamond, J. et al. (2019), *Supporting the uptake of resilient repair in the recovery process (FD2706): Final Report*, Department for Environment, Food and Rural Affairs. [50]

Ludlam, S. (2021), *Investing in Disaster Prevention in the EU with the World Bank and EU Commission*, JBA Risk Management. [23]

Maynard, T. and N. Ranger (2012), "What Role for "Long-term Insurance" in Adaptation? An Analysis of the Prospects for and Pricing of Multi-year Insurance Contracts", *The Geneva Papers on Risk and Insurance. Issues and Practice*, Vol. 37/2, pp. 318-339, https://www.jstor.org/stable/41953180?seq=1 (accessed on 15 June 2022). [66]

Medders, L. and J. Nicholson (2018), "Evaluating the Public Financing for Florida's Wind Risk", *Risk Management and Insurance Review*, Vol. 21/1, pp. 117-139, https://doi.org/10.1111/rmir.12092. [64]

Melecky, M. and C. Raddatz (2011), "How Do Governments Respond after Catastrophes? Natural-Disaster Shocks and the Fiscal Stance"*, Policy Research Working Paper*, No. 5564, World Bank, https://openknowledge.worldbank.org/bitstream/handle/10986/3331/WPS5564.pdf?sequence=1&isAllowed=y (accessed on 22 March 2018). [81]

Miceli, R., I. Sotgiu and M. Settanni (2008), "Disaster preparedness and perception of flood risk: A study in an alpine valley in Italy", *Journal of Environmental Psychology*, Vol. 28/2, pp. 164-173, https://doi.org/10.1016/J.JENVP.2007.10.006. [43]

NAIC Center for Insurance Policy and Research (2021), *NAIC/Center for Insurance Policy and Research (CIPR) Catastrophe Model Center of Excellence (COE): Frequently Asked Questions (FAQ)*. [36]

O'Hare, P., I. White and A. Connelly (2016), "Insurance as maladaptation: Resilience and the 'business as usual' paradox", *Environment and Planning C: Government and Policy*, Vol. 34/6, pp. 1175-1193, https://doi.org/10.1177/0263774X15602022/ASSET/IMAGES/LARGE/10.1177_0263774X15602022-FIG1.JPEG. [51]

OECD (2022), *Report on the implementation of the OECD Recommendation on Disaster Risk Financing Strategies*, OECD, https://one.oecd.org/document/C(2022)166/REV1/en/pdf. [27]

OECD (2021), *Enhancing Financial Protection Against Catastrophe Risks: The Role of Catastrophe Risk Insurance Programmes*, OECD, https://www.oecd.org/finance/enhancing-financial-protection-against-catastrophe-risks.htm. [57]

OECD (2018), *The Contribution of Reinsurance Markets to Managing Catastrophe Risk*, OECD, http://www.oecd.org/finance/the-contribution-of-reinsurance-markets-to-managing-catastrophe-risk.pdf (accessed on 23 January 2019). [83]

Poussin, J., W. Botzen and J. Aerts (2014), "Factors of influence on flood damage mitigation behaviour by households", *Environmental Science & Policy*, Vol. 40, pp. 69-77, https://doi.org/10.1016/J.ENVSCI.2014.01.013. [39]

PRA (2019), *A framework for assessing financial impacts of physical climate change A practitioner's aide for the general insurance sector*, Bank of England Prudential Regulation Authority. [7]

Priest, S., E. Penning-Rowsell and C. Suykens (2016), "Promoting adaptive flood risk management: the role and potential of flood recovery mechanisms", *E3S Web of Conferences*, Vol. 7, p. 17005, https://doi.org/10.1051/E3SCONF/20160717005. [45]

Reask (n.d.), *Products*, Reask, https://reask.earth/products/ (accessed on 6 June 2022). [74]

Rosenfield, A. (2022), *Reinstatement 101 – (rein)stating the obvious?*, Fenchurch Law, https://www.fenchurchlaw.co.uk/reinstatement-101-reinstating-the-obvious/ (accessed on 9 June 2022). [54]

Sclafane, S. (2022), "Vendor Cat Models Not Capturing Climate Change Impact: RenRe CEO", *Carrier Management*, https://www.carriermanagement.com/news/2022/07/27/238687.htm?utm_content=escalating-risks-and-reinsurance-costs-rendez-vous-talking-points&utm_campaign=spotlight&utm_source=carriermanagement&utm_medium=newsletter (accessed on 24 October 2022). [10]

Seifert-Dähnn, I. (2018), "Insurance engagement in flood risk reduction - Examples from household and business insurance in developed countries", *Natural Hazards and Earth System Sciences*, Vol. 18/9, pp. 2409-2429, https://doi.org/10.5194/NHESS-18-2409-2018. [31]

Sims, J. and D. Baumann (1987), "The adoption of residential flood mitigation measures: what price success?", *Economic Geography*, Vol. 63/3, pp. 259-272, https://doi.org/10.2307/143953. [40]

Smart Home America (n.d.), *List of Mitigation Insurance Discounts and Tax Savings*, Smart Home America, https://www.smarthomeamerica.org/fortified/discounts-and-incentives/list-of-fortified-discounts-and-incentives (accessed on 9 June 2022). [47]

Sousounis, P. and H. Little (2017), *Climate Change Impacts on Extreme Weather*, AIR Worldwide Corporation. [14]

Surminski, S. et al. (2015), "Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union", *Natural Hazards*, Vol. 79/3, pp. 1451-1479, https://doi.org/10.1007/S11069-015-1832-5/TABLES/3. [48]

Surminski, S., J. Barnes and K. Vincent (2022), "Can insurance catalyse government planning on climate? Emergent evidence from Sub-Saharan Africa", *World Development*, Vol. 153, p. 105830, https://doi.org/10.1016/J.WORLDDEV.2022.105830. [28]

Surminski, S. and A. Thieken (2017), "Promoting flood risk reduction: The role of insurance in Germany and England", *Earth's Future*, Vol. 5/10, pp. 979-1001, https://doi.org/10.1002/2017EF000587. [46]

Suykens, C. et al. (2016), "Dealing with flood damages: will prevention, mitigation, and ex post compensation provide for a resilient triangle?", *Ecology and Society, Published online: Oct 11, 2016 | doi:10.5751/ES-08592-210401*, Vol. 21/4, https://doi.org/10.5751/ES-08592-210401. [38]

Swiss Re sigma (2022), *Natural catastrophes in 2021: the floodgates are open*, Swiss Re sigma. [2]

Swiss Re sigma (2020), *Natural catastrophes and man-made disasters: 1990-2019 (dataset)*, Swiss Re. [1]

Thieken, A. et al. (2010), "Coping with floods: preparedness, response and recovery of flood-affected residents in Germany in 2002", *https://doi.org/10.1623/hysj.52.5.1016*, Vol. 52/5, pp. 1016-1037, https://doi.org/10.1623/HYSJ.52.5.1016. [41]

UNFCCC (n.d.), *What do adaptation to climate change and climate resilience mean?*, United Nations Framework Convention on Climate Change (website), https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean (accessed on 25 October 2022). [79]

University of Cambridge Institute for Sustainability Leadership (CISL) (2021), *Risk sharing in the Climate Emergency: Financial regulation for a resilient, net zero, just transition*, University of Cambridge Institute for Sustainability Leadership. [49]

Verisk Extreme Event Solutions (2022), *Verisk Extreme Event Solutions Releases Climate Change Projections for U.S. Hurricane and Caribbean Tropical Cyclone Models*, Verisk, https://www.air-worldwide.com/news-and-events/press-releases/verisk-extreme-event-solutions-releases-climate-change-projections-for---u-s--hurricane-and-caribbean-tropical-cyclone-models/?elq_mid=15039&elq_cid=1272441&utm_source=Eloqua&utm_medium=email (accessed on 24 October 2022). [17]

Von Peter, G., S. Von Dahlen and S. Saxena (2012), "Unmitigated disasters? New evidence on the macroeconomic cost of natural catastrophes", *BIS Working Papers*, No. 394, Bank for International Settlements, https://www.bis.org/publ/work394.pdf (accessed on 22 March 2018). [82]

Warner, K. et al. (2009), *Adaptation to Climate Change: Linking Disaster Risk Reduction and Insurance*, United Nations International Strategy for Disaster Reduction (UNISDR). [30]

Wawanesa Insurance (2022), *Wawanesa helps Canadians adapt to climate change*, Wawanesa Insurance, https://www.wawanesa.com/canada/news/wawanesa-helps-canadians-adapt-to-climate-change?language_id=1 (accessed on 15 June 2022). [75]

Williams, N. (2022), "Canadian village razed by wildfire wrestles with climate-proofing its future", *Reuters*, https://www.reuters.com/world/americas/canadian-village-razed-by-wildfire-wrestles-with-climate-proofing-its-future-2022-08-05/ (accessed on 24 October 2022). [69]

Young, M. (2022), *U.S. Wildfire: Calculating the Value of Mitigation Benefits From Forest Treatment Strategies*, RMS, https://www.rms.com/blog/2022/03/16/us-wildfire-calculating-the-value-of-mitigation-benefits-from-forest-treatment-strategies (accessed on 8 June 2022). [35]

Zurich Resilience Solutions and South Pole (n.d.), *Climate action. Not climate words*, Zurich (website), https://www.zurich.com/en/products-and-services/protect-your-business/what-we-protect/zurich-resilience-solutions/zrs-south-pole (accessed on 31 January 2023). [80]


NET ZERO+
Climate and economic
resilience in a changing world