The 8th OECD Forum on Green Finance and Investment
Virtual Conference

High-Level Plenary: Physical climate risks and the financial system: A spotlight on materiality
Wednesday 13 October, 14h15-15h15 CET

Background Paper

Watered down? Investigating the financial materiality of water-related risks in the financial system

Table of contents

1 Executive summary 4
Overview 4
Key messages 5
Questions for discussion 6

2 Water-related risks are already material to economies and societies 7
Water-related risks already pose significant costs on economies and societies and are set to rise in the future 7
The impacts of water-related risks propagate through multiple channels 8

3 Understanding financial materiality in the context of water-related risks 10
Financial materiality as a key driver of financial decision making 10
Focus on the financial system 10
Financial materiality as an accounting principle 11
Financial materiality in specific contexts 12
The dynamic nature of financial materiality 13
The impact of discount rates on financial materiality 13

4 Limited evidence to date of the financial materiality of water-related risks for the financial system 15
Typologies of water-related risks in the financial system 15
Estimates of financial system exposure to water-related risks by Central Banks 16
Estimates of water-related risks in insurance 17
Other estimates of water-related risks in the financial system 17
Issues affecting the financial materiality of water-related risks for the financial system 18

5 Implications for policy considerations 25
Finance regulators 25
Water community 26

Annex A. Transmission channels of water-related risks to the financial sector 28
Financial transmission at micro level 28
Financial transmission at macro level 29

References 31

Tables

Table 4.1. ECB examples of climate-related and environmental risks drivers 15
Table 4.2. Definition of risks in banks prudential regulation 21
Table 4.3. ECB examples of environmental risks drivers in prudential regulation 22

Boxes

Box 1.1. Water security defined 8

1 Executive summary

Overview

Water-related risks (e.g. floods, droughts, water stress, degraded water quality, etc) impact economies, communities and the environment. Climate change exacerbates those risks by increasing the frequency and severity of potential impacts and generating greater uncertainty about future conditions. This paper explores how water-related risks are taken into account (or not) by the financial sector. It considers how financial regulation currently defines financially material risks to the financial sector, and how water-related risks are accounted for (or not) in those definitions. The paper also takes stock of some current market practices and of some quantitative evaluations of water-related risks by the financial sector, and concludes with possible implications for policy makers.

The purpose of this paper is to support a dialogue initiated in the context of the Roundtable on Financing Water between the water community and the financial community on the issue of water-related risks and financial materiality. Water-related risks constitute a number of physical climate risks and environmental risks, which are becoming an increasing concern for the financial sector (see, for example the "physical climate risks" listed in the Task Force on Climate-related Financial Disclosures (TCFD, 2017[1]), or the analysis of environmental risks by the ECB (ECB, 2021[2]) and the NGFS (NGFS, 2021[3])).

However, based on the investigation undertaken for this paper, it appears that the transmission of water-related risks into materially financial impacts on the financial sector remains minimal to date. The paper provides insights on how the financial system considers water-related risks at present, considering the prudential regulations and accounting standards that define financial materiality and identifies several factors that contribute to explaining why water-related risks are not currently considered financially material in the financial system, although they may become so in the future.

If and when water-related risks are considered financially material by the financial system, this could trigger reactions by the financial system in relation to those risks. For example, the financial system could allocate more capital to investments that would mitigate such risks. Another possible consequence could be that the financial system allocates less capital to certain sectors or regions because of perceived level of water-related risks. The paper does not investigate the possible consequences. But it does recognise that the financial materiality of water-related risks for the financial system is a topic of interest to the water community in relation to potential impacts on the allocation of capital to water-related investments. Finally, the focus on financial materiality does not imply that this is sufficient to meet environmental objectives, but it is only one element of a broader context, which also includes considerations of environmental materiality of companies' activities, among other dimensions.

The financial community is increasingly interested in assessing and managing the financial impact of water-related risks, even if they do not appear as financially material now. The water community gathers a lot of expertise on water-related risks; as the financial system is opening up to this new field of research for them, the time may be ripe for the water and finance community to strengthen their dialogue on water-related risks. Consequently, there may be an opportunity for the water community to support financial actors, in particular financial supervisors and regulators, in fostering a faster uptake of water-related risks

in the risk assessment frameworks of the financial sector. Helping to bridge data gaps is one form such support could take.

In turn, the design and enforcement of water management practices and policies can impact the financial materiality of water-related risks. For instance, improving efficiency, long-term planning and adaptation to climate impacts is likely to preserve the credit rating of water utilities. Water policies are also likely to impact the credit-worthiness of sovereign and municipal issuers, which account for a large share of capital markets. For instance, credit rating agencies recognise strong regional planning and water management, including storage and conservation, as a mitigating factor to the credit risk of local governments and their water utilities. Enhancing a dialogue on these issues between the financial and water community could be beneficial to both, and could increase the chances to achieve resilience to water-related risks.

Key messages

- Financial materiality is a key driver of financial decision making. When risks, such as water-related risks, are considered financially material, action to mitigate their financial impact ensues. Such actions can include investing in the mitigation of the risks.
- Financial materiality can be defined as the way in which the physical or economic risk manifests itself in the finance community (i.e. how the risk affects the financial industry or part thereof). It is driven by a series of financial regulations and risk assessment and management techniques in place in the finance industry and financial markets.
- Water insecurity, manifesting through water-related risks driven by “too much”, “too little” and “too polluted” water, already generates significant economic and social impacts. Climate change exacerbates these risks. In fact, the water cycle is one of the main channels through which climate impacts manifest.
- The transmission of such water-related risks into material financial impacts in the financial sector appears modest to date. As a result, there could be a “materiality gap” between the substantial economic impact of water-related risks (which are well-documented and rising) and their financial materiality in the global financial system.
- Several factors may explain this apparent gap:
  1) Existing evidence and analysis on financial materiality for the financial system remains patchy. Current approaches to risk modelling and risk assessment do not fully capture all types of risks (including water-related risks); and when these are covered, they are not fully priced. This may in fact “mask” certain risks and their potential impact on the financial sector, leaving regulators and institutions unprepared.
  2) Current prudential regulations for the financial sector do not contain explicit mention of environmental risks.
  3) Where material financial risks arise, the financial sector can make use of risk hedging or transfer tools, which may reduce the perception of the financial materiality of the risks in the financial system.
- Awareness of the potential materially-financial impact of environmental risks (including water-related risks) has grown considerably in recent years. If risks are not properly assessed and disclosed, and yet financially material, the judgement of investors on the level of risk-taking when investing in a company (but also a financial institution, or a sovereign or sub-sovereign borrower) could be impaired.
- If and when some water-related risks are considered financially material in the financial system, this could in turn impact the allocation of financial flows, encouraging more money going into

investments that reduce the physical or economic exposure and vulnerability to water-related risks, and less money supporting investments that increase exposure and vulnerability to such risks.

Even if the impacts of water-related extreme events (or other growing pressures such as water scarcity or pollution) may not reach the financial materiality threshold now, if these events increase in frequency and/or intensity (as they are expected to, particularly in light of rapid and unprecedented climate change), their impacts are most likely to hit the threshold in the future. This underscores the importance of "dynamic materiality", which recognises that financial materiality is not a static notion, but one that can change over time.

- These issues are topical for policy makers and financial institutions, warranting further investigation. For financial regulators, the issue is that material financial risks may be "masked" by the current practices of the financial system. This would mean that if and when risks materialize, the financial sector may not be equipped to deal with them.
- Enhancing a dialogue on these topics between the financial and water community is beneficial to both communities. At the same time, further developing the evidence base to understand the linkages between water-related risks and financial materiality can increase the chances to achieve resilience in the face of the costly consequences associated with water-related risks.

Questions for discussion

Question 1. The background paper identifies a possible "tragedy of the horizons" for water-related risks when it comes to financial materiality: in a nutshell, many anticipated impacts would be too far away in time to be financially material for most of the financial system at present. Would you agree that this "tragedy" exists, and if so, what actions can investors take to help address it?

Question 2. Water related risks are complex because water impacts companies and communities in different ways, and impacts on all ecosystems. Do investors have the data they need to assess the financial materiality of water related risks? How does the Executive Order on Climate-related Financial Risk in the US impact disclosure? What are the next steps on data provision in relation to water related risks?

Question 3. Water related risks are already manifesting in advanced economies, triggering an increase in property and damages insurance premiums, and, in certain coastal areas, unavailability of commercial insurance coverage. This may make adaptation investments more difficult for the private sector. How can the insurance sector contribute to the urgent need of water-related investment to adapt to climate change?

2 Water-related risks are already material to economies and societies

Water-related risks already pose significant costs on economies and societies and are set to rise in the future

Water insecurity, manifesting through water-related risks, already poses significant costs on economies and societies (see Box 2.1 for a definition of water security). There is significant evidence related to the cost that water-related risks can pose on economies and societies, today and in the future. Some telling figures include:

- Some partial estimates of the scale of **global economic losses** related to water insecurity include USD 260 billion per year from inadequate water supply and sanitation, USD 120 billion per year from urban property flood damages, and USD 94 billion per year of water insecurity to existing irrigators (Sadoff, et al., 2015[4]).
- Over the past 20 years, the number of deaths caused by **floods and droughts** alone has exceeded 166 thousand and caused economic losses of almost USD 700 billion (EM-DAT, 2019[5]). Further, the number of people exposed to floods is expected to grow from the current 1.2 billion to 1.6 billion by 2050 (UN, 2020[6]). Similarly, the value of assets exposed to flood risk will grow to USD 78 trillion by [add year], which I equivalent to about 57% of the world's current GDP (427, 2020[7]).
- Today, over four billion people live in areas subject to **severe freshwater scarcity** at least one month every year (Mekonnen and Hoekstra, 2016[8]) and about 1.2 billion people live in extremely water-scarce agricultural areas (FAO, 2020[9]). By 2050, 52% of the world's population is projected to live in water-stressed regions (Kölbel, Strong and Noe, 2018[10]). By 2040, over a third of today's agricultural area will be subject to high water stress, threatening food security in some regions (427, 2020[7]).
- As of 2020, 2 billion people around the world do not have access to safely managed **drinking water**, while 3.6 billion people lack safely managed **sanitation services** and 2.3 billion lack basic hand-washing facilities (UN-Water, 2021[11]).

Box 2.1. Water security defined

The OECD defines water security as achieving and maintaining acceptable levels for four inter-related water risks:

- Too little water (including droughts): Lack of sufficient water to meet demand for beneficial uses (households, agriculture, manufacturing, electricity and the environment);
- Too much water (including floods): Overflow of the normal confines of a water system (natural or built), or the destructive accumulation of water over areas that are not normally submerged;
- Too polluted water: Lack of water of suitable quality for a particular purpose or use; and
- Degradation of freshwater ecosystems: Undermining the resilience of freshwater ecosystems by exceeding the coping capacity of surface and groundwater bodies and their interactions.

These risks to water security can also increase the risk of (and be affected by) inadequate access to safe water supply and sanitation.

Source: (OECD, 2013[12]).

Pressures on water resources and socio-economic exposure to water-related risks is increasing due to a number of trends. Demographic trends and economic growth spur increased water demand from households, agriculture, industry, and energy production. Rapid urban development creates a growing need to secure access to safely managed water supply and sanitation services in growing urban and vulnerable rural areas. Urban development can also increase exposure to water-related disasters, such as floods and land erosion, when it occurs in exposed and vulnerable areas. At the same time, the growing value of physical and financial assets over the past decades, increases the value of assets exposed to water-related risks.

Adding to these trends, climate change is exacerbating water insecurity, with the global water cycle being a main channel through which climate impacts manifest. Climate-induced impacts on water security entail negative effects on food security, energy production, biodiversity as well as human health and livelihoods and the overall achievement of the Sustainable Development Goals (SDGs) and other policy objectives (IPCC, 2021[13]; Kerres et al., 2020[14]; Smith et al., 2019[15]; UNESCO, 2020[16]).

The impacts of water-related risks propagate through multiple channels

The impact of water-related risks is evident today all over the globe. Images of catastrophic flooding and extreme rains in Germany, the Netherlands or Japan, and drought in the U.S. and Canada have been omnipresent in the news over the past months. The impacts of water-related risks can propagate through multiple channels, disrupting industrial operations, agricultural production, supply chains and global commodity markets. These risks can materialise at multiple scales, with impacts from the household to corporate level, to industry and sector scale, to systemic risk. For instance, in 2021, the island of Taiwan experienced its worst drought in decades. Taiwan is home to some of the world biggest and most advanced high-tech manufacturers of semi-conductors – a global USD 450 billion industry that is extremely water-intensive. The sudden lack of rain in Taiwan is slowing down chip production to the point where it creates an unprecedented and overall shortage of chips in notebooks, monitors, TVs, smartphones, tablets and cars. On the back of this disruption, some large chip manufacturers in Taiwan have started plans to relocate facilities in the U.S. and in other Asian countries, with a view to reduce the water-related risk exposure of their supply chain (IndustryWeek, 2021[17]).

Emerging analysis is beginning to assess potential linkages of these water-related risks on markets and financial actors. For example, a recent study by the Dutch Central Bank, De Nederlandsche Bank, evaluated the exposures of Dutch financial institutions to businesses operating in water stressed regions, noting that businesses operating in water-stressed regions are exposed to increased risk (De Nederlandsche Bank (DNB), 2019[18]) (further details are provided in Chapter 4).

In a recent report, Standards and Poor's Global (S&P Global), a leading provider of sustainability-related data to the financial sector, characterised water stress as the main medium-term climate risk for Europe's biggest economies. It states that of the 10 studied countries, Greece, Italy, Spain and Belgium are the most exposed to the five physical risks in aggregate. On a scale of 1 to 100, where 100 is the maximum physical risk, Greece scores nearly 70, while Italy and Spain are each around mid-60. Flooding will continue to be a major risk factor in specific parts of Germany, Belgium and other countries, while issues such as water stress is a risk across a large swath of the European continent (S&PGlobal, 2021[19]). A report by Mc Kinsey mentions that for Florida alone, the projected increase in tidal flooding frequency and severity could result in a USD 10 billion to 30 billion devaluation in exposed properties by 2030, and USD 30 billion to 80 billion by 2050 (McKinsey, 2020, p. 76[20]). Other examples abound.

In a number of organisations are evaluating corporate exposures to water-related risks in advanced economies. Analysis from CDP shows that water-related risks can have significant impacts on business value, now and increasingly in the future. The financial value of water-related detrimental business impacts of over 2 900 corporates, disclosing information in the 2020 CDP survey on water security amounted to USD 16.7 billion. Companies also reported that currently identified water-related risks could potentially have impacts on business value of up to USD 336.3 billion in the future (CDP data, 2020[21]). However, today, corporate water-related risk disclosure remains limited: from about 5 500 companies asked to provide data via the CDP water security questionnaire by their investors or business customers, just above half did so (CDP, 2021[22]).

3 Understanding financial materiality in the context of water-related risks

Financial materiality as a key driver of financial decision making

The concept of financial materiality originally developed as an accounting principle. It can be described broadly by saying that an event is financially material when its impact would affect the judgement of an investor. Accounting standards in most advanced economies require financially-material events to be publicly disclosed in financial reporting, including risks which might materialise in the future and affect the financial performance of the reporting entity, whether it is a non-financial (corporate) or financial entity.

The identification of the financial materiality of a risk is a strong driver for actions to mitigate the potential financial impact of the risk. Mitigation action can include eliminating the risk, for instance by cutting finance flows to certain sectors or regions. It can include transferring the risk to a third party, for instance via insurance. It can also include setting aside financial resources to cover for future potential estimated losses. In any case, the identification of financially-material risks triggers, or should trigger, financial action in the face of the risk.

Awareness of the potentially materially-financial impact of climate-related and environmental risks (including water-related risks) has grown considerably in recent years. Insurance and bank supervisors, as well as credit rating agencies, have started to include water-related risks in their guidance and risks assessments (see Chapter 4 below). Annex A presents a rough characterisation of how water-related risks may transmit to the financial system.

Focus on the financial system

Water-related risks affect multiple economic and social systems. They can impact corporates, particularly in sectors which are highly dependent on water such as mining and materials, as well as agriculture and energy production. Several organisations are undertaking research on how water-related risks affect the financial situation of non-financial corporates (CERES, 2020[23]) (CDP, 2020[24]) (WRI, 2020[25]).

This paper focuses on the financial system, which will be affected by financially material impacts on non-financial corporates, but not only. Non-financial corporates account for only a share of what the financial system globally finances: there are also sovereign issuers, households, etc. This paper takes the global financial system as its focus, drawing on the emergence of a body of evidence developing due to the increased attention of financial institutions to climate-related and environmental risks, including water-related risks, in recent years.

The report attempts to shed some light on the extent to which water-related risks are currently considered financially-material by the financial system. The function of the financial system is to price and allocate capital into economic systems. Therefore, the perception by the financial system of the financial materiality of water-related risks will be key to capital allocation decisions for mitigating water-related risks.

Financial materiality as an accounting principle

Definition

Financial materiality is an accounting principle. Financially-material events or information include any events or facts that would affect the judgment of an informed investor. More precise definitions exist in various contexts, such as accounting standards. Several accounting standards require that financially-material events should be publicly disclosed along with the corresponding financial statements.

An evolving concept

The definitions of financial materiality have evolved over time, with for instance the International Accounting Standards Board revising its definition of financial materiality in late 2018 (IASB, 2018[26]). The emergence of the notion of financial materiality may be traced back to the years 2000, notably in the wake of the Enron scandal in the U.S. The bankruptcy of Enron in 2001, an American gas utility, was the largest bankruptcy at the time in U.S. history. After hiding the risks linked to financial activity on gas trading for many years, Enron suddenly went bankrupt. Its auditor, Arthur Andersen, went out of business in this scandal. Those risks should have been considered by the company and its auditors as financially material, and therefore disclosed in its audited accounts, enabling investors to make an informed judgement on the risks they were taking when investing in Enron.

For environmental risks, including water-related risks, there could be a similar issue, that if they are not properly assessed and disclosed, and yet financially-material, the judgement of investors on their level of risk taking when investing in a company (but also a financial institution, or a sovereign or sub-sovereign borrower) could be impaired.

A matter of judgement and assessment

As a principle, financial materiality is a matter of judgement and assessment, rather than of clear-cut rules involving pre-established quantitative thresholds. The financial materiality of a risk depends on the likelihood of the risk materialising and generating financial impacts at some point in the future (see below for a discussion on the role of discount rates). When risk transfer arrangements, such as insurance, have been put in place, the financial materiality assessment is done on the basis of the residual financial impact remaining for the assessing entity. The assessment then considers the impact on the bearing entity, given the financial resources it has at the time of impact to cover for it. For instance, the loss of a house to a flood may be financially material to a household if the house was a large part of their net worth and the damages are not covered by insurance. But the same loss of the same house may not be financially material for the bank that owns a mortgage on it, because the loss is small in terms of the banks resources, the risk was insured, or hedged.

National and sectoral regulators can provide guidance to their communities on what constitutes a financially-material risk. For instance, the New York Department of Financial Services (NYDFS) proposes thresholds for assessing the materiality of a given climate risk, (e.g. 5% of the profit of the insurance company or one-half of 1% of its total assets), noting that they are subject to adjustment based on professional judgment. The NYDFS also notes that certain risks may be material, regardless of their numerical impact, based on external factors such as the industries in which an insurer operates or investor expectations. It states that “if climate risks are not considered material, for example, because the insurer has minimal exposure to these risks, DFS expects the justification to be documented in the company’s regulatory solvency reporting (Own Risk and Solvency Assessment, ORSA).” (NYDFS, 2021[27]).

Financial materiality in specific contexts

Financial materiality and non-financial corporate reporting

In recent years, against the backdrop of an increased awareness of the importance of environmental risks, new regulation has emerged that requires companies to report non-financial information, and in particular, the environmental, social and governance risks to which they are exposed. A number of non-financial reporting tools and standards have emerged, such as the Sustainability Standards Board (SASB). SASB Standards guide the disclosure of financially material sustainability information by companies to their investors. Available for 77 industries, the Standards identify the subset of environmental, social, and governance (ESG) issues most relevant to financial performance in each industry (SASB, 2021[28]). This is an example where the notion of "financial materiality" is used for non-financial reporting: issues that could be relevant to the financial performance of an industry are reported under this standard. It should be stressed, however, that any financially material information needs to be reported in the financial statements (not in the non-financial reporting), as per the accounting principle mentioned above.

Financial materiality in investment regulation

The notion of financial materiality is also part of investment regulations in certain countries. This can have important impacts on the legal responsibilities of fiduciaries in their investment decision making. A case in point is the Employee Retirement Income Security Act of 1974 (ERISA) regulation issued by the US Department of Labour (DoL), regulating investments by private pension and health schemes in the US, which are an important driver of global investment markets. On Nov. 13, 2020, the department published a final rule on "Financial Factors in Selecting Plan Investments," which adopted amendments to the "Investment Duties" regulation under Title I of ERISA. The amendments generally require pension plan fiduciaries to select investments and investment courses of action based *solely* on consideration of "pecuniary factors." i.e., on consideration of financially material impacts for investors.

The US DoL announced in March 2021 that is was suspending the enforcement of this rule, on the basis that "These rules have created a perception that fiduciaries are at risk if they include any environmental, social and governance factors in the financial evaluation of plan investments". The DoL added that it "intends to conduct significantly more stakeholder outreach to determine how to craft rules that better recognize the important role that environmental, social and governance integration can play in the evaluation and management of plan investments, while continuing to uphold fundamental fiduciary obligations" (DoL, 2021[29]).

Financial materiality and climate-related and environmental risks

The Financial Stability Board (FSB) is an international body that monitors and makes recommendations about the global financial system. The FSB was established in the aftermath of the Great Financial Crisis (GFC) in 2009 with the objective to assess vulnerabilities affecting the global financial system at a macroeconomic, systemic level. In 2015, in the wake of the Paris Agreement, the Financial Stability Board (FSB) established the Task Force for Climate-Related Financial Disclosures (TCFD).

The Financial Stability Board established the TCFD to develop recommendations for more effective climate-related disclosures that could promote more informed investment, credit, and insurance underwriting decisions and, in turn, enable stakeholders to understand better the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks (FSB, 2021[30]). The TCFD states that "In most G20 jurisdictions, companies with public debt or equity have a legal obligation to disclose material information in their financial filings – including material climate-related information. The Task Force believes climate-related issues are or could be material for many

organizations and its recommendations should be useful to organizations in complying more effectively with existing disclosure obligations" (CDSB, 2018[31]).

The TCFD recommendations to the financial sector for more and better disclosures of financially material, or potentially material, climate-related risks, has raised awareness of climate-related risks in the finance sector, but have yet been to be massively followed (FSB, 2020[32]). Some jurisdictions, like the U.K., are considering mandating the disclosures recommendations (BEIS, 2021[33]).

Central Banks also joined forces to investigate the materiality of climate-related risks in the Network for Greening the Financial System (NGFS), created in December 2017. The NGFS states that "Climate-related risks are a source of financial risk and it therefore falls squarely within the mandates of central banks and supervisors to ensure the financial system is resilient to these risks" (NGFS, 2018[34]). The NGFS develops methodologies and collects data about climate related risks in its 89 member network, as well as stress tests to assess the exposure of the banking system to climate risks. In its May 2020 Guide for supervisors on integrating environmental risks into prudential supervision, the NGFS provides a number of examples of water-related risks, such as water pollution including nitrogen and phosphorous run-off, water stress, scarcity of freshwater, flooding (NGFS, 2020[35]).

In its Guide on climate-related and environmental risks published in November 2020, the European Central Bank's supervision arm shared 13 supervisory expectations for banks with a view to directly addressing climate and environmental risks. "Climate-related and environmental risks cannot just be an afterthought – they pose a very real challenge today and could have serious implications tomorrow," said Frank Elderson, Vice-Chair of the ECB's Supervisory Board, when stressing the urgent need for action. The ECB notes that those banks that already systematically assess climate and environmental risks report that these risks have, or will have, a material impact on their risk profile (ECB, 2021[36]).

The increased provision of data and information by the financial system against the backdrop of these supervisory initiatives provides insights on whether and how the financial system considers environmental risks, of which water related risks, as financially material. Preliminary findings are presented below.

The dynamic nature of financial materiality

Assessing the financial materiality of water-related risks (and other climate- and environmental risks) is not a static exercise, but a dynamic one. In light of rapid and unprecedented climate change, we know that the future will not look like the past for water-related risks; thus estimations of risk based on historical patterns will very likely underestimate the risk. The impact of water-related events may not hit the financial materiality threshold now, but if these events increase in frequency and/or intensity (as they are expected to), we know the impact will hit the threshold in the future (SASB, 2020[37]).

The dynamic nature of financial materiality is acknowledged by some actors in the financial system, for instance Moody's, a credit rating agency that has looked into the incorporation of climate change and water-related risks into municipal credit ratings. Current methodologies focus mostly on historical instances of extreme weather events, local governments' adaptive capacity and financial resilience. Moody's acknowledges that climate change can influence credit risks, but that, "in the absence of forward-looking climate projections, such estimates may grossly underestimate the magnitude of future risks, in particular water-related risks which can be exacerbated by climate change" (427, 2018[38]).

The impact of discount rates on financial materiality

The financial materiality of a given risk, such as a water-related risks is also dependent on the discount rate used by the assessor to estimate impacts at a future point in time. The higher the discount rate, the smaller the impact when considered at its present value. Changes in discount rates will modify the

materiality of future risks assessed at the present time, even when the evaluation of the future impact is unchanged.

In the current financial context, and although they vary widely between sectors and countries, discount rates are generally in the range of 5 to 10% for cash flows generated in advanced economies, and above 10% for emerging economies (Damodaran, 2021[39]). At such levels, the present value of future impacts is discounted quickly. For the sake of illustration, when discounted at 10%, a cash flow of USD 100 occurring in three years' time is worth USD 75 now; 62 if it happens in 5 years from now, 51 in 7 years, and 38 in ten years' time.

The discount rates used by the financial system to compute the present value of future cash flows reflect the cost of capital used to generate this cash flow[1]. The generally high level of current discount rates reflects the fragilities of the current global financial system, with globally high risks, and returns, on capital invested. They blur the perception of the future, and embed short termism in global financial systems. Improving the stability of the global financial system would decrease the cost of capital, and give more importance to the future in today's investment decisions (VividEconomics, 2014, p. 65[40]).

An example of the recognition of this impact is provided by asset manager Norges Bank Investment Management (NBIM). In a letter to the Norwegian Ministry of Finance (MoF) in relation to its management of the largest pension fund in the world, the Global Pension and Investment Fund (GPIF)[2], NBIM notes the important influence of discounting at currently high rates: "The equity portfolio's estimated losses in the various scenarios are expressed in today's value. This means that potential losses well into the future have a smaller value than those closer in time. Losses as a percentage of the equity portfolio may be much higher at the time they arise than their value today" (NBIM, 2021[41]).

[1] This principle is part of international accounting standards, for instance the International Accounting Standard Board (IASB) guidance on using discount rates to compute the fair value of financial assets using the Discounted Cash Flow (DCF) valuation methodology.

[2] With a stock market capitalisation of over USD 1.3 trillion as of end 2020, or about 1% of global listed stock markets.

4 Limited evidence to date of the financial materiality of water-related risks for the financial system

This chapter provides information on the quantification of impacts of water-related risks in the financial system, at aggregate levels. It finds that impacts are generally small and unlikely to be considered financially material at this stage. The next chapter looks into specific factors that can contribute to explaining why the impact of water-related risks in the financial sector appear to be modest at present, despite the above noted importance of water-related risks for economies and societies.

Several reasons may contribute to explain this apparent gap. Firstly, current approaches to risk modelling and risk assessment do not fully capture all types of risks, and even when such risks are considered in risk assessments, they are often not fully priced. Secondly, current prudential regulations for the financial sector do not explicitly mention of environmental risks. The example of emerging supervisory guidance in the Eurozone banking system shows that the uptake by banks of environmental risks in their risk assessment practices is slow and limited. It also shows that banks that already systematically assess environmental risks report that these have, or are likely to have, a material impact on their risk profile (ECB, 2021[36]). Thirdly, the financial sector can make use of risk hedging or transfer tools, such as Credit Default Swaps or the issue of catastrophe bonds, which may reduce the perception of the financial materiality of the risks in the financial system.

Typologies of water-related risks in the financial system

Water-related risks form an important part of the risks identified by the financial sector as climate and environmental risks. For instance, the ECB suggests the following examples of climate-related and environmental risks drivers in its supervisory guidance (Table 4.1).

Table 4.1. ECB examples of climate-related and environmental risks drivers

Risks affected	Physical		Transition	
	Climate-related	***Environmental***	***Climate-related***	***Environmental***
	Extreme weather events	Water stress	Policy and regulation	Policy and regulation
	Chronic weather patterns	Resource scarcity	Technology	Technology
		Biodiversity loss	Market sentiment	Market sentiment
		Pollution		
		Other		

Source: (ECB, 2021, p. 12[2]).

Physical risks relate to risks of hazardous events occurring, like floods or droughts. Transition risks related to water may include transition risks arising from changing regulations and policies that can shift the allocation of water resources, require more stringent quality standards, or increase the cost of water use (via tariffs, abstraction charges, etc.), among others.

Another example of physical risk guidance to the financial sector is provided by Four Twenty Seven (427), a climate research and data provider recently acquired by one of the largest credit rating agencies (CRAs), Moody's. Water-related risks feature prominently among the physical risks identified for sovereign and municipal issuers. Physical risks identified are floods, heat stress, sea level rise, water stress, hurricanes and wildfires. Only the two last items are not water-related.

One clear observation is that relevant data and analysis to understand and quantify the linkages between water-related risks and financial materiality remain very limited. Due to resource constraints, not much evidence could be gathered for the present research. However, resource allowing, more evidence could be researched from desktop research of publicly available reports and by engaging into dialogue with financial actors. The patchy and limited analysis to date prohibits stronger conclusions.

Estimates of financial system exposure to water-related risks by Central Banks

As noted above, De Nederlandsche Bank evaluated the exposures of Dutch financial institutions to businesses operating in water stressed regions, noting that businesses operating in water-stressed regions are exposed to increased risk. DNB results tend to confirm that the corporate businesses held in the equity portfolios of Dutch financial institutions are highly exposed to water-related risks. For instance, the study estimated that the financial sector in the Netherlands has a combined exposure of EUR 83 billion to facilities located in extremely water-stressed regions in its equity portfolios (amounting to approximately 17% of all equity holdings). Pension funds account for 94% of this exposure, given their relatively large equity holdings (De Nederlandsche Bank (DNB), 2019[18]). Looking only at specific sectors for which water is considered "vitally important" (such as agriculture, mining and energy production) the exposure to businesses operating in extremely water-scarce regions still remains significant, at EUR 37 billion (De Nederlandsche Bank (DNB), 2019[18]).

On the other hand, the exposure of insurance firms and banks were found to be limited, at 3.9% and 2.1%, respectively. Of the bank loans to large businesses, out of a volume of bank loans outstanding of EUR 810 billion, only EUR 14 billion was found to be exposed to extreme water stress.

DNB underscores that the Dutch financial sector has not yet fully considered the impact of water-related risks in its risk assessment and acceptance processes, and that a more detailed understanding of individual investments is needed to assess the magnitude of the risk related to water stress. It suggests that water stress can have a major impact on society and businesses, and hence on the investments of financial institutions (DNB, 2019, p. 24[42]).

The European Central Bank (ECB) together with the European Systemic Risk Board (ESRB) conducted a similar exercise in 2021 for corporate exposures to a number of climate related risks, including water risks, using data from 427 (ECB, 2021[2]). With difference to the DNB study, the ECB novel methodology for this study estimates the impact not to corporate physical assets, but to corporates financials: equity, debt, liquidity and solvency. Water-related risks in scope include hydrological events such as floods (river / coastal) and climatological events (drought). Similarly to the DNB study above, the report find moderate numbers for financial sector exposure. For instance, 10.6% of bank credit exposures to non-financial corporations in the Eurozone are subject to high or increasing flood risk, 1.4% to coastal floods/sea level rise, 12.2% to water stress (ECB, 2021[2])..

The report underlines that physical risks does not appear to be priced in in the Eurozone banking system. It notes "the likelihood that the estimates only represent the lower bound for climate-related losses in the

financial system….. Notwithstanding the notable progress made in measuring and assessing the impacts of climate change on financial stability, much remains to be done" (ECB, 2021[2]).

Estimates of water-related risks in insurance

Insurance plays a major role in estimating and mitigating water-related risks. However, insurance regulations are different in various countries and regions, and the insurance sector is more fragmented and less integrated internationally than the banking sector. For this report, no evidence was found of global approaches by the insurance sector of water-related risks. Rather, two individual reinsurers' approaches are proposed as an illustration.

According to reinsurer Munich Re, flooding accounts for some 40% of all loss-related natural catastrophes since 1980, with losses worldwide totalling more than USD 1tn. However, Munich Re underscores that only 12% of these losses were insured, which means that the direct impact on the insurance sector is much smaller than the total losses (MunichRe, 2020[43]). Property owners and governments bear the uninsured risk.

Another reinsurer, Swiss Re, provides interesting details of the methodology and impacts of certain water-related risks. In terms of methodology, the reinsurer makes a distinction between "primary" and "secondary" perils. The term "primary perils" references large-scale catastrophes, notably tropical cyclones, earthquakes and European winter storms. Events tend to be less frequent, but resulting losses can be extreme. "Secondary perils" is an umbrella term for natural catastrophes that typically generate losses of low to medium magnitude, but that can happen relatively frequently. These include thunderstorms, hail and tornadoes, drought, wildfire, snow, flash floods and landslides. Importantly, the reinsurer notes that "secondary peril events are not fully monitored nor modelled. Given the rise of their associated losses, secondary perils need to be better understood for the purpose of more complete and accurate risk assessment. Critically, the complex interplay of factors – natural world and socioeconomic – shaping secondary peril developments need to be further investigated and much better understood."

In terms of estimates, the reinsurer underscores that the " largest annual insured loss total from secondary peril events –USD 62 billion – occurred in 2011, the year of devastating floods in Thailand and high-loss tornado outbreaks in the US (SwissRE, 2021[44]).. Over the past decade, in Europe, South America and Asia, flooding was the main secondary peril (more specifically, river flooding, flash flooding and surface water flooding, the latter occurring when urban drainage systems are overwhelmed). At the global level, flooding represents 16% of all secondary peril insured losses in 2011–2020. If floods resulting from hurricane- or typhoon-induced precipitation and storm surge are included, (i.e., secondary effects of primary perils), the share increases to 20–25%, making it the number two contributing secondary peril of the last decade, after severe convective storms and wildfires. However, due to lower insurance penetration, flood loss events tend to be under-reported (SwissRE, 2021[44])..

While the upward trend of global flood losses has been less pronounced than that of wildfires and storms, research has demonstrated that about a third of the cumulative flood related losses in the US can be attributed to precipitation changes in recent decades. Hence, the potential for a significant future increase must not be underestimated, considering the increasing water-holding capacity of the atmosphere in a warming climate, growing exposure in flood-exposed low-elevation coastal zones, and more and more surface being sealed in urban areas" (SwissRE, 2021[44]).

Other estimates of water-related risks in the financial system

Four Twenty Seven researched the exposure of sovereign borrowers to climate risks, including water-related risks. It estimates that roughly USD 78 trillion, equivalent to about 57% of the world's current GDP,

is situated along flood-prone coastlines, river ways, and low-lying deltas. It found that two-thirds of all sovereigns evaluated are highly exposed to at least one climate hazard deemed “high” or “very high” risk, and nearly half of all sovereigns are exposed to two or more hazards (427, 2020[7]). This is one more indication of the potential materiality of water-related risks to the particular segment of sovereign bonds, although it falls short of precise quantification.

The BlackRock Investment Institute estimated the risk of climate risks, including water risks, to US municipal issuers, noting that “Climate-related risks are underappreciated in the U.S. municipal bond market. A lot is at stake: The market has USD 3.8 trillion of outstanding debt, according to late-2018 Federal Reserve data.” They found that “ Within a decade, more than 15% of the current S&P National Municipal Bond Index (by market value) would be issued by Metropolitan Statistical Areas (MSAs) suffering likely average annualized economic losses of up to 0.5% to 1% of GDP. This would have big implications for the creditworthiness of MSAs” (BlackRock, 2019[45]). It must be noted that this estimate does not include the quantification of financial materiality for the financial sector.

Issues affecting the financial materiality of water-related risks for the financial system

As discussed so far, the transmission of such water-related risks into material financial impacts on the financial sector appears modest to date. Data and analysis to understand and quantify the linkages between water-related risks and financial materiality are very limited. As a result, we posit that there could be a “materiality gap” between the potentially substantial economic impacts of water-related risks (which are well documented and rising) and their financial materiality in the global financial system. This section identifies several specific reasons for this “materiality gap”,

As noted above, the limited evidence from this paper tends to show that the potential impacts from water-related risks are poorly understood and assessed to date. More monitoring of water-related risks in the financial system may be warranted, as risks that are not currently material could become so in the future. Besides, from an investment point of view, such increased awareness would likely trigger more action in the face of those risks. Such action could include avoiding building future liabilities (when financial flows contribute to financial exposure and vulnerability to water-related risks), and allocating more capital to the mitigation of those risks. The final chapter will propose some policy considerations in relation to fostering an increased recognition of the financial materiality of water-related risks in the financial system.

This section aims to raise the attention of the water community on possible issues that could warrant further examination. It does not derive from a comprehensive review of all potential impacts of water-related risks on the financial sector. Further research across representative segments of the financial system would be necessary to assess the relative importance of these issues.

Current approaches to risk modelling and risk assessment may not fully capture and price risks

Financial markets do not appear to fully price water-related risks at present

Emerging evidence from some central banks and financial institutions reveal that water-related risks are typically not fully captured in risk assessment approaches and when they are incorporated, these risks are usually not fully priced. As an illustration, one of the largest global asset managers, BlackRock, recently observed two municipal bonds with similar characteristics: Jupiter, Florida, USA, is an area beset by the hurricanes that affect the greater Miami region. Jupiter’s location and its numerous waterways make the city especially vulnerable to tropical storms and hurricanes. By contrast, Neptune, New Jersey is far more insulated against severe storms. They compared a Jupiter water revenue bond against a Neptune bond

with fairly similar characteristics. The two bonds were found to have almost identical yields after adjusting for credit quality. If water and climate-related risks were being considered as a key factor in the bonds' pricing, the Neptune bond would carry a lower yield (meaning a higher price) than the Jupiter bond. They found similar results for other spot checks of bonds in areas of relatively high and low climate and water-related risk (BlackRock, 2019, p. 11[45]).

BlackRock also found that revenue bonds tied to specific projects — those issued by water and sewer utilities — may suffer direct harm from sea level rise, floods or droughts. Their conclusion is that "extreme weather risks already threaten utility stocks — and are set to rise in frequency and intensity over time — but are not fully priced in" (BlackRock, 2019, p. 10[45]). The analysis also found that extreme weather events are not priced into the equities of U.S. electrical utilities. Extreme weather events can disrupt water utilities, as evidenced for instance by a recent cold snap in Texas, which crashed the power grid (Reuters, 2021[46]).

Data may not be available at the required level of granularity

The general approach to risk assessment in the financial system is a granular, individual asset risk level approach. The financial system measures financial risks, and proposes financial instruments or regulation to take those risks into account. More specific considerations in relation to the prudential regulation of the financial system for banks and insurance companies are provided below.

The lack of data as a limitation to properly assess water-related risks, as well as more generally environmental and climate related risks, is increasingly recognised as an issue for the financial sector. For instance, the credit rating agency (CRA) Moody's, a major player, expresses this concern. CRAs play a major role in financial markets. They provide ratings of the credit risks of borrowers, particularly in the huge fixed income (bond) markets. The credit rating provided by CRAs influences the pricing of an issue, therefore its feasibility given current market conditions. It enables the fast distribution of newly issued paper on capital markets, without borrowers having to carry on their own credit risk assessment.

It is important to underscore that CRAs rate the credit risk of a given issuer, not the economic risk. For instance, water scarcity can be an economic risk as continued declines in the supply or access to water can limit the economic development in a region or country and hinder GDP growth (The World Bank Group, 2016[47]) (Sadoff, et al., 2015[4]). But the credit risk of the region or country will be impacted only if this economic impact translates in a financial impact, more precisely an impact on the capacity of the issuer to repay its debt[3]. While economic and financial performance are generally linked, it is not necessarily so[4].

An illustration of the nuanced assessment of the impact of heat stress on the credit risk of governments is provided in a recent report by CRA Moody's. It quantified the exposure of local US governments to heat stress. It found that roughly USD190 billion (21%) of the outstanding USD 895 billion in debt for all Moody's-rated local governments has been issued by entities in counties with high or very high exposure to heat stress, with nearly 80% of this amount is in the Midwest and Southeast combined. It however noted that "while heat stress is a credit risk, local governments' economic and fiscal strengths will help manage exposure to public health, infrastructure and other threats" (Moody's, 2019[48]).

[3] Even more precisely, the debt that is rated by the CRA.

[4] For instance, one can consider a region adapting to water scarcity and decreasing population by developing a financial services industry instead of other, water-intensive economic activities. The financial services industry can be a source of cash for the region, via local taxes, employment, etc. But the financial services industry is a small contributor to GDP, because only fees, not interest nor capital gains, are subject to Value Added Tax. In this instance, the GDP of the region could decrease, while its cash position and creditworthiness increases. This is an extreme example, which however touches on the wider issue of the impact of the financialization of the economy on GDP growth, which is outside the scope of this paper.

Lack of spatial, forward-looking and second-order level data

Sovereign borrowing is a major component of the newly issued paper on global financial markets. The International Capital Markets Association (ICMA) estimates that as of August 2020, sovereign bonds represented half of total global bonds issued and outstanding (USD 63.7 trillion out of global bond markets of USD 128.3 trillion) (ICMA, 2020[49]). Four Twenty Seven, an affiliate of credit rating agency (CRA) Moody's, observes that "Sovereign climate risk assessments have not typically integrated a view on who and what are exposed to specific hazards [including water-related hazards] within a country because hazard data and exposure data capturing the location of populations or economic productivity have generally been unavailable or too coarse to be useful" (427, 2020, p. 3[7]).

Municipal borrowing is also an important part of global bond issuance. In the US, the largest global bond market, municipal bonds for water infrastructure comprise the largest share of the municipal bond market. As for sovereign borrowers, current CRA's methodologies for incorporating climate change and water-related events into municipal credit ratings focus mostly on historical instances of extreme weather events, local governments' adaptive capacity and financial resilience. Moody's acknowledges that climate change can influence credit risks, but in the absence of forward-looking climate projections, such estimates may grossly underestimate the magnitude of future risks, or at least fail to characterize the type of climate risks that may eventually make it more difficult for a municipality to meet its financial obligations (427, 2018[38]).

Similar concerns in relation to the lack of granular data is expressed in other parts of the financial system. For instance, in the above referenced letter to the Norwegian MoF, asset manager NBIM notes that "Access to relevant, high-quality data is limited. Unlike assessments of other types of risk, we can make limited use of historical data. There is also considerable uncertainty about the possible financial consequences of climate change and about the likelihood and timing of specific developments". This relates to climate and environmental risks, including water-related risks (NBIM, 2021, p. 3[41]).

For listed equities, the asset manager signals that its current scenario analysis fails to "capture the effects of dramatic climate shifts with a substantial long-term economic impact via possible second-order effects such as migration, political unrest and financial instability. The relationship between climate change and potential second-order effects is highly complex and so difficult to estimate."

Research points that some water-related variables are more sensitive to measurement errors and modelling assumptions, notable changing patterns of precipitation and extreme events (Stocker, 2013[50]) (Tankov, 2019[51]).

Nevertheless, data gaps need not be overstated. The ECB emphasises the "need for banks to take intermediate steps when data or methodological gaps exist. They should use qualitative metrics, develop proxies with the data sources that are available and adjust their strategies accordingly to enhance their resilience against climate and environmental risks. However, some of the supervisory expectations do not have considerable data needs, so banks should meet these expectations more quickly" (ECB, 2021[36]).

A different risk approach as an alternative to more data

German asset manager DWS (formerly Deutsche Bank Asset Management) advocates a different approach to the integration of water-related risks in the assessment of sovereign debt, a key component of capital market. It notes that "Estimating water risk for governments is certainly possible, as is investor engagement with governments. Vast resources are used in countries' national offices for statistics. It is time that such offices start to report on all water risks. In the same way as rating agencies use a multiplicity of indicators to rate companies, a number of indicators ought to be defined to highlight water risks and report on progress being made….Investors should also put pressure on governments to strengthen water policies and increase public water-related infrastructure investments. Having a water risk framework for sovereigns bonds is of paramount importance in providing capital to developing economies where there is a water risk related to the growing population" (Curto, 2020[52]).

Current bank prudential regulations do not integrate environmental risks

Because of their crucial role in economies and societies, global financial systems are strongly regulated, both at the global and national level. The definition and accounting methodology of risks is part of this regulation. Therefore, financial regulation shapes the way the financial system defines and accounts for risks, including water-related risks.

The Basel III prudential regulation of banks applies across advanced economies, under the supervision of the Bank for International Settlements. Banks are also regulated at the national level. The Basel prudential regulation was initially developed in the late 1980s. Its purpose was to strengthen the solvency of individual banks so as to avoid a systemic banking crisis. Banks are strongly connected between themselves via interbank lending. Therefore, the default of a given bank may trigger by contagion the default of the entire banking system, as was experienced during the Great Financial Crisis (GFC) in 2008. The regulation was amended, with increased individual solvency requirements for banks, after the GFC. The regulatory changes will be fully implemented in 2023 (BIS, 2021[53]).

In a nutshell, the regulation requires banks to compute and publish a solvency ratio. This solvency ratio compares the equity capital that the bank holds, to the risks it bears. The risks are defined in the regulation in the form of a list of risks, which need to be reported on to the regulators and markets, presented in more detail below. The reporting bank sums all of its risks and expresses it as a percentage of its total equity capital. The regulation requires that this percentage, called the prudential solvency ratio, does not get below 4% (this is a gross simplification of a highly complex regulation). In case it would, the regulator could take regulatory action against the bank, asking it to increase its equity capital, or, restricting its licence to operate.

Table 4.2 below presents the three broad categories of risks that require mandatory reporting by banks. The first category is credit risks: risks on the lending activities of banks. The second category is market risks: risks on the trading activities of banks. Trading activities consist in holding financial products for the purpose of selling them at a profit. The third category is operational risk: the risks stemming from the technical operations of a bank, such as cyber risk, fraud, litigation and liability fines.

The credit risk assessment is based on the estimation by banks of the risk of that the debtor will default, and of how much the bank would lose if this default event occurs. This risk assessment is made by the bank using its internal credit risks models but may be controlled by regulators. For instance, if a bank lends EUR 100 million to a corporate, it may consider that it has a 40% probability of defaulting over the credit period, and that in this case all will be lost (in case there is no insurance, or asset to recover as guarantee). In this case, the bank will book EUR 40 million as a risk exposure for this credit.

Table 4.2. Definition of risks in banks prudential regulation

Type of risk	Definition
Credit risk	Internal assessment based on the probability of default, and loss given default to account for guarantees, or other recoverable amounts such as the value of mortgages.
Market risk	Computed on financial products that banks hold for trading purposes. The risk is evaluated on the basis of internal risk models based on the past observed probabilities of default (Value at risk or VAR calculation).
Operational risk	Technical risks such as fraud, cyber risk, and failure to operate following for instance fire, flooding or litigation

Source: Authors.

It is important to note that the prudential regulation has not been revised to include climate, environmental (C&E) risks, including water-related risks. Central banks have started to give supervisory (but not regulatory) guidance. For instance, the ECB published a guide in November 2020 which includes some

guidance for banks on how to amend their risk models to account for C&E risks (ECB, 2021[2]). The guidance is summarised in the Table 4.3 below.

Table 4.3. ECB examples of environmental risks drivers in prudential regulation

Risks affected	Physical risks	Transition risks
	(Of which water stress)	(of which policy, regulation, technology and market sentiment)
Credit risk	The probabilities of default (PD) and loss given default (LGD) of exposures within sectors or geographies vulnerable to physical risk may be impacted, for example, through lower collateral valuations in real estate portfolios as a result of increased flood risk.	Energy efficiency standards may trigger substantial adaptation costs and lower corporate profitability, which may lead to a higher PD as well as lower collateral values.
Market risk	Severe physical events may lead to shifts in market expectations and could result in sudden repricing, higher volatility and losses in asset values on some markets.	Transition risk drivers may generate an abrupt repricing of securities and derivatives, for example for products associated with industries affected by asset stranding.
Operational risks	The bank's operations may be disrupted due to physical damage to its property, branches and data centres as a result of extreme weather events.	Changing consumer sentiment regarding climate issues can lead to reputation and liability risks for the bank as a result of scandals caused by the financing of environmentally controversial activities.
Other types of risks (liquidity, business model)	Liquidity risk may be affected in the event of clients withdrawing money from their accounts in order to finance damage repairs.	Transition risk drivers may affect the viability of some business lines and lead to strategic risk for specific business models if the necessary adaptation or diversification is not implemented. An abrupt repricing of securities, for instance due to asset stranding, may reduce the value of banks' high quality liquid assets, thereby affecting liquidity buffers.

Source: (ECB, 2021, p. 12[2]).

The ECB recently noted however that the uptake of this advice by banks in the Eurozone is too slow, stating that "very few banks have incorporated sound C&E risk management processes or clearly integrated C&E risks into their strategies or risk mitigation processes. By contrast, those banks that already systematically assess C&E risks report that these risks have, or will have, a material impact on their risk profile. This means that banks cannot properly control or manage those risks.…Looking at credit risk management…most banks are still lacking a sound risk classification structure or loan pricing framework for C&E risks. In other words, these banks are generally not yet in a position to identify, manage and monitor C&E risks at counterparty level" (ECB, 2021[2]).

Two particular areas for a better assessment of environmental risks by banks are worth mentioning, in relation to water-related risks. The first area is the credit risk assessment of sovereign borrowers. Sovereign borrowers are a large part of banks credit exposures. In the Eurozone, as of end 2020, sovereign lending represented 9% of total banks' balance sheets (i.e., a much larger share of lending activities, a subset of the total balance sheet) (DBResearch, 2021[54]). As indicated above, there is reason to believe that sovereign borrowers, or some of them, may be highly exposed to water-related risks, and that this exposure has not been fully priced in by financial markets. As a rule, banks assign limited risks weights to sovereigns (in the indicative range of 2 to 5% of total exposure), because they are the lenders of last resort in their currencies (in most cases). So, the current limited risk weight of sovereigns could be insufficient to cover for significant water related impacts on sovereign credit quality of they were to materialize, with consequences for the banks solvency. This would require further research to be substantiated.

Another relevant focus point for water-related risks are banks prudential operational risks. As the ECB points out from its recent supervisory survey, "Operational risk management, is among the areas that

requires the most work. Less than around two-fifths of banks have developed plans that are (broadly) adequate in those areas. Often the plans do not foresee any assessment of how many of their activities are exposed to liability and/or litigation risks driven by C&E factors" (ECB, 2021[36]). Examples may be found however where water-related risks may directly affect a banks operation. In 2018, for instance, the alert level of river Seine in Paris was nearly reached. The French systemically important[5] bank Société Générale has its headquarters and servers in La Défense, a part of Paris that would be cut from staff access in case the Seine river floods. Banks tend to report risks in this area on the basis of past events, assuming a stationarity that may not be suitable for water-related events.

As an illustration of the above, operational risks reported in 2020 by the largest banking group in the EU, BNP Paribas, does not contain any reference to climate or water-related risks. In its audited 2020 reference document, the bank describes operational risks as "risk of incurring a loss due to inadequate or failed internal processes, or due to external events, whether deliberate, accidental or natural occurrences. External events include, but are not limited to floods, fire, earthquakes and terrorist attacks." The bank reports that in 2019, and also on average from 2012 to 2020, damages to physical assets represent just 1% of operational losses accounted for as operational risks. Fraud represents 14%, execution and delivery issues 17%, "Clients, products and business practices", which includes fines for non-compliance with regulations, accounts for 62%. In other words, based on historical data, damage to physical assets is a minor risk consideration in comparison to other issues. The total amount of operational risks reported by the bank for the year 2020 was € 70.6 billion (BNPP, 2020, p. 458[55]).

Time horizon of water-related risks and the financial system: the role of hedging and risk transfer practices

As noted above, the financial materiality of a future impact is evaluated by the financial system in terms of net present value. The relatively high level of discount rate used as part of standard industry practice currently rapidly discounts the impact of events after 5 years. As a result, business planning in finance is generally focussed on a three- to five-years basis, which does not foster the consideration of longer term risks. The limitations of such an approach for currently longer-term climate and environmental risks was acknowledged recently by the New York Department of Financial Services (NYFS) in its guidance to the industry to address climate and environmental risks: "A strategic response to climate change requires a longer-term view than the typical business planning horizon of three to five years. The time horizon for analysing financial risks and opportunities related to climate change should gradually go beyond the standard three to five years to a medium-term (e.g., ten years) and ultimately long-term (e.g., 30 years) view" (NYDFS, 2021[27]).

The asset manager NBIM recognizes an exposure to physical risks, including water-related risks, as well as challenges to incorporate them in existing models. "The physical consequences of climate change are often much further ahead in time than would normally be captured by models used to analyse financial markets…One way of circumventing this challenge has been to limit the analysis to the most obvious and immediate cases….One example is that the interest rate at which US counties can borrow tends to increase with the counties' expected economic losses from rising sea levels" (NBIM, 2021, p. 3[41]).

[5] In the wake of the GFC, the Basel Committee on Banking Supervision established a list of banks that are deemed systematically important, i.e. the default of which could trigger a systemic crisis. This list is maintained at the global financial system level, and specific lists exist for each country. See https://www.fsb.org/work-of-the-fsb/market-and-institutional-resilience/post-2008-financial-crisis-reforms/ending-too-big-to-fail/global-systemically-important-financial-institutions-g-sifis/.

Role of risk management and risk transfer techniques in financial institutions

For risks that are considered financially material, financial institutions can use a range of risk management techniques to mitigate the financial impact of such risks on their own accounts. For example, banks use widely a particular financial product called Credit Default Swap (CDS) to assess the risk of default on a given exposure in the context of their prudential assessment of risk. A CDS is a contract by which a third party accepts to take the losses on a credit in case of default. CDSs are offered by banks, but also by non-banking financial entities (specialised investment funds called hedge funds). However, CDSs are mostly available in the market for maturities below five years, very few for up to 10 years, and none above. For maturities longer than 10 years, such as typically project finance debt, banks use proxies derived from observation of the CDS market. But because this market is so short term, such proxies fail to consider all longer term risks, including climate and water-related risks.

A group of researchers from the investment banking community developed a model to factor in longer term climate risks, such as sea level rise. They find that there could be significant changes in the evaluation of the impact of climate-related risks by better capturing longer term effect in risks assessment models (Kenyon, 2021[56]).

In the case of insurers, risk transfer is common. This is a market practice that has developed in recent years to allow insurers to sell risks that they do not wish to bear, to capital markets. This is often done via issuing a specific capital market instrument known as “catastrophe bond”. The World Bank, in a guidance document for sovereign issuers, included flood and drought in the risks of perils that can be addressed with this instrument (WorldBank, 2018[57]). Insurers and reinsurers sell the risk to a Special Purpose Company (SPC). The SPC issues a bond to capital markets (the “catastrophe bond”). This practice could signal that such risks are considered material (or under-priced) by insurers (Schroders, 2019[58]). Such practices, transferring the risks to capital markets, enable insurers and reinsurers to reduce their exposure to such risks. It is worth noting that the risk transferee, a Special Purpose Company, will generally not be subject to insurance regulation, in particular the solvency requirements that would mandate a risk assessment.

5 Implications for policy considerations

While further research is required to more fully document the potential interlinkages between water-related risks and financial materiality, this paper highlights some key issues for consideration and further exploration relevant for policy makers and financial institutions.

Finance regulators

The apparent disconnect between the material economic impacts and financial materiality of water-related risks is topical for policymakers in many ways. For financial regulators, it raises the issue that material financial risks may be "masked" by the current practices of the financial system. This would mean that if and when risks materialise, the financial sector may not be equipped to deal with them. The recent history of the GFC has shown that the consequences of financial instability for economies and societies may be dire. The impact of the GFC for advanced economies can be estimated at between 10 and 15% of GDP[6]. Besides, the legacy from the GFC and other enduring imbalances in global financial systems results in a generally high cost of capital, as mentioned above. This cost of capital resulting from financial instability makes the transition to a sustainable economy more expensive. It also embeds short termism in financial decision making.

Finance supervisors have started to provide guidance on the integration of water-related risks in global financial system risks assessments. Examples were provided with the ECB and the NYDFS. However, the financial system appears to be slow in its uptake of the assessment of those risks, and many institutions continue to rely to a large extent on historical rather than forward looking data, despite evidence that they are present and mounting.

There may be a role for the water community to engage with finance supervisors to bridge the data and methodological gaps that may prevent a quick uptake of risks assessment by the financial system. However, the trigger for such collaboration must come from a willingness of the financial system to change its practices, and to change them fast.

On the basis of this paper, again with due care due to its limited scope in terms of research, financial regulators together with the water community could focus their efforts on:

- Measurement of water related operational risks for banks (prudential regulation): measuring the potential impact of water related risks on banks premises, including data centres and offices, and including the risk assessment in the prudential reporting, as per ECB guidance, would seem a relatively quick win. It could also contribute to enhancing the water related risks culture within the banks, opening the way for a larger update of risk assessment tools beyond the operational risk.

[6] «Measured by decrease in per capita United States GDP compared to the pre-crisis trend, by 2016 the crisis had cost the country 15% of GDP, or $4.6 trillion" (Mukunda, 2018[69]).

- Measurement of water related risks in the prudential regulation adjusted from the use of Credit Default Swap, for risks maturities that exceed the current availability of the CDS market (5 years, with exceptions up to 10 years). From the existing research mentioned in this paper, this seems a promising avenue to better capture longer term risks, including water-related risks, in the financial system.
- Improve the understanding of possible water-related credit risks for sovereigns and municipalities.

Water community

Why the water community is concerned

The water community has been advocating for more financing for investments that contribute to water security and sustainable growth, including through climate adaptation and resilience. A key assumption underpinning the present research is that if and when the financial materiality of water-related risks increases in the financial system, this could trigger action by financial actors to contribute to the mitigation of these risks, including via more investment.

It should be noted though that the consequences of the water-related risks becoming financially material for the financial system could be multiple. They could also include action by financial actors to reduce their exposure to risks that are perceived as financially material, by re-allocating capital from risk exposed assets and contexts. To a certain extent, the existing practice of risk transfer via the issuance of catastrophe bonds is an example of such action. The GFC has shown that risks (sub-prime lending risks) that had been transferred from highly regulated entities, banks, to less regulated entities, Special Purpose Companies, were “diluted” in the global financial system to the extent that they could trigger a systemic financial crisis, even when prudential banking regulation was in place to avert it.

Action on the research front

Notwithstanding, the water community, as part of its work to attract more financial investment to mitigate water-related risks, could engage with financial actors, including supervisors and regulators, to explore how a better recognition of the financial materiality of such risks could trigger more investment. It could engage for example by researching with individual financial actors, how they would react to the unexpected, but not unlikely, realisation of a water-related risk.

For instance, how French Banks the servers and offices of which are situated in La Défense would cope if the Seine River was to overflow next year, cutting access to staff and core data transfer infrastructure with the Paris centre. This is obviously an anecdotal example, focussed on an advanced economy (however, French banks rank high in terms of size in the global banking system). Such an investigation could help identify concrete adaptation action, and trigger an investment need.

Connecting water policy to financial materiality for sovereign and sub-sovereign issuers

On a more general level, water policies, regulations and management practices directly impact water security of municipalities, regions and countries. Physical, economic and financial water-related risks are also driven by policies in other sectors (agriculture, urban development and housing, land use, energy, among others). In this respect, the water community also needs to engage with other communities in the effort to mitigate water-related risks. Therefore, these actions directly affect the financial impacts of water-related risks on sovereigns and municipal issuers (such as in the examples discussed previously). Investments to improve water security can be a key factor in mitigating financial risk (notably in the short term credit risk of states and local water utilities).

For instance, recently the US Bureau of Reclamation announced cuts to water deliveries from the Colorado River to Arizona. Declining water levels in Lake Mead, a major reservoir in the West, and resulting supply cuts highlight the long-term environmental risks from accelerating climate change for communities in drought-prone areas. This has a direct implication on the financial system, as "persistent drought conditions will require continual expenditure by municipal authorities on resource management, material levels of capital investment and increased costs, and could impede future development and population growth". The analysis by a credit rating agency also underscores that "Western local governments and their utilities are well prepared to manage current cuts. [Despite mounting long term risks], in the more immediate term the credit impact on major water utilities in Arizona and Nevada will be mitigated by strong regional planning, robust storage and conservation efforts. Las Vegas Valley Water District and Phoenix Water Enterprise, the biggest water systems in Nevada and Arizona, illustrate the strong water management in each state" (Moodys, 2021[59]).

The research in this paper, however, tends to point at gaps in the assessment of the financial materiality of water-related risks for sovereign and municipal issuers, which together form a substantial part of new issuance and stocks of debt on capital markets. The water community could be instrumental in bridging this gap by considering not only the economic implications of policy action, but also its potential financial impacts. While this role has been traditionally devoted to financial analysts such as those employed in CRAs, water-related risks are a new area of investigation for the financial sector. An enhanced dialogue between the water and financial community on financial impacts could help bridge the existing materiality gap. It could also increase the information channels of the water community on which type of policy action is considered as a mitigant by the financial sector from the point of view of financial impacts (strong regional planning, robust storage and conservation efforts in the above example), which could help prioritise investment.

Annex A. Transmission channels of water-related risks to the financial sector

This annex presents a rough characterisation of how water-related risks transmit to the financial system. Water-related risks may affect individual financial actors: this is called micro level transmission in the presentation below. Macro level transmission, in turn, would affect the financial system on a global level. This is a conceptual presentation that is not supported by quantitative research. Getting a sense of magnitude of these various transmission channels, of which ones would be more impactful, could be an avenue for future research. It could help target, prioritize or sequence policy responses to the mitigation of water-related risks in the financial system.

Financial transmission at micro level

Water-related risks ("too much, too little or polluted water") risks may transmit to the financial system at various levels. Five categories of financial institutions may be considered: banks, insurance companies, asset owners such as pension funds, asset managers, and central banks.

Transmission of water-related risks to banks

A large part of the lending activity of banks in advanced economies concerns mortgage lending. On average, 60% (Schularick, 2014[60]). Mortgage credits may be affected by water-related events as they could impact the market value of property, and/or the solvency of borrowers (in particular when a flood or a flood risk affects a whole area, in terms of housing but also employment).

Another substantial parts of banks' holdings are financial derivative products. A financial derivative is a contract according to which the bank is due to take a certain action (sell or buy a certain quantity of a given product) if an underlying condition is met (the price of a commodity for instance). Financial derivatives are held by banks in order to hedge the risk of their clients. They are also held by banks as trading instruments for the banks themselves, because their price varies according to market conditions. The materialization of water-related risks could impact a wide range of prices: water itself, agricultural or industrial commodities dependent on water availability, such as irrigated crops, livestock, steel, mining, blue chip, hydropower, among others. Credit default swaps, an insurance provided by banks against the default of a corporate or sovereign issuer, could also be affected by water-related losses for corporates ans sovereign issuers whose credit quality may be affected by water-related risks, and pose losses on banks.

The maturity of banks' exposures should be considered as well. As an illustration, as of end 2020, the BNPP banking group, one of the largest banking groups in the Eurozone, had 15% of assets with a maturity over 5 years. So, water-related risks likely to materialize beyond a 5 year horizon would only be relevant to 15% of the bank's global exposures (BNPP, 2020, p. 452[55]).

Insurance companies may be affected by water-related risks in the same manner as banks, by losses in the valuation of the assets they hold, in particular real estate assets. Insurance companies may be affected also by the need to pay out insurance damage cover on water-related events such as flood, drought or pollution. In certain jurisdictions, the exposure of insurance companies to certain water-related risk is

shared by the State (such as France with the “catastrophes naturelles” legislation). Alternatively, some State agencies may offer coverage where private insurance is not available (such as the Federal Emergency Management Agency in the US). Insurance companies may also have the option to decrease the insurance coverage before the event occurs, notably by insuring catastrophe bonds, and/or to increase premia which may partially offset the future loss. Insurance and reinsurance companies have long maturities portfolios, spanning over several decades in advanced economies, so they will bear the longer term water-related risks.

Asset owners are typically holding corporate securities (equity and debt) and government bonds. Asset owners specializing in infrastructure may be proportionately more exposed to water-related issues than other types of asset owners such as pension funds. Corporate securities valuation may suffer from water-related events, particularly in agribusinesses and industries highly dependent on water availability or quality.

Asset managers are exposed to the consequences of higher perceived or real risks in their portfolios by their clients. When water-related risks materialize, clients may ask to sell off of related assets which may lead to performance decrease, in particular in case of herding.

Central banks have become the largest asset owners of advanced economies since the Great Financial Crisis (GFC) in 2008, therefore they are exposed to the same risks as asset owners. The consequences are not the same however, since Central Banks cannot default as they can print money.

The above discussion illustrates the fact that water-related risks, at the micro level, can negatively impact the financial system and its actors in multiple ways. Whether the impact is considered financially material for the financial institutions will depend on the particular situation (importance of water-related risks to the exposures, available resources to face the risks). The session below will mention the potential transmission channels of macro level water-related risks to the financial sector.

Financial transmission at macro level

Water-related risks can impact the economy of a given country not only at the micro level, but also at the macro level. In terms of financial risks, sovereign borrowing has become a key dimension of financial markets in the past decades, and especially since the GFC in 2008. As mentioned above, ICMA estimates that sovereign bonds in August 2020 represented half of total global bonds issued (USD 63.7 trillion out of global bond markets of USD 128.3 trillion) (ICMA, 2020[49]).

Major water-related events such as flooding or drought could affect negatively sovereign bonds markets, by deteriorating the solvency of sovereign borrowers. The solvency of sovereign borrowers can deteriorate following a multiplicity of factors: either economic such as the need to finance immediate investment needs following a water hazard, or financial, such as the need to bail out insurance companies. Not only acute but also chronic water risks can affect the solvency of sovereign borrowers, in particular chronic drought.

Banks can also be affected by macro level risks related to water. For instance, floods can affect critical banking infrastructure such as servers or office space in a given country, putting the whole financial infrastructure at risk. Macro level risks may also stem from monetary instability, triggered for instance by a sudden (acute) or slower (chronic) outflow of foreign currency following a water-related event.

Water-related risks can impact the economy of a country if it is highly dependent on a sector itself dependent on water. A recent example is provided by drought affecting the manufacturing of chips in Taiwan, and disrupting the global supply chain, inducing relocation by some of the major manufacturers. Again the materiality for the country will depend on the reliance of its economy on sectors affected, and the financial materiality from the financial position and resources of the country.

Whether at micro or macro level, the transmission channels of water-related risks to the financial sector appear numerous and potentially substantial. The many ways risks can affect the financial sector contrast with the limited evidence of such risks being recognized by the financial sector as material. A detailed study of the channels mentioned above, in dialogue with the financial sector, would shed light on current risks assessment practices and enable to substantiate more precisely if water-related risks are financially material or not, and why.

References

427 (2020), *http://427mt.com/wp-content/uploads/2020/12/Measuring-What-Matters-Sovereign-Climate-Risk-427_12.2020.pdf*. [7]

427 (2018), *https://427mt.com/2018/05/22/assessing-exposure-to-climate-change-in-us-munis/*. [38]

BEIS (2021), *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972422/Consultation_on_BEIS_mandatory_climate-related_disclosure_requirements.pdf*. [33]

BIS (2021), *https://www.bis.org/bcbs/basel3.htm?m=3%7C14%7C572*. [53]

BIS (2019), *https://www.bis.org/publ/othp31.pdf*. [65]

BlackRock (2019), *https://www.blackrock.com/us/individual/insights/blackrock-investment-institute/physical-climate-risks*. [45]

BNPP (2020), *https://invest.bnpparibas/en/document/universal-registration-document-and-annual-financial-report-2020*. [55]

Carney (2015), *https://www.bankofengland.co.uk/-/media/boe/files/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability.pdf?la=en&hash=7C67E785651862457D99511147C7424FF5EA0C1A*. [64]

CDP (2021), *A wave of change The role of companies in building a water-secure world*. [22]

CDP (2020), *https://www.cdp.net/en/research/global-reports/global-water-report-2020*. [24]

CDP data (2020), *Analysis based on CDP water security 2020 questionnaire*. [21]

CDSB (2018), *https://www.cdsb.net/sites/default/files/materiality_and_tcfd_paper.pdf*. [31]

Centre for Research on the Epidemiology of Disasters (CRED), U. (ed.) (2019), *The Emergency Events Database*, http://www.emdat.be. [5]

CERES (2020), *https://feedingourselvesthirsty.ceres.org/water-risks-and-food-sector*. [23]

Curto (2020), *https://www.dws.com/en-sg/insights/global-research-institute/a-transformational-framework-for-water-risk/#:~:text=DWS%20is%20part%20of%20a,risks%20identified%20by%20the%20WEF.*. [52]

Damodaran (2021), [39]

http://people.stern.nyu.edu/adamodar/New_Home_Page/dataarchived.html#region.

DBResearch (2021), *https://www.dbresearch.com/PROD/RPS_EN-PROD/PROD0000000000517425/What_to_do_with_home_sovereign_exposure%3F_Reducing_.pdf?undefined&realload=zre5JAZqZfryr/8UaCPbHXMWnnqYfIGqoNYiUEk4puVhfDiKwevmxE3GPX3cHIdM*. [54]

De Nederlandsche Bank (DNB) (2019), *Values at risk? Sustainability risks and goals in the Dutch financial sector*. [18]

DNB (2019), *https://www.dnb.nl/media/hm1msmzo/values-at-risk-sustainability-risks-and-goals-in-the-dutch.pdf*. [42]

DoL, U. (2021), *https://www.dol.gov/newsroom/releases/ebsa/ebsa20210310*. [29]

EC (2021), *https://ec.europa.eu/info/business-economy-euro/banking-and-finance/insurance-and-pensions/risk-management-and-supervision-insurance-companies-solvency-2_en*. [62]

ECB (2021), *https://www.bankingsupervision.europa.eu/press/publications/newsletter/2021/html/ssm.nl210818_5.en.html*. [36]

ECB (2021), *https://www.ecb.europa.eu/pub/pdf/other/ecb.climateriskfinancialstability202107~87822fae81.en.pdf*. [2]

FAO (2020), *The State of Food and Agriculture, Overcoming water challenges in agriculture*, https://doi.org/10.4060/cb1447en. [9]

FAO (2018), *The State of Food Security and Nutrition in the World 2018*. [67]

Fiedler, T. et al. (2021), "Business risk and the emergence of climate analytics", *Nature Climate Change*, http://dx.doi.org/10.1038/s41558-020-00984-6. [61]

FSB (2021), *https://www.fsb-tcfd.org/about/*. [30]

FSB (2020), *https://www.fsb.org/2020/10/2020-status-report-task-force-on-climate-related-financial-disclosures/*. [32]

HLEG (2018), *https://ec.europa.eu/info/sites/default/files/180131-sustainable-finance-final-report_en.pdf*. [63]

IASB (2018), *https://www.ifrs.org/news-and-events/news/2019/01/materiality-modernised/*. [26]

ICMA (2020), *https://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/Secondary-Markets/bond-market-size/*. [49]

IndustryWeek (2021), *https://www.industryweek.com/supply-chain/article/21161812/taiwans-worst-drought-in-decades-deepens-chip-shortage-jitters*. [17]

IPCC (2021), *Summary for Policymakers. Climate Change 2021: The Physical Science Basis*, Cambridge University Press. [13]

Kenyon, B. (2021), *https://arxiv.org/pdf/2102.10691.pdf*. [56]

Kerres, M. et al. (2020), *Stop Floating, Start Swimming, Water and climate change - interlinkages and prospects for future action*, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), https://www.everydrop-counts.org/imglib/pdf/Water%20Climate%20Report%202020.pdf. [14]

Kölbel, J., C. Strong and C. Noe (2018), *Mapping Public Water Management by Harmonizing and Sharing Corporate Water Risk Information*, http://www.wri.org/publication/mapping-public-water. [10]

McKinsey (2020), *https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/McKinsey%20on%20Climate%20Change/McKinsey-on-Climate%20Change-Report.pdf*. [20]

Mekonnen, M. and A. Hoekstra (2016), "Four billion people facing severe scarcity", *Science Advances*, Vol. 2/2, http://dx.doi.org/doi.org/10.1126/sciadv.1500323. [8]

Moodys (2021), *https://www.moodys.com/researchdocumentcontentpage.aspx?docid=PBC_1300214*. [59]

Moody's (2019), *https://www.moodys.com/researchdocumentcontentpage.aspx?docid=PBM_1190572*. [48]

Mukunda (2018), *https://hbr.org/2018/09/the-social-and-political-costs-of-the-financial-crisis-10-years-later*. [69]

MunichRe (2020), *https://www.munichre.com/en/risks/natural-disasters-losses-are-trending-upwards/floods-and-flash-floods-underestimated-natural-hazards.html*. [43]

NBIM (2021), *https://www.nbim.no/en/publications/submissions-to-ministry/2020/climate-risk-in-the-government-pension-fund-global/*. [41]

Nelson, G. et al. (2014), "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks", *Proceedings of the National Academy of Sciences*, http://dx.doi.org/DOI:10.1073/pnas.1222465110. [68]

NGFS (2021), *https://www.ngfs.net/node/368148*. [3]

NGFS (2020), *https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_for_supervisors.pdf*. [35]

NGFS (2018), *https://www.ngfs.net/sites/default/files/medias/documents/ngfs_first_comprehensive_report_-_17042019_0.pdf*. [34]

NYDFS (2021), *https://www.dfs.ny.gov/system/files/documents/2021/03/proposed_ins_climate_guidance_2021_public_comment_1.pdf*. [27]

OECD (2013), *Water Security for Better Lives*, OECD Publishing Paris. [12]

Reuters (2021), *https://www.reuters.com/article/us-usa-weather-texas-power-insight-idUSKBN2AL00N*. [46]

S&PGlobal (2021), *https://www.spglobal.com/esg/insights/water-stress-is-the-main-medium-term-climate-risk-for-europe-s-biggest-economies?utm_source=social&utm_medium=LinkedIn*. [19]

Sadoff, et al. (2015), *Securing water, sustaining growth : report of the GWP/OECD task force on* [4]

water security and sustainable growth.

SASB (2021), *https://www.sasb.org/about/*. [28]

SASB (2020), *https://www.sasb.org/blog/double-and-dynamic-understanding-the-changing-perspectives-on-materiality/*. [37]

Schroders (2019), *https://www.schroders.com/en/uk/tp/markets2/markets/what-are-insurance-linked-securities-and-how-do-they-work/*. [58]

Schularick (2014), *https://www.frbsf.org/economic-research/files/wp2014-23.pdf*. [60]

Smith, M. et al. (2019), *Adaptation's thirst: Accelerating the convergence of water and climate action*, Background Paper prepared for the 2019 report of the Global Commission on Adaptation. [15]

Stocker (2013), , https://doi.org/10.1017/CBO9781107415324. [50]

SwissRE (2021), *https://www.swissre.com/dam/jcr:16271084-77b5-478f-b6ce-8948f94cba4e/sigma-1-2021-secondary-perils-en.pdf*. [44]

Tankov (2019), *ssrn.com/abstract=3480156*. [51]

TCFD (2017), *https://assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf*. [1]

The World Bank Group (2016), *High and Dry: Climate change, Water and the Economy*, International Bank for Reconstruction and Development / The World Bank, https://openknowledge.worldbank.org/bitstream/handle/10986/23665/K8517.pdf?sequence=3&isAllowed=y. [47]

UN (2020), *Climate Action Pathway, Water, Executive Summary*. [6]

UNESCO, U. (2020), *United Nations World Water Development Report 2020*, UNESCO, Paris. [16]

UNISDR, CRED and EM-DAT (2015), *The Human Costs of Weather-Related Disasters 1995-2015 Report*, https://www.unisdr.org/files/46796_cop21weatherdisastersreport2015.pdf. [66]

UN-Water (2021), *Summary Progress Update 2021: SDG 6-water and sanitation for all*, https://www.unwater.org/publications/summary-progress-update-2021-sdg-6-water-and-sanitation-for-all/. [11]

VividEconomics (2014), *https://www.vivideconomics.com/wp-content/uploads/2019/05/Financing_Green_Growth-1.pdf*. [40]

WorldBank (2018), *https://pubdocs.worldbank.org/en/555651528746619166/webinar-demystifyingcatastrophebondsfordebtmanagers2018-presentation-abigailbacaandakinchanjain.pdf*. [57]

WRI (2020), *https://www.wri.org/initiatives/corporate-water-stewardship*. [25]