

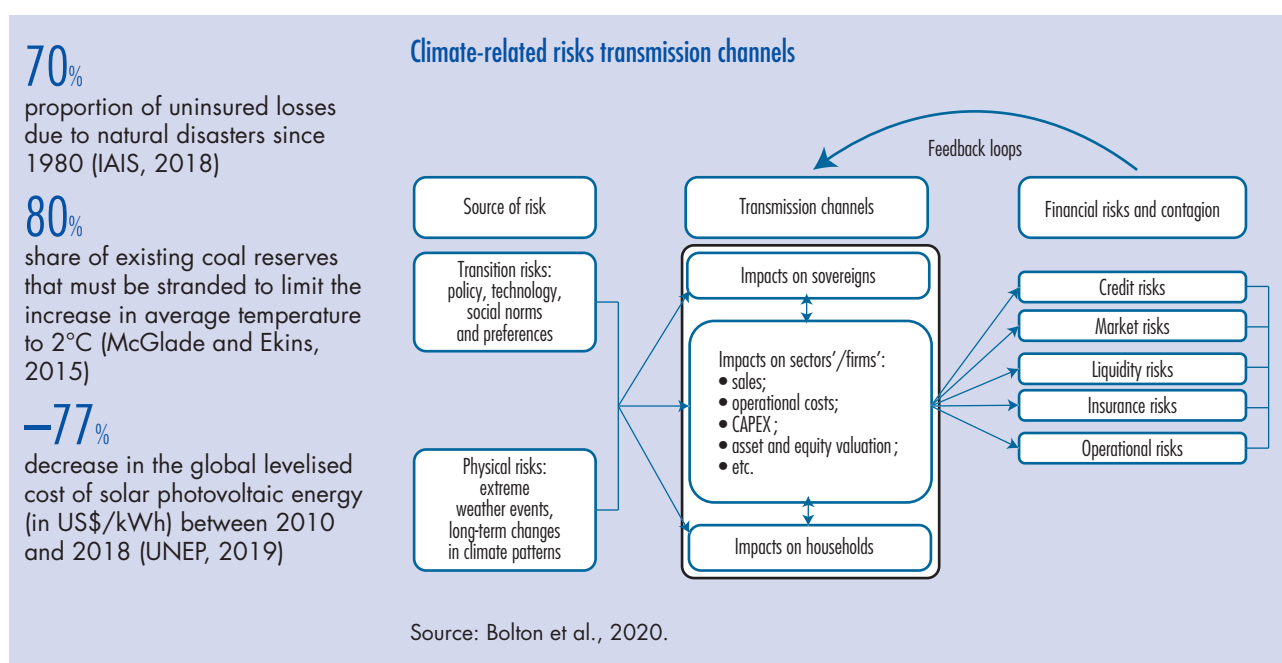


## “Green Swans”: central banks in the age of climate-related risks

Risks associated with climate change are beginning to affect central banks’ financial stability mandate. Recognition of extreme physical and transition risks, known as “Green Swans”, is particularly difficult in the field of financial stability supervision due to the radical uncertainty, non-linearity and cascade effects associated with such risks. Central banks can help prevent these risks and mitigate their consequences, including by developing scenario analyses, but these initiatives will not be sufficient on their own. Climate change, like the current COVID-19 crisis, requires unprecedented collective action and coordination efforts among various actors. The article explores how central banks can promote such coordination, within their mandate, in order to reduce these new ecological and health risks.

**Patrick Bolton**  
Columbia University  
**Morgan Després**  
Banque de France, Financial Stability Directorate  
**Luiz Awazu Pereira Da Silva**  
Bank for International Settlements  
**Frédéric Samama**  
Amundi  
**Romain Svartzman**  
Banque de France, Financial Stability Directorate

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### 1 “Green Swans”: a new reality for central banks

In recent years, the community of central banks, financial regulators and supervisors has recognised the need to address a new type of financial risk: climate-related risks (Carney, 2015; NGFS, 2018, 2019). While global warming is accelerating (IPCC, 2018) and its impacts on ecosystems and human societies are increasing (Masson-Delmotte and Moufouma-Okia, 2019), the scientific community warns that the worst is yet to come. For example, climate change could provoke conflicts, generate hundreds of millions of refugees (Abel et al., 2019), as well as pandemics (Legendre et al., 2015) potentially even more serious than COVID-19. Such events could cancel out progress made in poverty reduction (UN Human Rights Council, 2019) and cause “unprecedented suffering”, to quote the words of more than 11,000 scientists (Ripple et al., 2020).

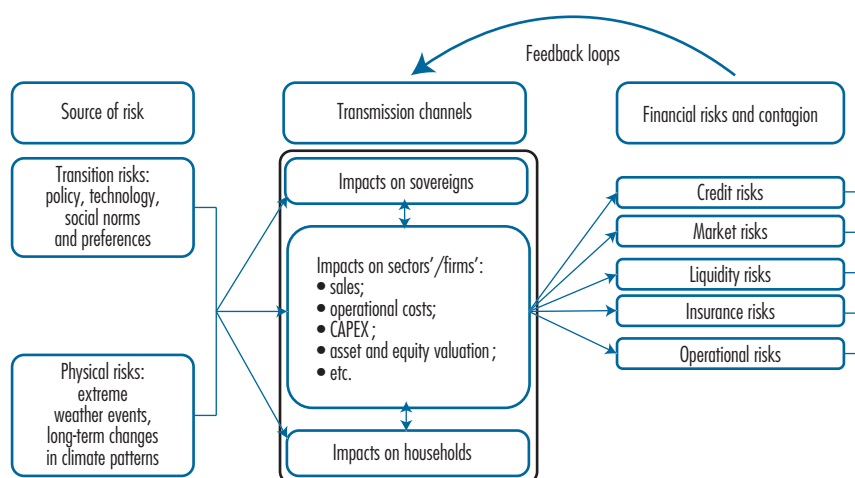
#### Physical and transition risks can give rise to “Green Swans”.

These climate impacts threaten the stability of our socio-economic and financial systems, and may affect central banks’ financial stability mandate<sup>1</sup> (NGFS 2018). Two main types of financial risks have been identified: physical risks and transition risks.

**Physical risks** include economic and financial losses related to the increased frequency and intensity of extreme weather events (such as hurricanes or floods) as well as to long-term changes in climate patterns (such as rising sea levels). For example, uninsured losses, which account for 70% of total losses due to natural disasters since 1980 (IAIS, 2018), could undermine the solvency of households, businesses and governments, and thus that of financial institutions exposed to them. Physical risks could also give rise to extreme disasters (Weitzman, 2011), which would severely damage the balance sheets of economic and financial actors.

A rapid and ambitious transition to a low-carbon economy would avert the worst physical risks, but would introduce others: **transition risks**. These risks arise from the financial consequences of public policies, technological breakdowns or obstacles, as well as changes in social norms and individual preferences associated with carbon-intensive activities. Limiting the increase in the average temperature to 1.5°C or 2°C particularly entails refraining from extracting a considerable proportion of the existing reserves of fossil resources (e.g. up to 80% of existing coal reserves, according to McGlade and Ekins – 2015). Such resources would thus become “stranded assets”. As a result, these reserves could rapidly lose value, triggering massive

#### C1 Transmission and contagion channels of transition and physical risks



Source: Bolton et al., 2020.

<sup>1</sup> Climate change may also affect the price stability mandate, particularly by creating stagflationary supply shocks (Villeroy de Galhau, 2019).



fire sales with potentially systemic effects (Pereira da Silva, 2019).

Physical and transition risks may materialise in different ways, generating various contagion and second-round effects (see Chart 1). In Bolton et al. (2020), we argue that these phenomena could give rise to climatic events extreme enough to trigger a systemic crisis, events described as “Green Swans” (see Box 1). The expression “Green Swans” refers not only to climate-related risks, but also to a range of ecological risks. In this sense, the current COVID-19 crisis can be considered a “Green Swan” in that it appears to have strong links with biodiversity erosion and raises systemic issues. Furthermore, “Green Swans” raise the question of the “tragedy of the horizon” evoked by Mark Carney (2015): while financial actors operate in a short-term time horizon, the ecological transition requires incorporating a long-term perspective into risk management processes.

### Definition of “Green Swans”

The “Green Swan” concept finds its inspiration in the now famous concept of the “Black Swan” developed by Nassim Nicholas Taleb (2007). “Black Swan” events have three characteristics: (i) they are unexpected in light of past events; (ii) their impacts are wide-ranging or extreme; (iii) they are rationalised by conceptual frameworks developed after the fact (retrospective rationalisation). In addition to these three characteristics, “Green Swans” present two more significant qualities. First, it is nearly certain today that these climate-related risks will materialise, even though there is profound uncertainty as to where, when and how they will emerge. Indeed, the scientific community concurs that climate change is “too risky to bet against” (Lenton et al., 2019), and that continuing to increase greenhouse gas emissions could backfire. Second, “Green Swans” may be even more extreme than “Black Swans”, as they are irreversible and potentially civilisational, and thus require a systemic response (Ripple et al., 2020). This attribute distinguishes them from simple shocks from which society could eventually recover.

### Initial epistemological break in systemic risk management

Faced with the risk of systemic destabilisation, central banks, supervisors and financial regulators must therefore integrate “climate-related risks into financial stability monitoring and micro-supervision” (NGFS, 2019, p. 4). In other words, climate-related risks must be identified in order to address the “tragedy of the horizon”.

However, this integration of climate-related risks into financial stability supervision and prudential regulation presents a significant challenge: traditional approaches to risk, based on historical data and normal distribution assumptions, will necessarily lead to a poor appreciation of climate-related risks (Dépoues et al., 2019), for two main reasons. First, most climate-related risks cannot be detected by past data: physical risks are just beginning to materialise (recent increase in the number and intensity of natural disasters), and transition risks remain low due to the lack of political ambition in this area at the global level. Second, climate-related risks tend not to follow “normal” distributions and can lead to extreme values (Weitzman, 2011), which are outside the probabilities used in standard risk management tools.

This can be characterised as an **epistemological** obstacle (Bachelard, 1938): certain scientific methods, although appropriate in some contexts, can become problematic and prevent scientific progress in other contexts that require a new approach or even a redefinition of the problem (or an epistemological break). In the case at hand, the concept of risk itself must be reinterpreted if we are to grasp the systemic dimension of climate-related risks.

This epistemological break seems to be underway in the financial community (Pereira da Silva, 2019): new methodologies are being developed to better identify climate-related risks. They are based on scenario analyses, which use plausible hypotheses for the future without assigning probabilities of materialisation to these hypotheses.

Today, central banks and supervisors agree on the need to use this scenario approach, with two possible regulatory applications. First, the analysis of climate



scenarios could be integrated into stress tests aimed at assessing the capacity of financial institutions to cope with an adverse macro-financial scenario. Central banks and financial supervisors have already started to develop methodologies for such tests (Allen et al., 2020; Bank of England Prudential Regulation Authority, 2019; Vermeulen et al., 2019). Second, scenario analysis could be systematically used in microprudential supervision. For instance, some countries, particularly emerging economies (Dikau and Ryan-Collins, 2017), have defined climate-related risk management expectations for banks and insurance companies (FEBRABAN, 2014). Other countries, such as France (Law on Energy Transition for Green Growth, 2015), have also introduced new climate-related risk communication requirements.

## 2 Integrating climate-related risks into scenario analysis: the issue of radical uncertainty

While scenario analyses are essential, they will not be sufficient to manage the systemic risks posed by climate change. This is because the radical uncertainty associated with climate change impacts (physical risks) and mitigation (transition risks) cannot be “resolved” or removed by scenario analysis alone (Chenet et al., 2019). New, more holistic approaches to risk are needed (see Section 3).

### Uncertainties related to the physical impacts of climate change

With regard to physical risks, the main sources of uncertainty involve:

- biogeochemical processes potentially triggered by climate change. Tipping points exist within the Earth’s ecosystems, but remain difficult to estimate with precision (see Chart 2), and exceeding them could generate cascade reactions on other biogeochemical processes, making risk analysis even more difficult (Lenton et al., 2019; Steffen et al., 2018). For example, geographically distant processes such as regeneration of the Amazon rainforest and the Greenland ice sheet may prove to be interdependent (see Chart 2);

- the socio-economic impacts of these biogeochemical processes. Numerous cascade reactions may also take place between ecosystems and human systems, involving social and geopolitical dimensions (Valantin, 2017) that are particularly difficult to anticipate. For example, climate change could generate mass migrations and conflicts (Abel et al., 2019). Such events could disrupt development around the world, but their probability of occurrence and impacts remain impossible to measure accurately and with an adequate degree of confidence.

In view of these considerations, it appears in particular that the damage functions used by integrated assessment models (IAMs), corresponding to the costs of climate change, do not reliably capture extreme climate-related risks (Calel et al., 2015). Choosing parameter values for the future damage function and discount rates can in fact provide “almost any result one desires” (Pindyck, 2013, p. 5) and lead to “grossly misleading” recommendations (Stern, 2016). Such uncertainties therefore call for great caution in interpreting any estimate of physical risks (Alestra et al., 2020).

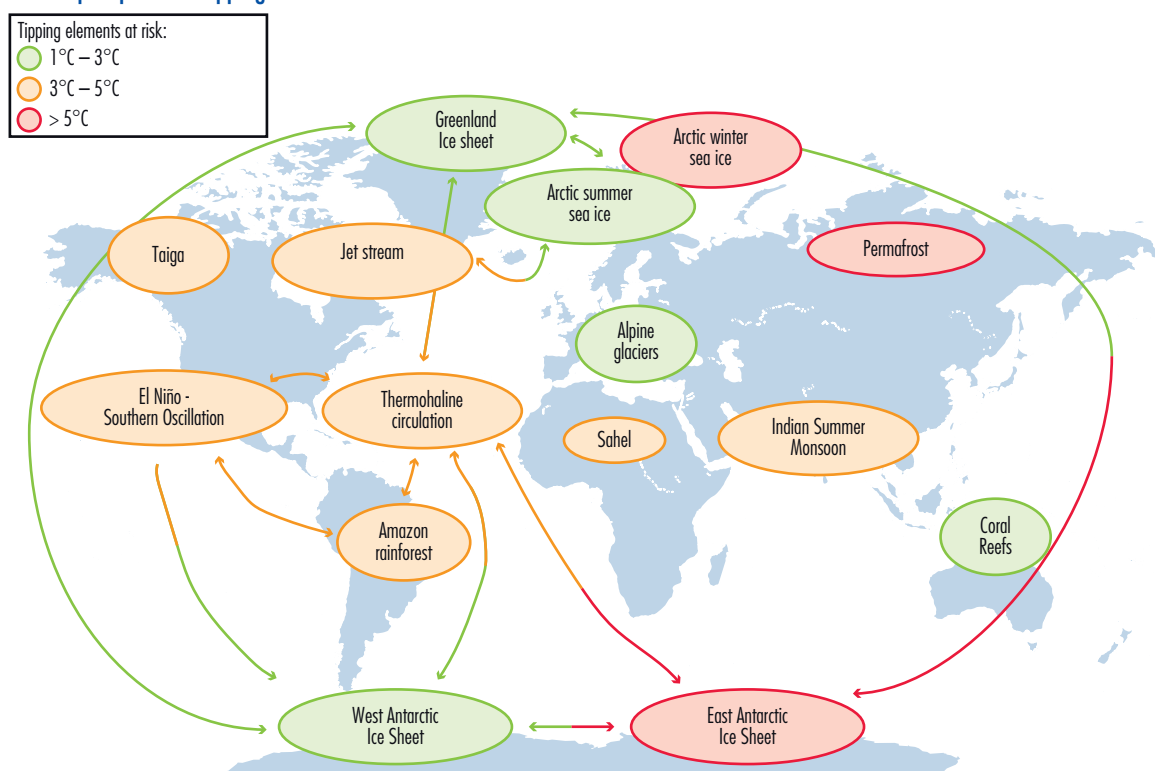
### Uncertainties associated with the low carbon transition

With regard to transition risks, one of the main sources of uncertainty is the general use of carbon prices in IAMs as the sole indicator of transition. This assumption tends to ignore many social and political forces that can influence the way the world is changing (IPCC, 2014, p. 422). Indeed, from a historical perspective, past developments in primary energy use have responded to a variety of technological, geopolitical and institutional considerations that cannot be reduced to a mere question of relative prices (Pearson and Foxon, 2012). In order to overcome the limitations associated with IAMs, some scenario analyses rely on “technology” models, primarily the scenarios developed by the International Energy Agency (IEA).

However, scenario analyses, whether based on IAMs or technology models, must address many sources of uncertainty. In particular, the technologies that will win out in a low carbon world remain highly uncertain (Barreto and Kemp, 2008). As such, some scenarios



### C2 Global map of potential tipping Cascades



Source: Steffen et al. (2018).

rely on rapid development of low carbon technologies to meet growing energy demand (IEA, 2017); others focus on reducing energy demand, which could be achieved through energy efficiency, but also through more resource-sparing lifestyles (NégaWatt, 2018); and still others focus strongly on negative emission and carbon capture and storage technologies, although such technologies are far from maturity (see Annex 1). The costs of these future technologies are also shrouded in uncertainty (ibid.), making it even more difficult to assess the risks and opportunities associated with the transition.

Moreover, integration of transition risks cannot be limited to a macroeconomic and sectoral analysis: a firm's vulnerability to climate-related risks depends not only on its exposure (which may be relatively similar for different firms in the same sector), but also on its capacity to adapt to a specific scenario, throughout its value chain. In particular, a firm may be exposed to climate-related risks via: (i) its direct emissions, known as "Scope 1" emissions (particularly significant in sectors

such as aviation and the chemical industry); (ii) "Scope 2" emissions resulting from the energy consumed (e.g. energy-intensive industries); and (iii) other emissions related to its entire upstream and downstream value chain, known as "Scope 3" emissions. For the automotive industry, for example, the main source of risk lies less in emissions related to manufacturing (Scope 1) or energy sources (Scope 2), than in the combustion of carbon by end-users (Scope 3).

However, the assessment of risks within these value chains and the potential cascade effects between firms and sectors (Cahen Fourot et al., 2020) remain extremely difficult to anticipate, as they are subject to multiple assumptions (ability to pass on higher costs upstream or downstream, new technologies, etc.).

With all these sources of uncertainty combined, it is not surprising that the different estimates of the value of stranded assets lead to highly divergent results (Carbon Tracker, 2018; IRENA, 2017).





### Integrating new approaches

We have shown that, regardless of the approach taken, measuring climate-related risks presents significant methodological challenges. As a result of these limitations, two main methods are generally proposed. We argue here that they should be pursued in parallel rather than exclusively.

First, central banks and supervisors could explore different approaches that take into account the uncertainty and non linearity associated with climate-related risks. For example, Mercure et al. (2019) argue that, unlike general equilibrium models, non-equilibrium models are better able to incorporate the main trends of a low carbon transition, such as path dependence<sup>2</sup> (Monasterolo et al., 2019), the role of the monetary and financial sector (Dafermos et al., 2017) or the role played by energy (The Shift Project and IFPEN, 2019). Ad hoc approaches to better capture the cascade effects generated by physical (Hildén et al., 2020) and transition risks will also be essential. Nevertheless, the descriptive and normative power of these approaches remains limited by the sources of radical uncertainty related to climate change, as mentioned above. In other words, although climate economic models and prospective analysis of climate-related risks can still be improved, the uncertainty is such that they cannot provide all the information required to ensure protection from “Green Swans”.

Therefore, the second method proposed consists in moving beyond strictly risk-based approaches to fully integrate the radical uncertainty we are facing. This amounts, for example, to emphasising the precautionary principle<sup>3</sup> (Aglietta and Espagne, 2016; Chenet et al., 2019; Svartzman et al., 2019). The issue of decision-making in the event of radical uncertainty in the economy (Keynes, 1936) has been making a comeback since the financial crisis of 2007-08 (Webb et al., 2017), and seems to be even more important in the case of environmental and health crises such as the COVID-19 pandemic. According to Mervyn King, former

Governor of the Bank of England, integrating the concept of radical uncertainty should lead, among other effects, to the development of comprehensive strategies to strengthen the resilience and robustness of the system, rather than managing each risk separately (King, 2016).

A second “epistemological break” would then be necessary to address the role of central banks, regulators and supervisors in the face of climate uncertainty. This would involve moving from a risk-management position to one that seeks to strengthen the resilience of complex socio-ecological systems (Schoon and Van der Leeuw, 2015), which will be impacted by climate-related risks in one way or another. In particular, we argue below that current efforts to measure, manage and monitor climate-related risks will only be useful if: (i) they take place in an institutional environment involving strong coordination between public and private actors; and (ii) they give rise to new theoretical approaches aimed at better understanding the complex relationships between economic systems and ecosystems.

### 3 Moving towards resilience for socio-ecological systems

#### Coordination as a risk-management strategy

Acknowledging the limitations of risk-based approaches and integrating radical uncertainty suggests that, in the age of climate-related risks, central banks may inevitably be dragged into uncharted territory. On the one hand, they cannot simply develop scenarios while waiting for government agencies to take action: this could expose central banks to the real risk of not being able to deliver on their financial stability mandate. Indeed, in the case of economies that are no longer viable because of climate change, central banks’ leeway could prove severely limited (Bolton et al., 2020). On the other hand, central banks cannot, whatever the expectations, substitute for public policies (fiscal, industrial, spatial planning, etc.), which have a primary role to play in climate matters (Volz, 2017).

<sup>2</sup> Path dependence is a theory of how decisions made in the past can influence future decisions. For example, a carbon tax may not be sufficient to promote public transport in urban areas where past land-use planning decisions have favoured urban sprawl and the use of private cars as the principal means of travel.

<sup>3</sup> The precautionary principle is used, particularly in the environmental field, to justify discretionary measures in situations where a risk of harm to the public exists but cannot be fully understood due to scientific uncertainty.



To break this deadlock, we defend a third position: without prejudice to the responsibility of policy makers, central banks must play a proactive role in calling for broader and coordinated change, in order to continue to fulfil their own financial stability mandates in a context of climate uncertainty. Indeed, the risks posed by climate change offer central banks a particular perspective that private actors and policy-makers may not necessarily be able to adopt given their respective interests and time horizons – being subject to the “tragedy of the horizon”. In this regard, current efforts to measure, manage and monitor climate-related risks will only be effective if they help to develop the coordination among stakeholders that is necessary to address climate change.

This coordination can take many forms (see Appendix 2). In *The Green Swan* (Bolton et al., 2020), we highlight four dimensions: (i) beyond climate-related risk management, central banks can promote long-term management and support the values promoted by sustainable finance (Fullwiler, 2015); (ii) better coordination of fiscal, monetary and prudential measures is essential to support a successful environmental transition (Krogstrup and Oman, 2019; Pereira da Silva, 2020), especially in the current context of low interest rates; (iii) increased international cooperation between monetary and financial authorities on environmental issues will be essential (Aglietta and Coudert, 2019); (iv) a more systematic integration of environmental criteria into national and corporate accounting frameworks can also help private and public actors to manage climate-related risks (de Cambourg, 2019).

### **In the age of COVID-19, it is essential to reconsider interactions between nature and the economy**

Climate change is only the “tip of the iceberg” (Steffen et al., 2011). Other “planetary boundaries” (Rockström et al., 2009) or biogeochemical cycles essential for life on Earth are also affected by human activity (e.g. biodiversity loss and soil erosion – IPBES, 2019; IPCC, 2019) and can present risks that are both interdependent and as systemic as climate change. For example, climate change may accelerate loss of biodiversity (IPBES, 2019).

In this regard, the COVID-19 crisis seems to be a “Green Swan”. Although we should be cautious about the origins of the pandemic, many experts believe that COVID-19 (as well as many infectious diseases that have emerged in recent decades) is due to degradation of our ecosystems (Vidal, 2020). In addition, climate disruption increases the risk of exposure to human pathogens; it could, for example, trigger new pandemics even more devastating than COVID-19, e.g. due to melting glaciers and permafrost (Legendre et al., 2015).

As central banks begin to address new ecological risks such as those related to biodiversity loss (Schellekens and Van Toor, 2019), the concept of radical uncertainty becomes even more fundamental. Indeed, measuring “biodiversity risk” meets with even more complexity and uncertainty than climate-related risks, particularly because the former relies on multiple local indicators related to the functioning of diverse ecosystems (Chenet, 2019). In this context, it seems that new conceptual approaches are needed to consider the resilience of our socio-ecological systems (Schoon and Van der Leeuw, 2015; OECD, 2019; Pereira da Silva, 2020) in the face of these new global ecological risks.

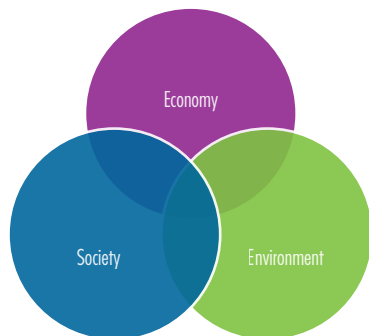
The interdisciplinary field of ecological economics (Daly and Farley, 2004), for example, may offer a more appropriate conceptual approach to the interdependence between economic systems and ecosystems (OECD, 2019). Rather than considering the economy, society and the environment as three independent spheres (the “weak sustainability” approach), ecological economics considers that the economic sphere is embedded within the social and biophysical spheres, and that the loss of ecosystem services can be only very partially offset by an increase in physical or human capital (“strong sustainability approach” – see Chart 3).

Reconsidering macroeconomic and financial systems in the light of these considerations will be essential to assess the sustainability of our economic and financial systems in the age of ecological risks. This article merely lays the groundwork and calls for development of such research in the future.

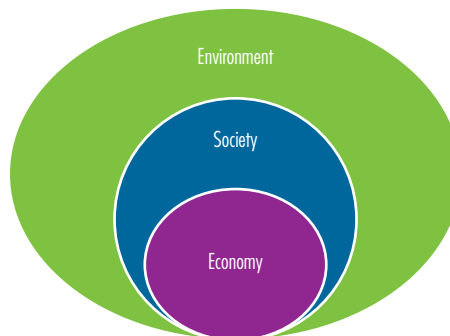


### C3 Two approaches to sustainability

**Weak sustainability:**  
hypothesis based on independence and substitutability  
between economic and environmental spheres



**Strong sustainability:**  
the economic system is dependent on the social and biophysical spheres,  
with limited substitutability between the different spheres



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## Appendix 1

### Uncertainty regarding the technologies and investments necessary for a low carbon transition

The role attributed to negative emissions (including reforestation) and carbon capture and storage (CCS) technologies is a significant source of technological uncertainty. The relative importance of these measures varies considerably from model to model: analysis of a set of scenarios to limit the rise in temperature to 2°C indicates that between 400 and 1,600 gigatonnes of carbon dioxide (10 to 40 years of current emissions) can be offset by negative emissions and CCS (Carbon Brief, 2018). Consequently, choosing a scenario that assigns a significant role to negative emissions and CCS would naturally lead to a reduction in the value of stranded assets. Conversely, a scenario that assigns less importance to these technologies would require a reassessment of the value of such assets.

In reality, regardless of the scenario chosen, negative emissions and CCS technologies engender considerable uncertainty. They remain subject to numerous technological

constraints, potentially high costs, as well as environmental and health risks (IPCC, 2014). Furthermore, relying on negative emissions, particularly reforestation, as a climate change mitigation option, could have negative consequences for many ecosystems (Heck et al., 2018).

Partly as a result of these sources of technological uncertainty, estimates of the volume of investments needed (a critical component in assessing the risk and opportunities associated with a low carbon transition) can also vary significantly. Analysis of six models (IPCC, 2018, p. 153) estimating additional energy investments necessary for the period from 2016 to 2050 – compared to the reference scenario – to limit global warming to 1.5°C, indicates values ranging from USD 150 billion to USD 1.7 trillion per year. Total annual investments in low carbon energy production also vary considerably, ranging from USD 800 billion to USD 2.9 trillion.





## Appendix 2

### How can central banks coordinate with other actors in the context of systemic risk linked to climate change?

Paradigmatic approach to climate change	Responsibilities	
	Measures to be considered <sup>1</sup> by central banks, regulators and supervisors	Measures to be implemented by other actors <sup>2</sup> (governments, private sector, civil society)
<b>Identification and management of climate-related risks</b> >> Focus on risks	Integration of climate-related risks (taking account of the availability of suitable forward-looking methodologies) in: <ul style="list-style-type: none"> <li>• prudential regulation;</li> <li>• financial stability monitoring</li> </ul>	Voluntary disclosure of climate-related risks by the private sector (Task Force on Climate-related Financial Disclosures) Mandatory publication of climate-related risks and other relevant information (e.g. Article 173 in France, classification of “green” and “brown” activities)
Limits: <ul style="list-style-type: none"> <li>• Epistemological and methodological obstacles to the development of coherent scenarios at the macroeconomic, sectoral and sub sectoral levels.</li> <li>• Covering climate-related risks will remain impossible in the absence of system-wide transformations.</li> </ul>		
<b>Internalisation of externalities</b> >> Focus on the Time Horizon	Promotion of a long-term vision as an instrument to overcome the “tragedy of the horizon”, in particular: <ul style="list-style-type: none"> <li>• integrating environmental, social and governance (ESG) considerations into central banks’ own portfolios;</li> <li>• exploring the potential impacts of sustainable approaches in the conduct of financial stability policies, where deemed compatible with existing mandates</li> </ul>	<ul style="list-style-type: none"> <li>• Carbon pricing</li> <li>• Systematisation of ESG practices in the private sector</li> </ul>
Limits: <ul style="list-style-type: none"> <li>• Isolated actions by central banks would be insufficient to reallocate capital with the necessary speed and magnitude, and could have unintended consequences.</li> <li>• Limitations of carbon pricing and internalisation of externalities in general: insufficient to reverse existing inertia and to generate the necessary structural transformation of the global socio-economic system.</li> </ul>		
<b>Structural transformation towards an inclusive and low carbon global economic system</b> >> Focus on the resilience of complex adaptive systems in a context of uncertainty	Recognition of deep-seated uncertainty and the need for structural change to preserve long-term climate and financial stability, including by exploring: <ul style="list-style-type: none"> <li>• green monetary, fiscal and prudential coordination at the effective lower bound;</li> <li>• the role of non equilibrium models and qualitative approaches to better account for the complex and uncertain interactions between climate and socio-economic systems;</li> <li>• potential reforms of the international monetary and financial system, based on the idea that climate and financial stability are interconnected public goods</li> </ul>	<ul style="list-style-type: none"> <li>• Green fiscal policy (made possible or facilitated by low interest rates)</li> <li>• Social debates on the potential need to reconsider the macroeconomic mix (regulatory, fiscal, monetary and prudential) in light of future climate imperatives and – more broadly – environmental imperatives in general</li> <li>• Integration of natural capital into accounting systems at the national and corporate level</li> <li>• Integration of climate stability as a public good to be supported by the international monetary and financial system</li> </ul>

1 Considering these measures does not imply full support for immediate implementation thereof. Potential nuances and limitations must be observed.

2 Measures that are considered essential to achieve climate and financial stability, but which fall outside the scope of action of central banks, regulators and supervisors.

Source: Bolton et al. (2020).



In *The Green Swan: Central Banking and Financial Stability in the Age of Climate Change* (Bolton et al., 2020), we put forward various avenues for cooperation between central banks and other actors (public, private, civil society, the international community) to address the systemic risks posed by climate change. We call on central banks to promote and contribute to

this coordination. The table above summarises different possible areas of cooperation, depending on whether climate change is addressed from a risk-based perspective, from the perspective of externalities, or from the perspective of the resilience of the system as a whole (as developed in the last part of this article).

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