Climate change and financial risks

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Topics that we will discuss during the class

- Climate scenarios and the role of decarbonizing energy systems finance to achieve the Paris Agreement
- Why climate change is a new type of risk for finance
- Channels through which climate drives financial risk (physical, transition)
- The policy context: green fiscal, monetary policies and regulations
- Why central banks and financial regulators worry about climate risks: climate policy relevant sectors, disclosure and climate stress-testing
- State-of-the-art science-based approaches to (i) price forward looking climate risks in financial contracts (CLIMAFIN, Battiston ea 2019), and (ii) to assess largest losses in investors’ portofolios (Climate Stress-test, Battiston ea 2017)

Objectives: what you will learn

- Students will acquire background notions and tools to understand and critically elaborate on:
  - Why climate change represents a risk for financial stability
  - What do we mean with *sustainable finance* and its role for achieving the *Paris Agreement*
  - Main climate policies and why they differ in terms of implementation
  - Why climate risks differ from traditional risks analysed in finance
  - Metrics and methods for pricing climate risks under deep uncertainty

What you need to do to pass the course

- Attend the lesson and contribute to the in-class discussion: doubts and questions welcomed!
- Study the slides and the course material
- Take the final exam
- Exam: Multiple choice test
  - All questions have the same weight on the final score.

Literature

- You can find the references to all literature, databases and reports that we will use in class **in this presentation**
- The databases we use can be accessed for free on the internet
- My contact email: irene.monasterolo@wu.ac.at

About me

- Assistant Prof. of Climate Economics and Finance at WU Wien, visiting research fellow at Boston University, Stanford University, Bicocca
- Ph.D. in Agri-food Economics and Statistics from the University of Bologna, and two post-docs in Cambridge and Boston University
- My research focuses on understanding how finance could be a driver/barrier in the low-carbon transition
  - Climate financial risk pricing models, network-based climate stress-testing
  - Stock-Flow Consistent behavioural models for climate policies' analysis

- Worked for/with development banks (World Bank, European Investment Bank, Inter-American Dev. Bank) and central banks on how to align finance to the Sustainable Development Goals and the Paris Agreement.
- Google scholar:https://bit.ly/2EKTpnF

Climate change

Key issues at stake

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1. **Anthropogenic climate change** (by burning of fossil fuels that produce Greenhouse Gases emissions) is increasing and negatively affects biodiversity loss, health, inequality, economic development. And financial stability
2. **Limiting global temperature increase to max 2℃** above pre-industrial level (**Paris Agreement**) is key to avoid massive socio-economic impacts (IPCC 2014)
3. **This implies decarbonizing** energy systems, production and consumption activities (IPCC 2018) and investors' portfolios: unburnable carbon (Leaton ea 2012)
4. But investors are largely exposed to fossil fuel based economic activities: risk of losses due to **carbon stranded assets** (van der Ploeg and Rezai 2020)
5. **Timely climate and sustainable finance policies can mitigate risk of losses**
   - Carbon tax, end of fossil fuel subsidies, and greening prudential frameworks of central banks to signal investors and the markets. But delayed.
6. **A disorderly low carbon transition** (sudden policy introduction) could drive financial risks
7. Assessing climate-related financial risk in investors' portfolios to inform risk management strategies: **climate stress-test** (Battiston et al. 2017)

The Paris Agreement

- At COP 21 in Paris, on 12 December 2015, Parties to the UNFCCC reached a **landmark agreement to combat climate change** and to accelerate and intensify the actions and investments needed for a sustainable low carbon future.
- The Paris Agreement for the first time brings all nations into a common cause to undertake efforts to **mitigate climate change and adapt** to its effects
- Max global temperature increase to 2ºC above pre-industrial levels (desirable 1.5ºC)
- Achieving this goal requires decarbonizing our production and consumption system by 2050 – i.e., cut anthropogenic CO_2 emissions

https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

Paris stock-take exercise

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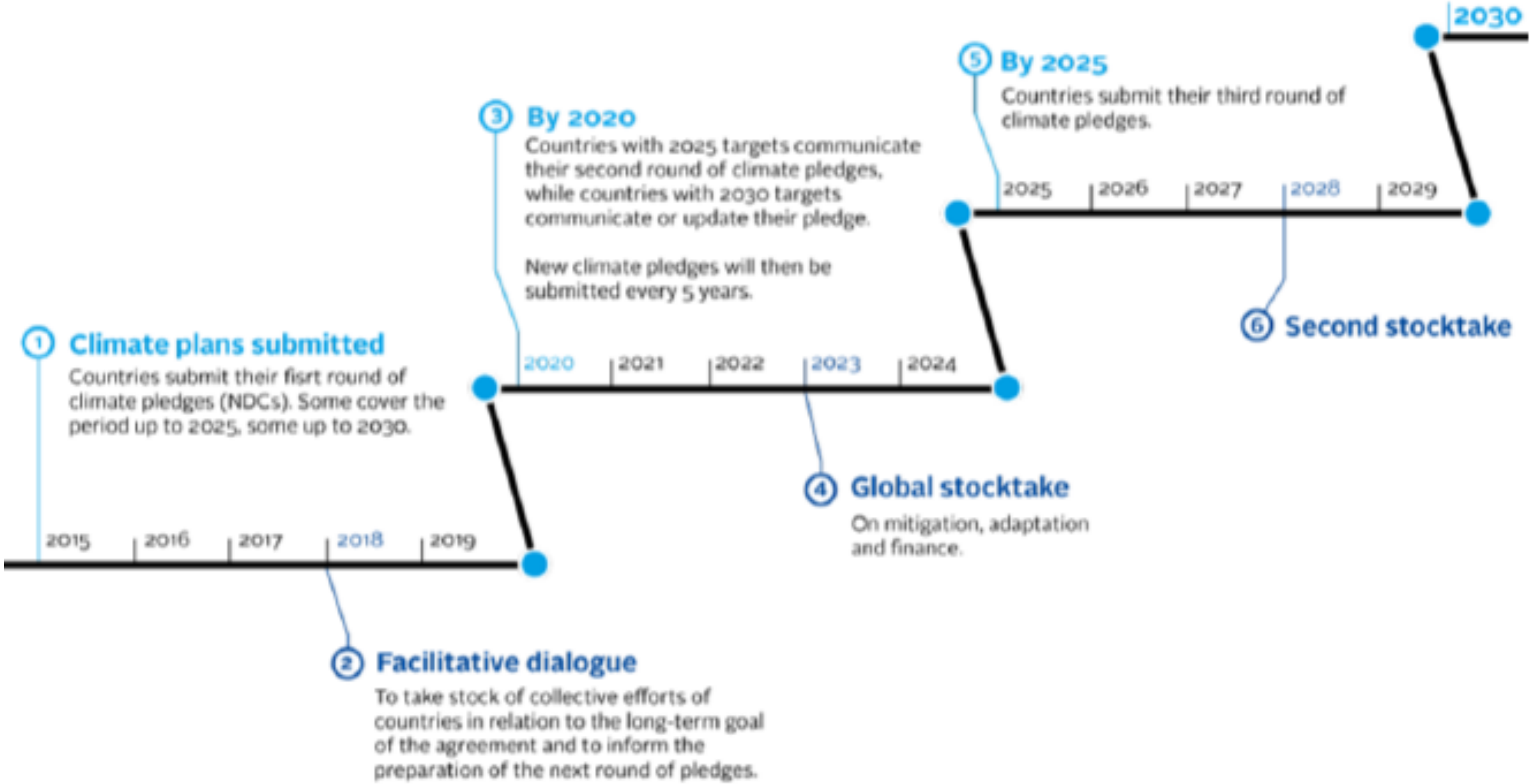
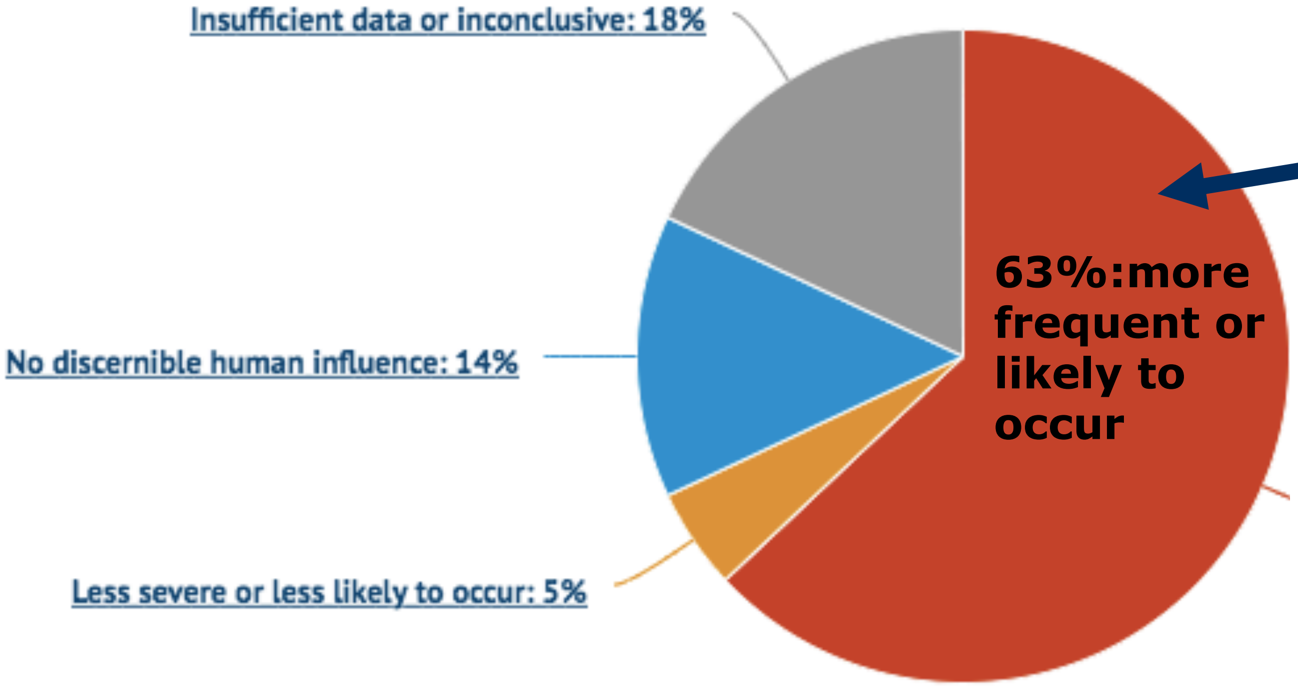
Timeline: How countries plan to raise the ambition of their climate pledges

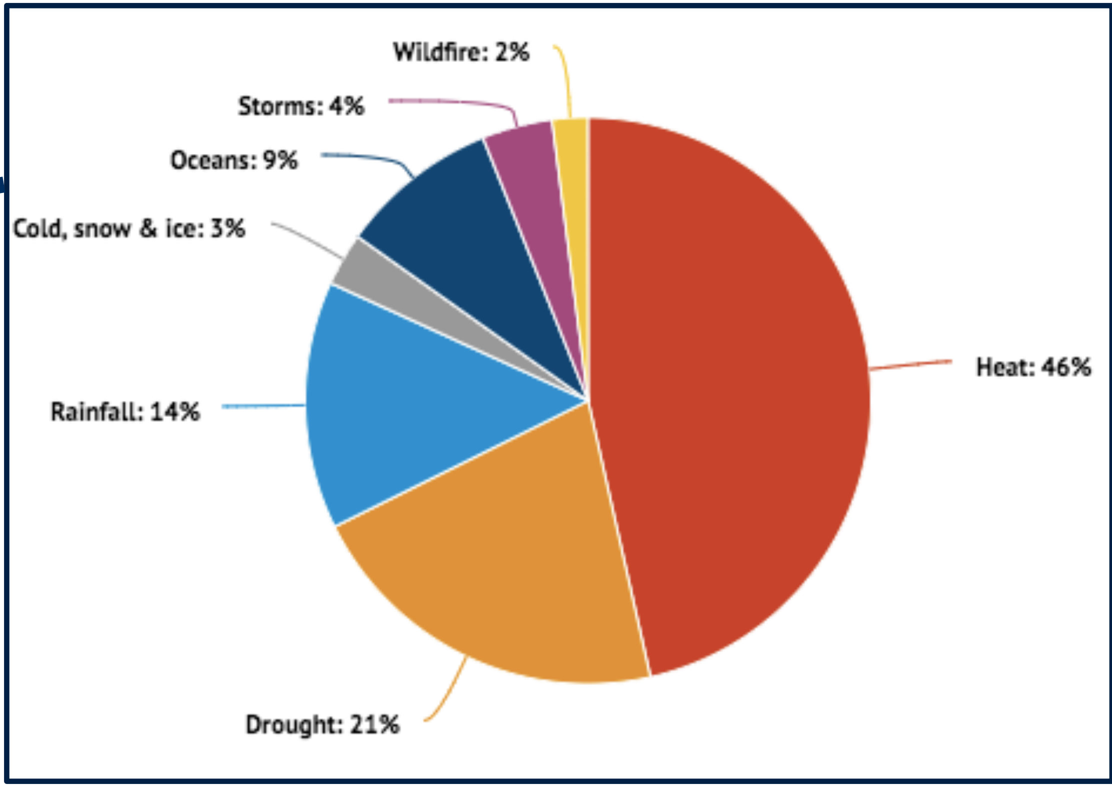
The Paris "ratchet mechanisim" is designed to steadily increase ambition over time, ensuring that the world reaches net zero emissions in the second half of the century and keeps temperature rise "well below 2°C".



Why the Paris Agreement?
Anthropogenic climate change

+ 140 peer-reviewed articles agree on influence of human activities on extreme weather events



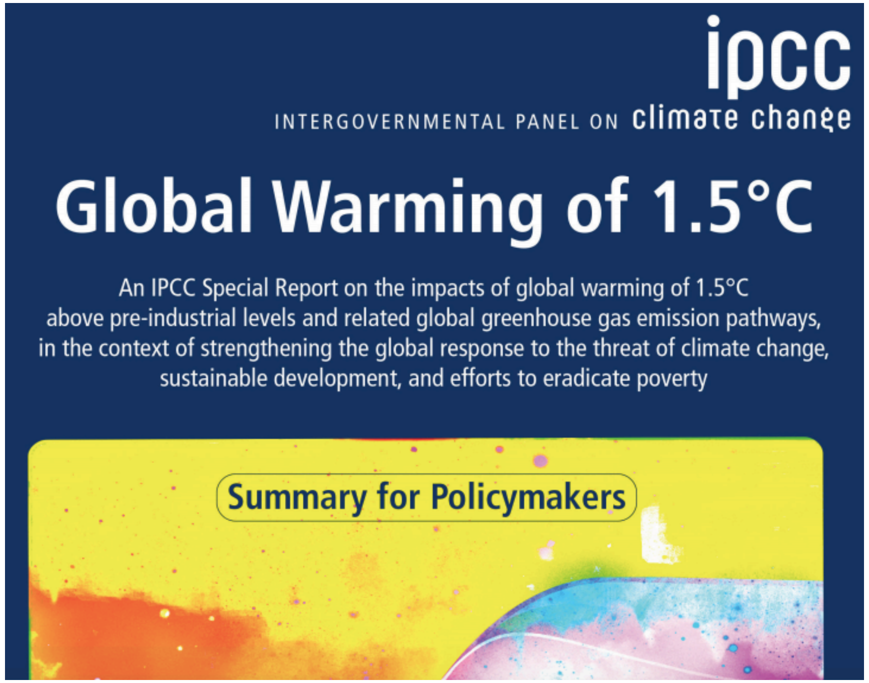


Source: Carbon Brief 2018

Interactive visualization:
https://bit.ly/2tYLjEP

The climate science: the IPCC report

- **Intergovernmental Panel on Climate Change (IPCC)** founded in 1988, is a United Nations body in charge of assessing (mostly) peer-reviewed research on climate and impacts, every 7years
- Its last report states that the world is on track for 3ºC of warming by 2100. We could reach 1.5 °C already btw 2030-2052 if global warming continues at its current rate.
- Limiting global warming to 1.5 °C will require drastic action by 2050: curb emissions by at least 49% of 2017 levels by 2030, carbon neutrality by 2050
- Most of this action will come from technological investments (decarbonize energy and transport)



http://www.ipcc.ch/report/sr15/

IPCC's 5th Assessment Report (AR5) Synthesis Report Summary for Policymakers

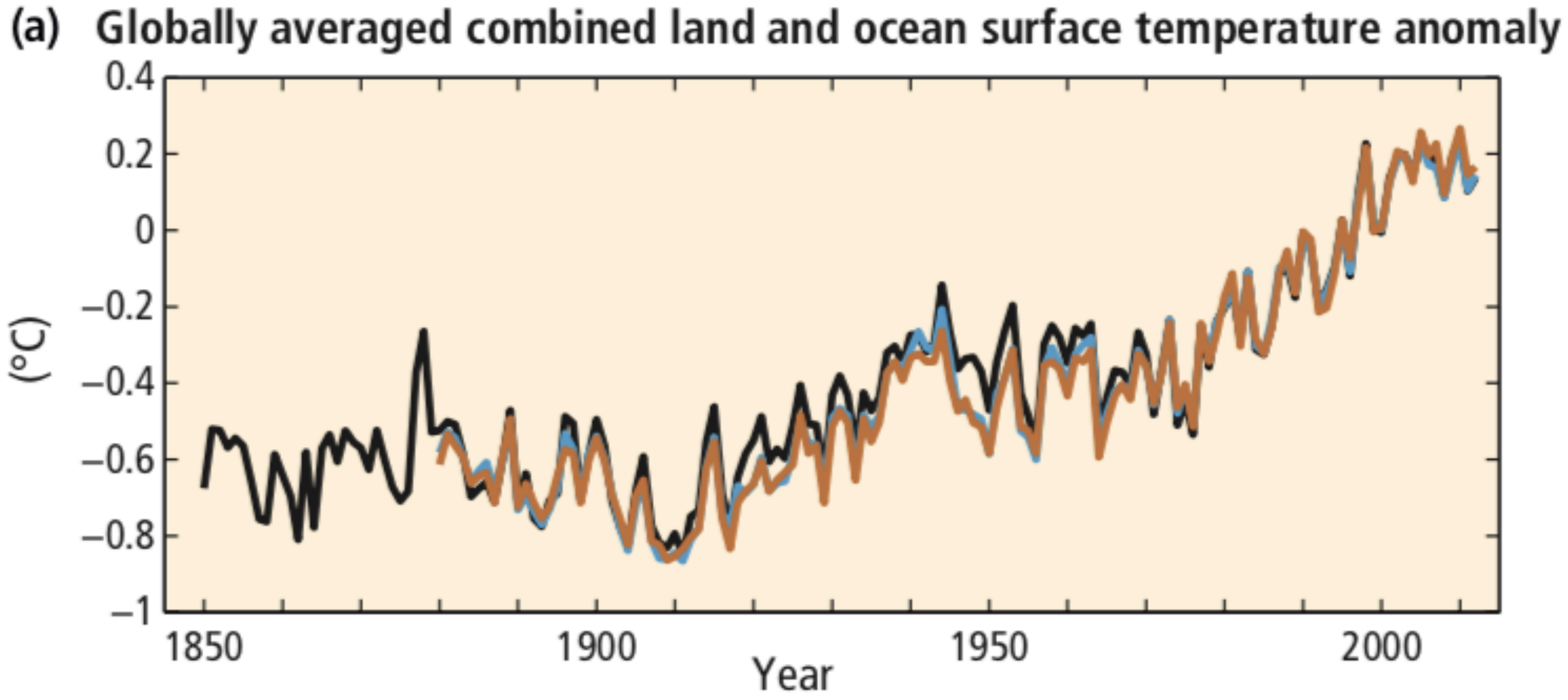
- Synthesis Report summary for Policymakers (**SPM**): key results and messages for broad audience and decision making
- https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

- **Structure**: Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development; Adaptation and mitigation.
- **Evidence**: limited, medium or robust.
- **Agreement:** low, medium or high.
- **Level of confidence,** five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*.
- **Assessed likelihood** of an outcome or a result:
  - virtually certain 99–100% probability, very likely 90–100%, likely 66–100%,
  - as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%.

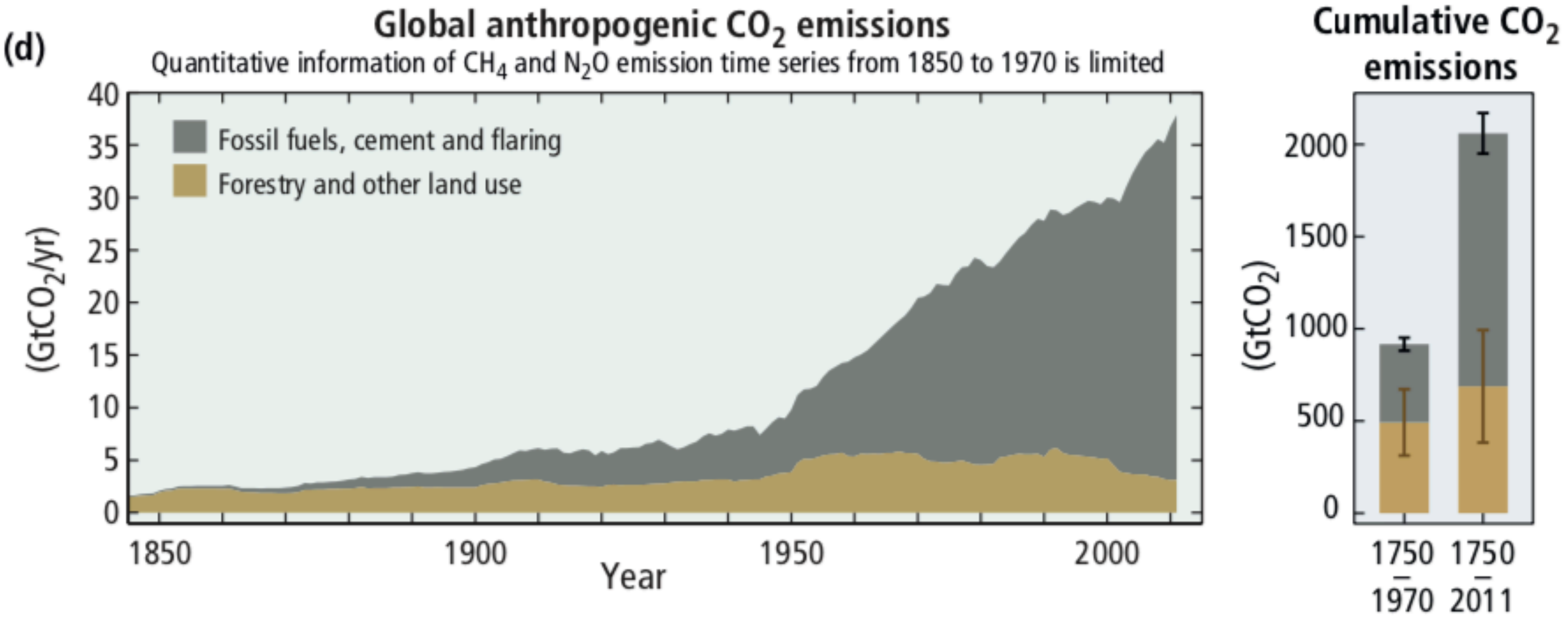
SPM 1. Observed changes and their causes

- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.
- **The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.**

NOTE. *Temperature anomalies: relative to the mean of 1986 to 2005 period, as annual and decadal averages*



Why climate change? Combustions of fossil fuels and loss of carbon sinks (e.g. forests)



- ***50% of cumulative anthropogenic CO2 emissions between 1750 and 2010 have occurred in the last 40 years***

Electricity and heat generation remains the most emitting sector

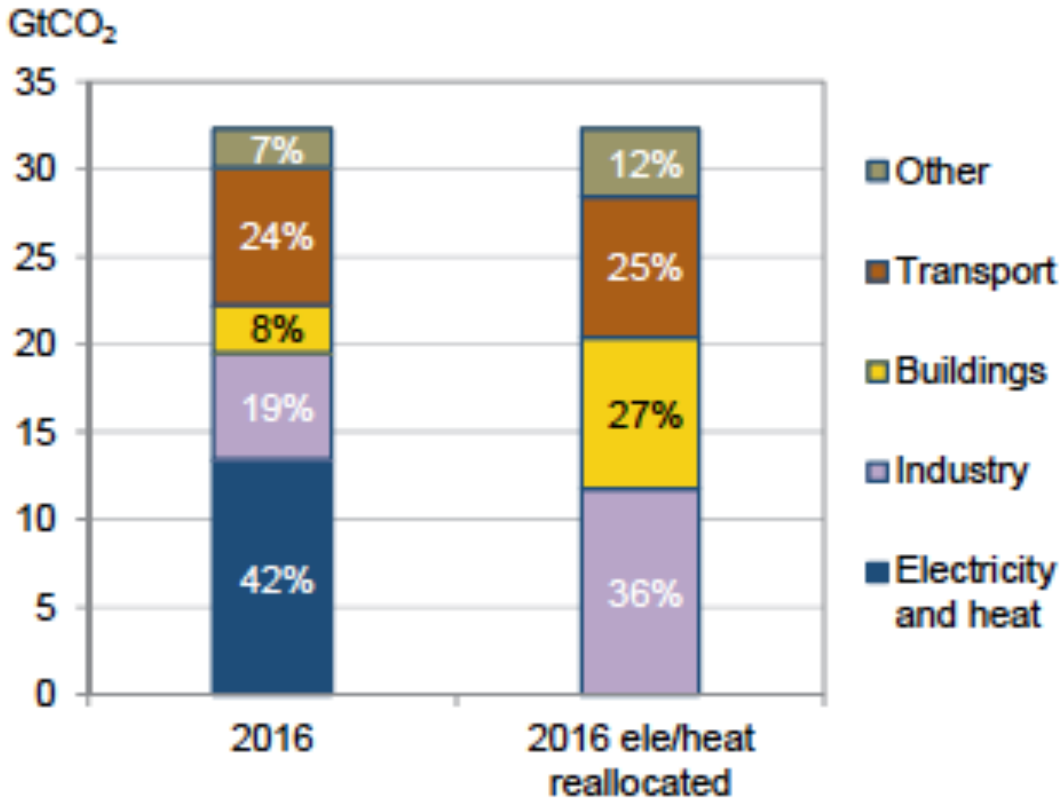


Fig. Global CO2 emissions by sector, 2016

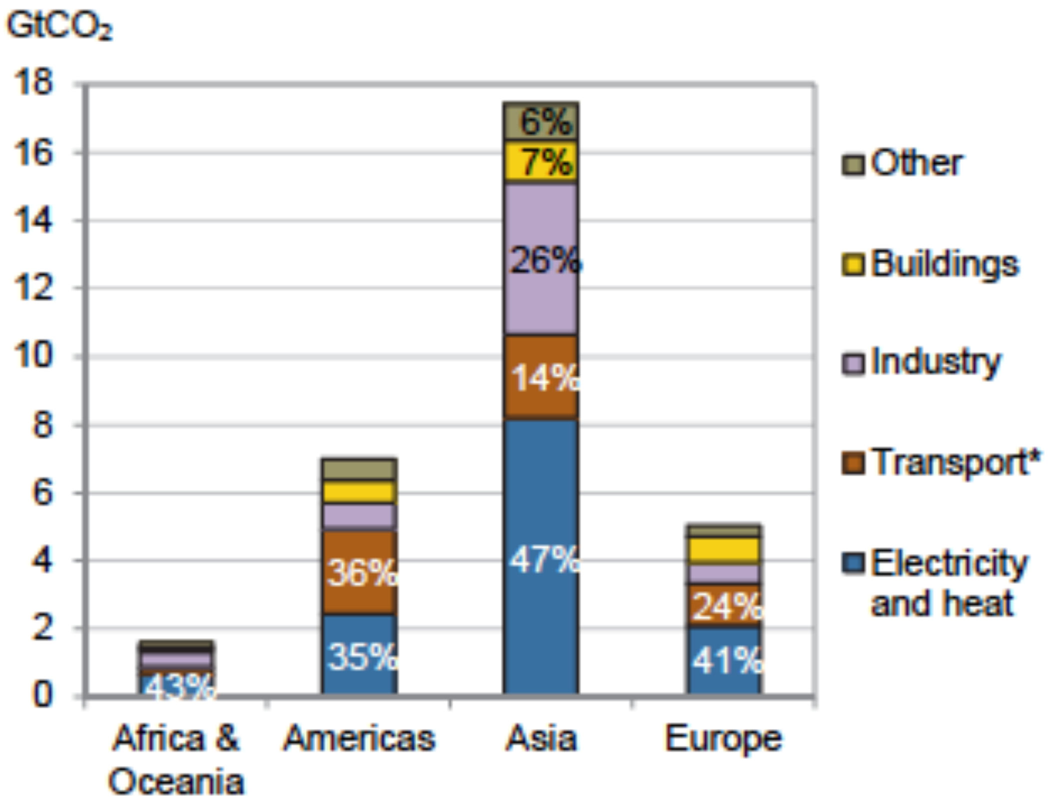
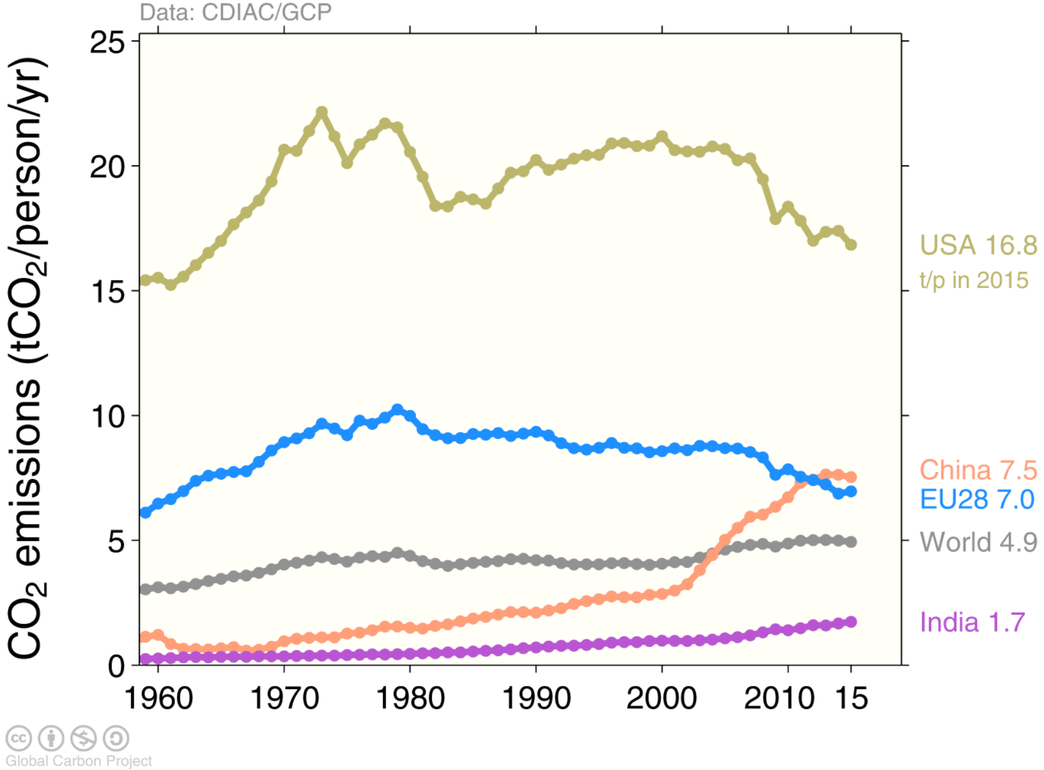
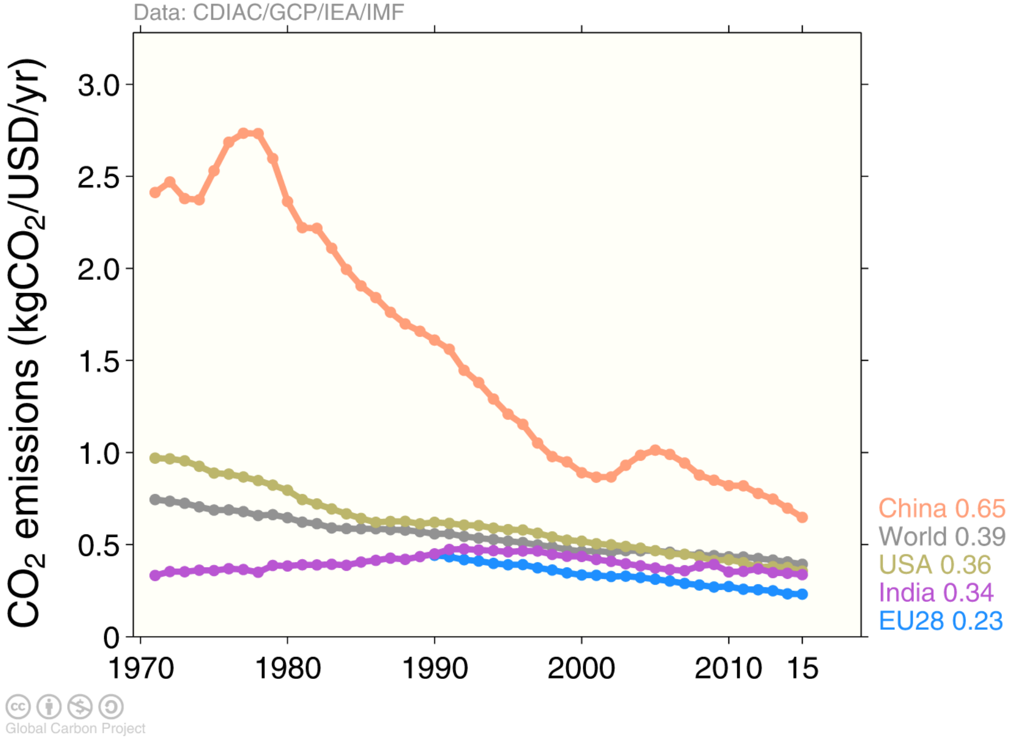


Fig. CO2 emissions by sector for selected regions, 2016

Top emitters (fossil fuels): per capita/dollar





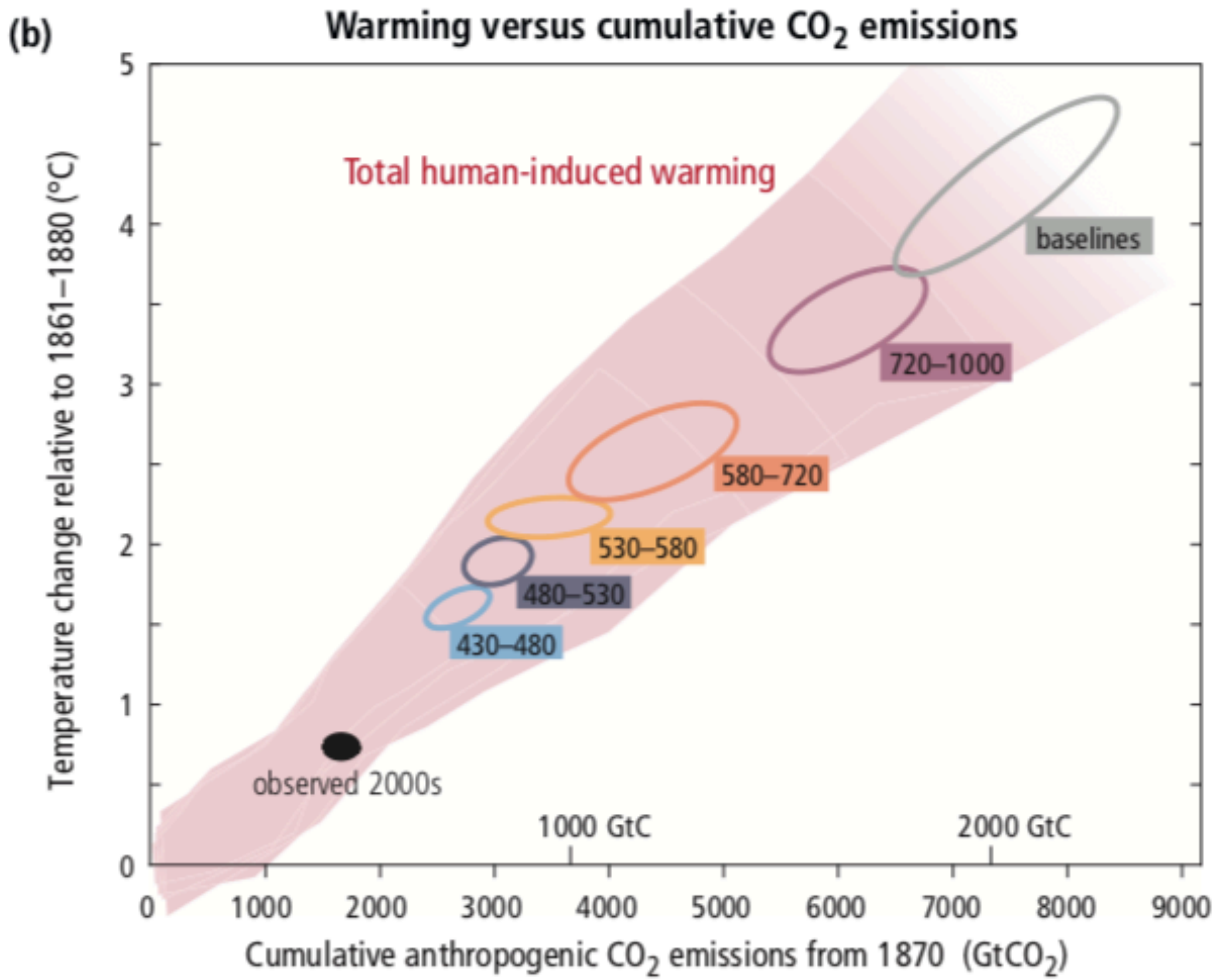
Fossil fuels and industry emissions (pc) reflect countries' development paths and economic structure

Emissions per unit economic output ('emissions intensity') generally declines
China's intensity is declining rapidly, but is still much higher than the world average

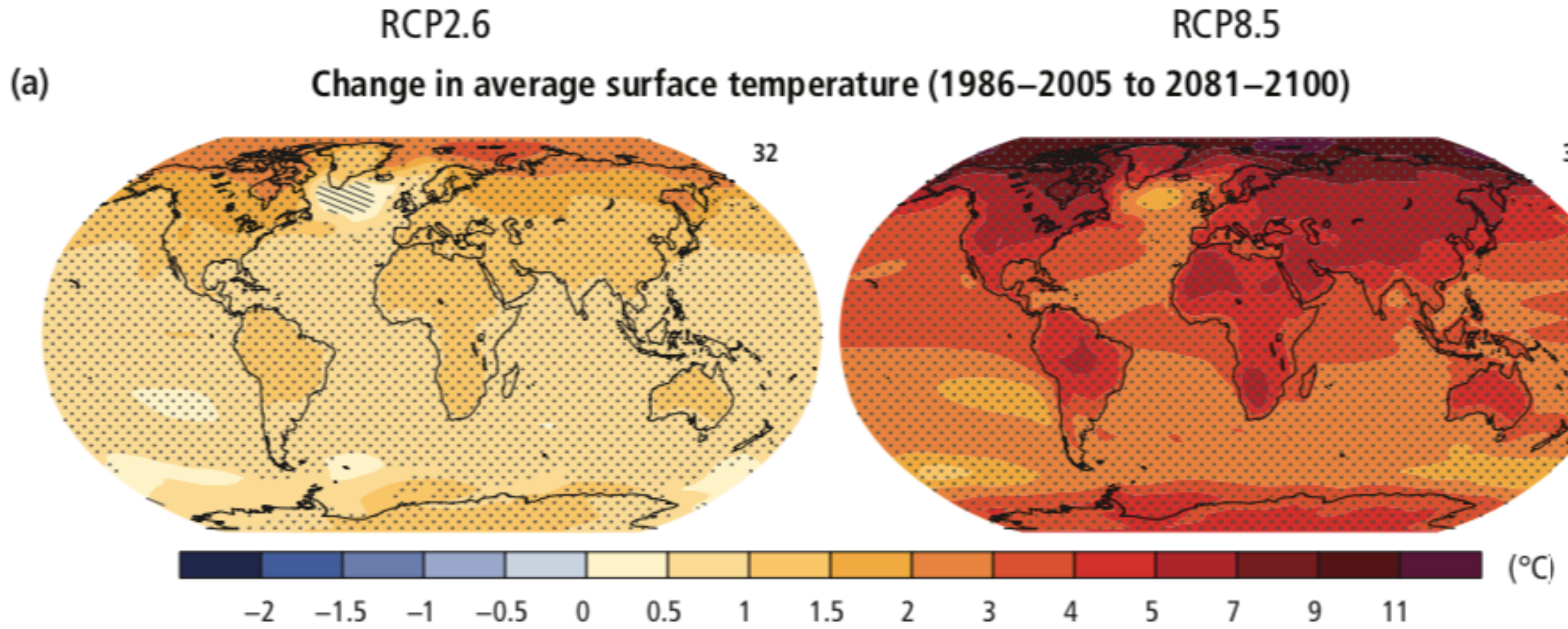
Source: CDIAC; Le Quéré et al 2016; Global Carbon Budget 2016

SPM 2. Future Climate Changes, Risks and Impacts

- **SPM 2.1 Key drivers of future climate.** Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. Projections vary depending on both socio-economic development and climate policy.
- https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

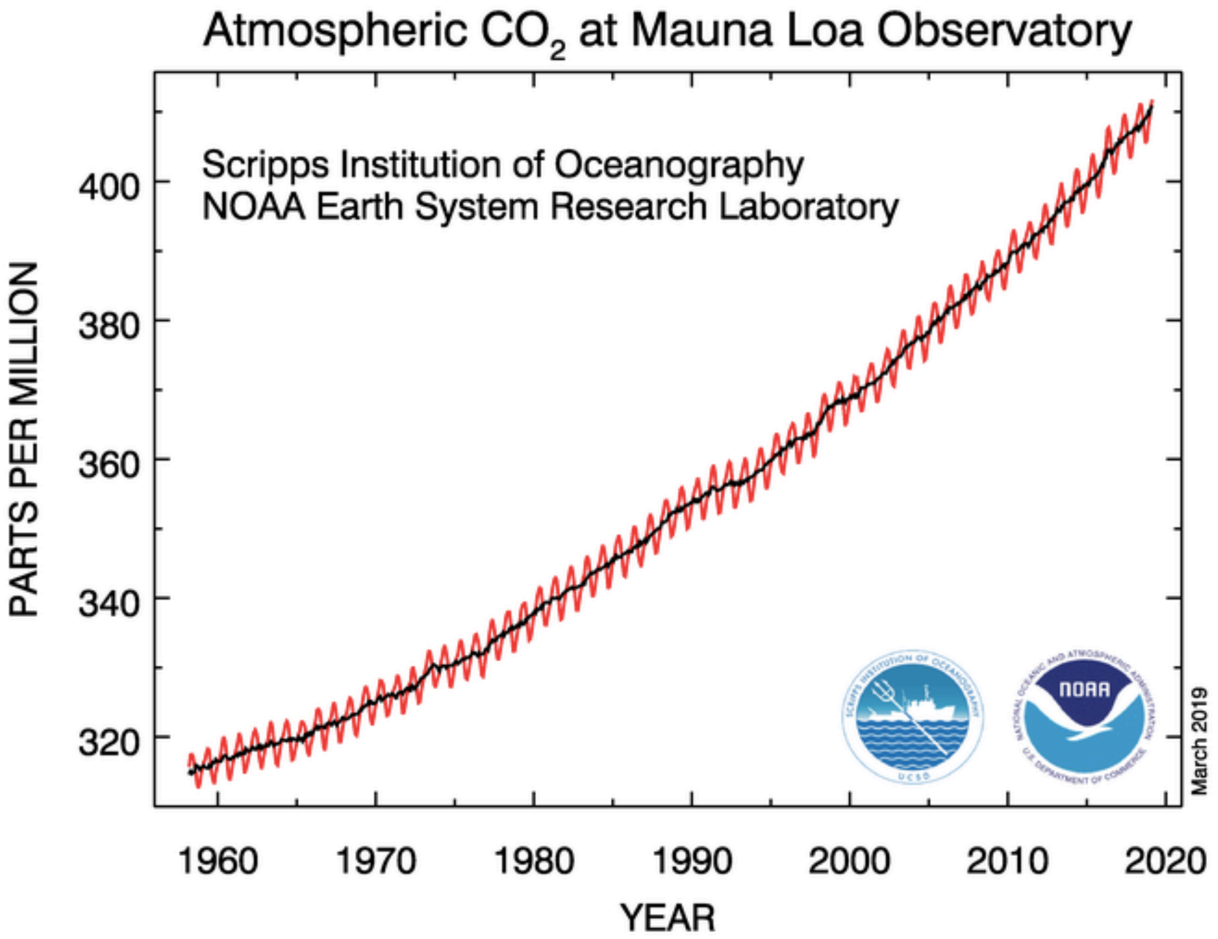


- **SPM 2.2 Projected changes in the climate system:**
- Surface temperature projected to rise over the 21st century under all scenarios. V*ery likely: more frequent and longer* heat waves extreme precipitation events in many regions.
  https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf



CO2 emissions are on the rise

- **Carbon dioxide (CO2) emissions** concentration due to human activities keeps increasing
- The concentration of CO_2 in the atmosphere has increased from 277 parts per million (ppm) in 1750 to 411.19 ppm (7th March 2019)
- Fossil fuels' emissions started before the industrial era but became the dominant source of anthropogenic emissions around 1950 and their relative share is increasing
- **To achieve 2°C target: concentration to 450 ppm**



CO2 data (red curve) measured in Mauna Loa constitute the longest record of direct measurements of CO_2 in the atmosphere (since 1958) The **black curve** represents the seasonally corrected data. https://bit.ly/2kIntE9

Always been like that? CO2 emissions trend

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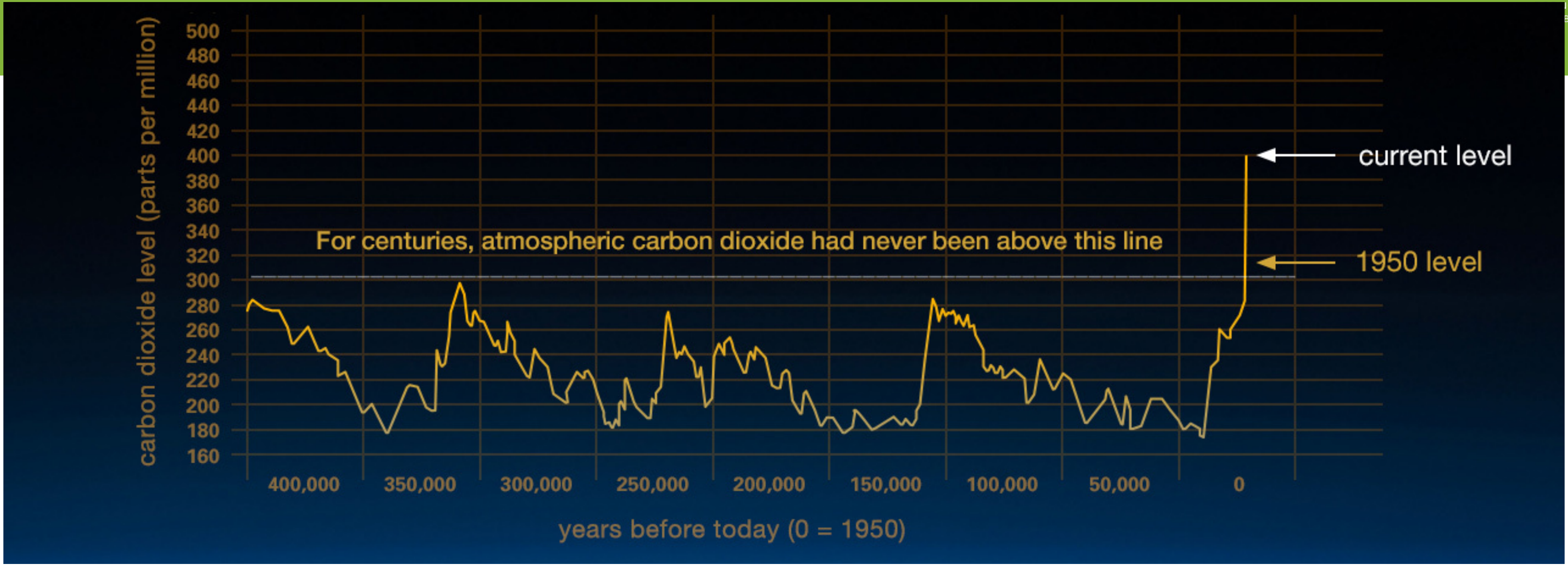
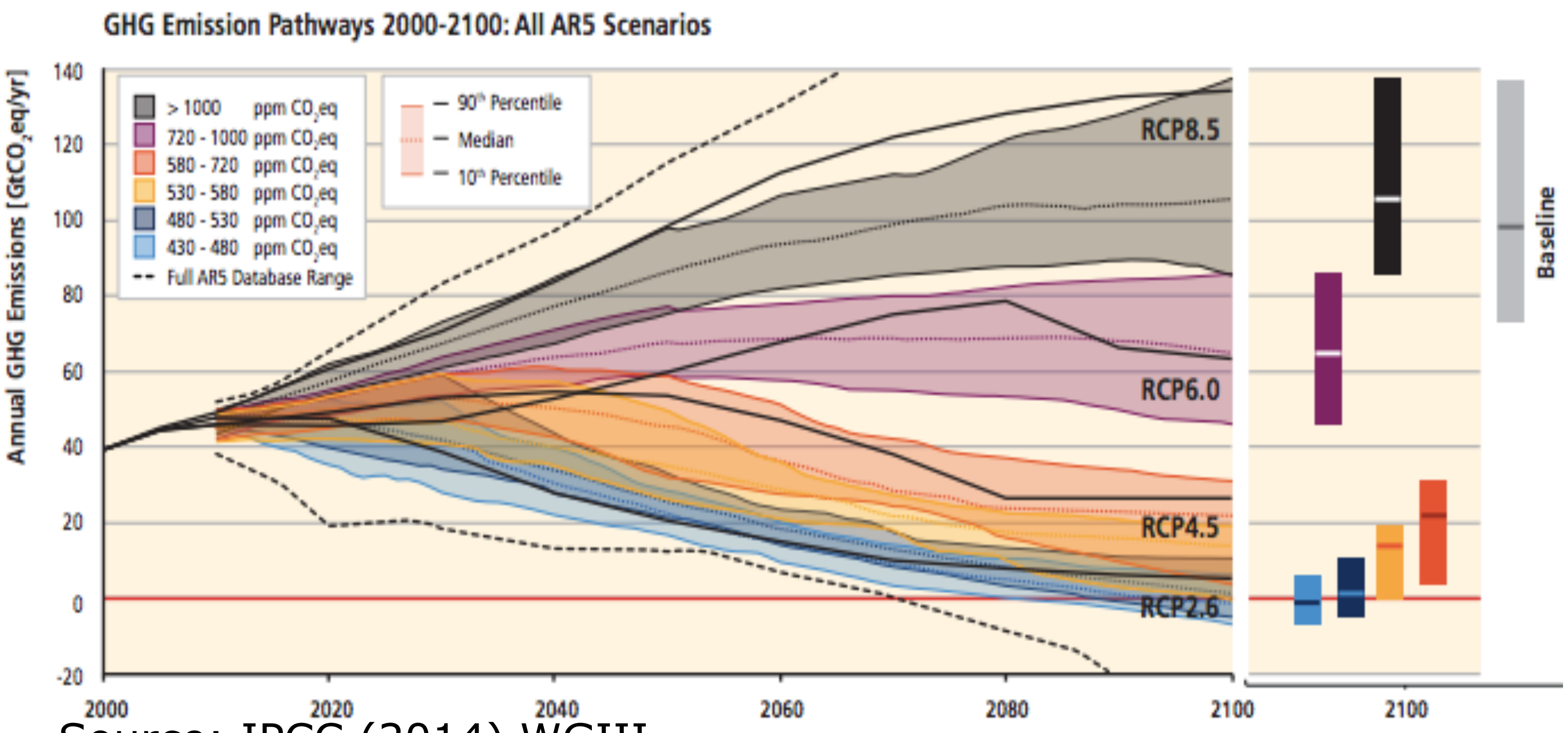


- Trend in CO_2 emissions concentration show how men modified atmosphere via fossil fuels' combustion for socio-economic activities
- After industrial revolution, emissions show an 'hockey stick' path
- Magnitude and pace od CO_2 concentration matter: always >400ppm after 2000, growing at 2-3 ppm-yr

CO2 emissions concentration lead to temperature increase and climate change

- 450 ppm-aligned scenarios are characterized by lower global GHG emissions in 2050 than in 2010 (40% to 70% lower globally) and negative emissions by 2100

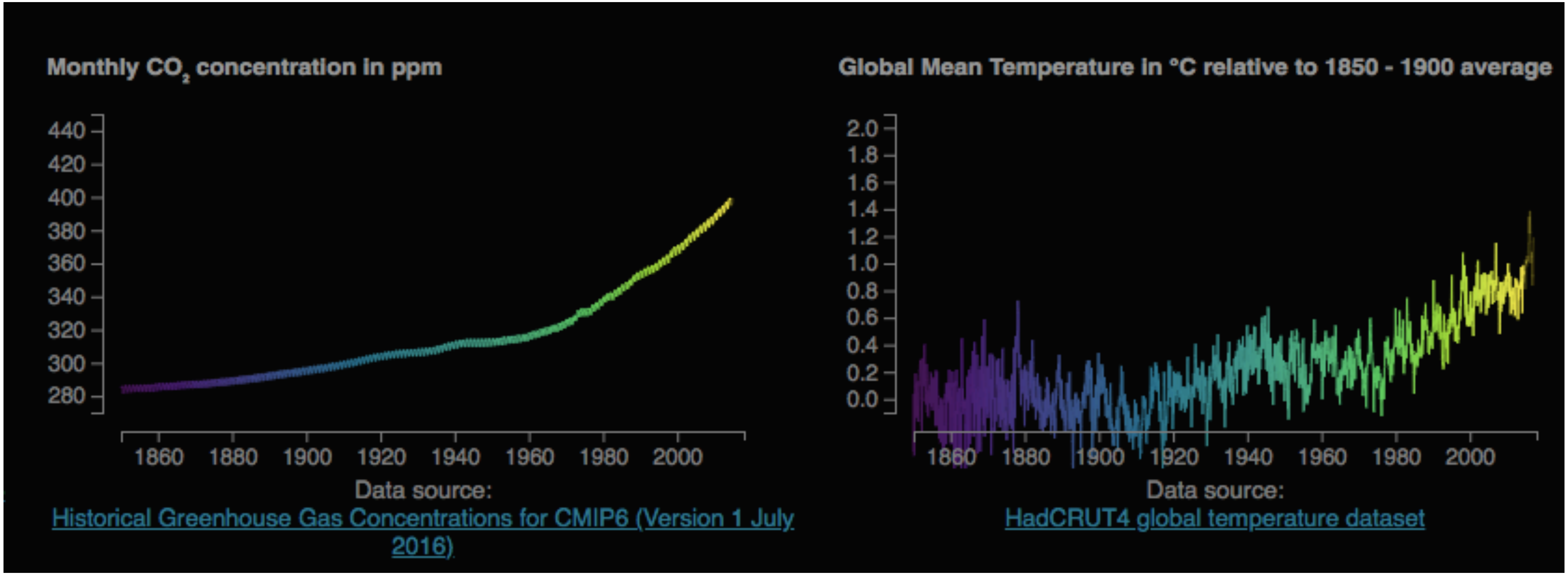
Across RCPs, global mean temperature is projected to rise by 0.3 to 4.8 °C by 2100



Source: IPCC (2014) WGIII

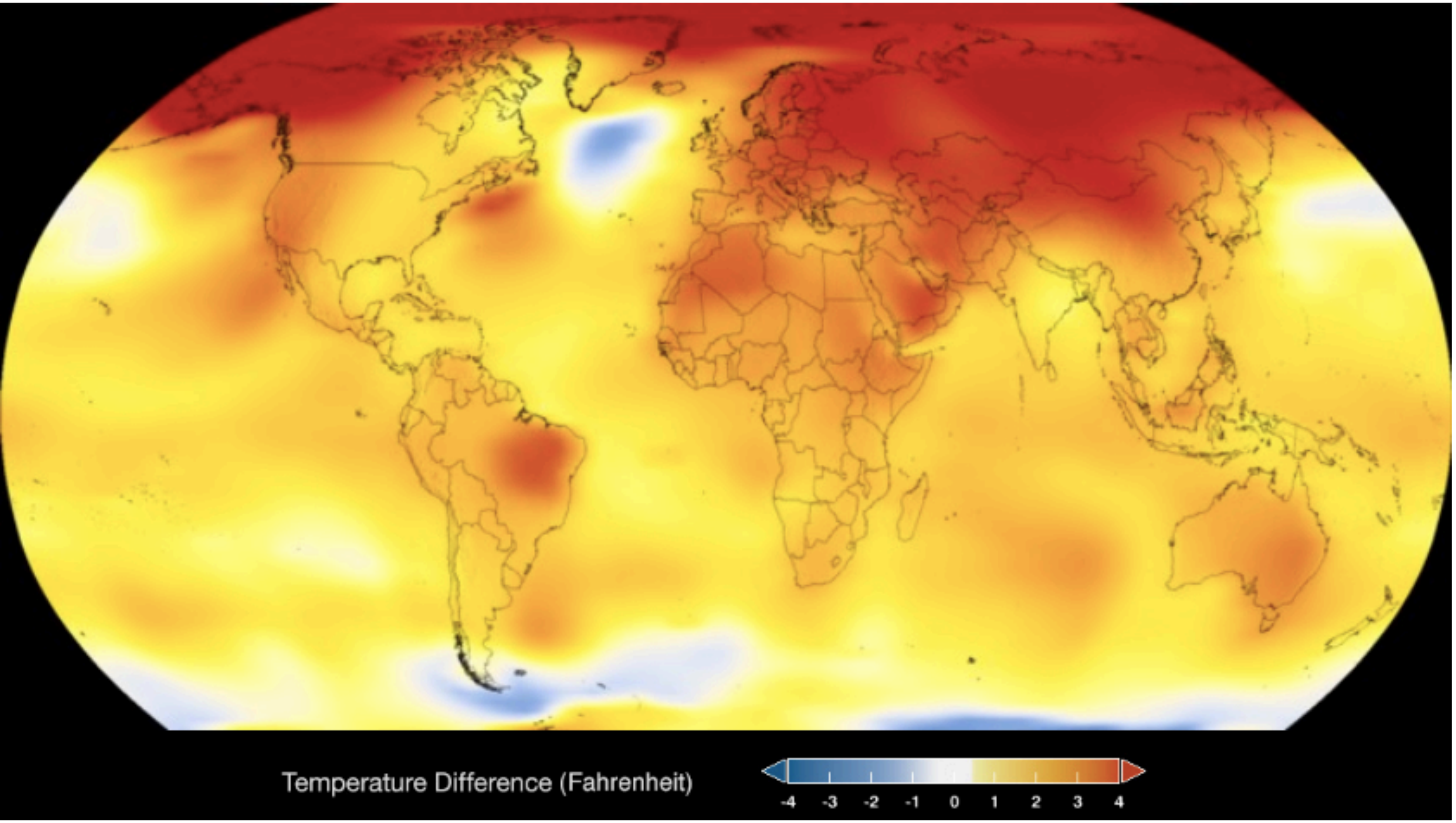
	2046–2065	2081–2100
Scenario	Mean and *likely* range	Mean and *likely* range
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

Emissions concentration, temperature increase, climate change in historical perspective



- Interactive website: https://bit.ly/2aj5RN6, PIK 2016

Trend in global temperature increase



The map shows a progression of changing global surface temperatures since 1884. Dark blue indicates areas cooler than average. Dark red indicates areas warmer than average.

Data source: NASA/GISS

Website:
https://go.nasa.gov/2n5A7Do

From climate change to the Planetary Boundaries

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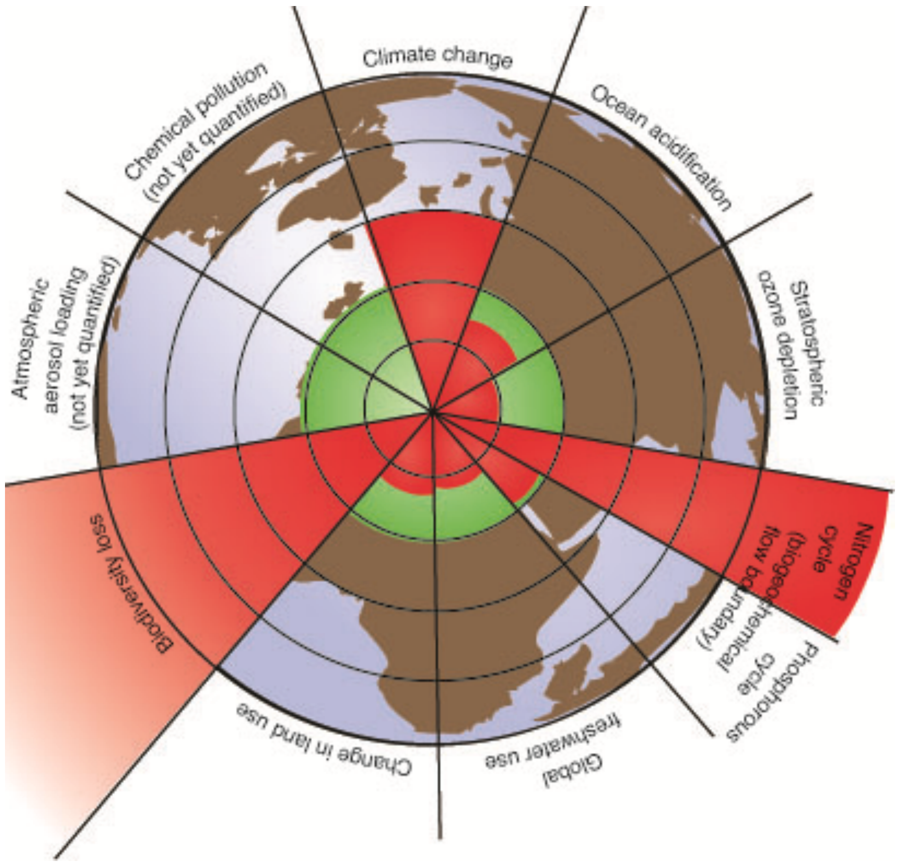
- **Earth-system processes** that are critical for keeping this planet in the stable state which allowed human population to grow over the past 10k years
- **9 Planetary Boundaries** (PB) which represent **'a safe operating space for humanity'** for avoiding danger zones that constitute an environmental ceiling
- Stressing these critical processes could **lead to tipping points** and irreversible environmental change
- Red wedges are current situation: 3 boundaries already crossed - climate change, biodiversity loss, and nitrogen use.



Rockström, ea. 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and society*, *14*(2). https://www.jstor.org/stable/26268316?seq=1#metadata_info_tab_contents

Welcome to the Anthropocene

- **Steffen et al. (2009) introduced a new term, Anthropocene**, to indicate a new epoch in Earth history, starting from the advent of the Industrial Revolution 1800, from which man through its activities (and related emissions) started to influence the environment.

- **Anthropocene as a new geology**: human-led climate change (more frequent floods, droughts) affect access to global resources and environment (ecological debt increasing as "Earth Overshoot Day" occurs earlier every year)

- Steffen, W. et al. 2018. Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences*, *115*(33), pp.8252-8259.

How to limit climate change? Climate mitigation and adaptation

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- **Climate mitigation**: efforts to reduce or prevent emission of greenhouse gases (GHG), including policies (carbon tax) and investments
  - new energy technologies, making older equipment energy efficient, change consumer behaviour (resource resilience), negative emission tech (Carbon capture storage ?)
  - E.g. renewable energy tech., energy efficiency (e.g. double-glazed windows)
  - https://ec.europa.eu/jrc/en/research-topic/climate-change-mitigation
- **Climate change adaptation:** policies and investments to build resilience to the adverse effects of climate change
  - using scarce water resources more efficiently (e.g. drop irrigation); building flood defences and raising the levels of dykes; developing drought-tolerant crops, etc.
- Both approaches are necessary: mitigation addresses the root causes by reducing GHG emissions while adaptation seeks to cope with risks posed by the consequences of climatic changes.

From carbon budget to carbon stranded assets

Carbon budget: how much can we still emit to stay within the 2ºC?

- **Global carbon budget**: assessment of anthropogenic CO_2 emissions and redistribution among atmosphere, ocean, terrestrial biosphere (Le Quere 2018)
- **5 components**:
  - Fossil CO2 emissions (EFF) based on energy statistics and cement production data
  - Emissions from land use and land-use change (ELUC), mainly deforestation based on land use and land-use change data
  - Atmospheric CO2 concentration measured directly and its growth rate (GATM) is computed from the annual changes in concentration.
  - Ocean CO2 sink (SOCEAN) and terrestrial CO2 sink (SLAND) are estimated with global process models constrained by observations.
- Thus, it is important to understand the **global carbon cycle and inform** climate policies and climate change projections

Le Quéré, C. et al, 2018. Global carbon budget 2018. *Earth System Science Data*, *10*(4), pp.2141-2194.

Carbon budget and temperature increase

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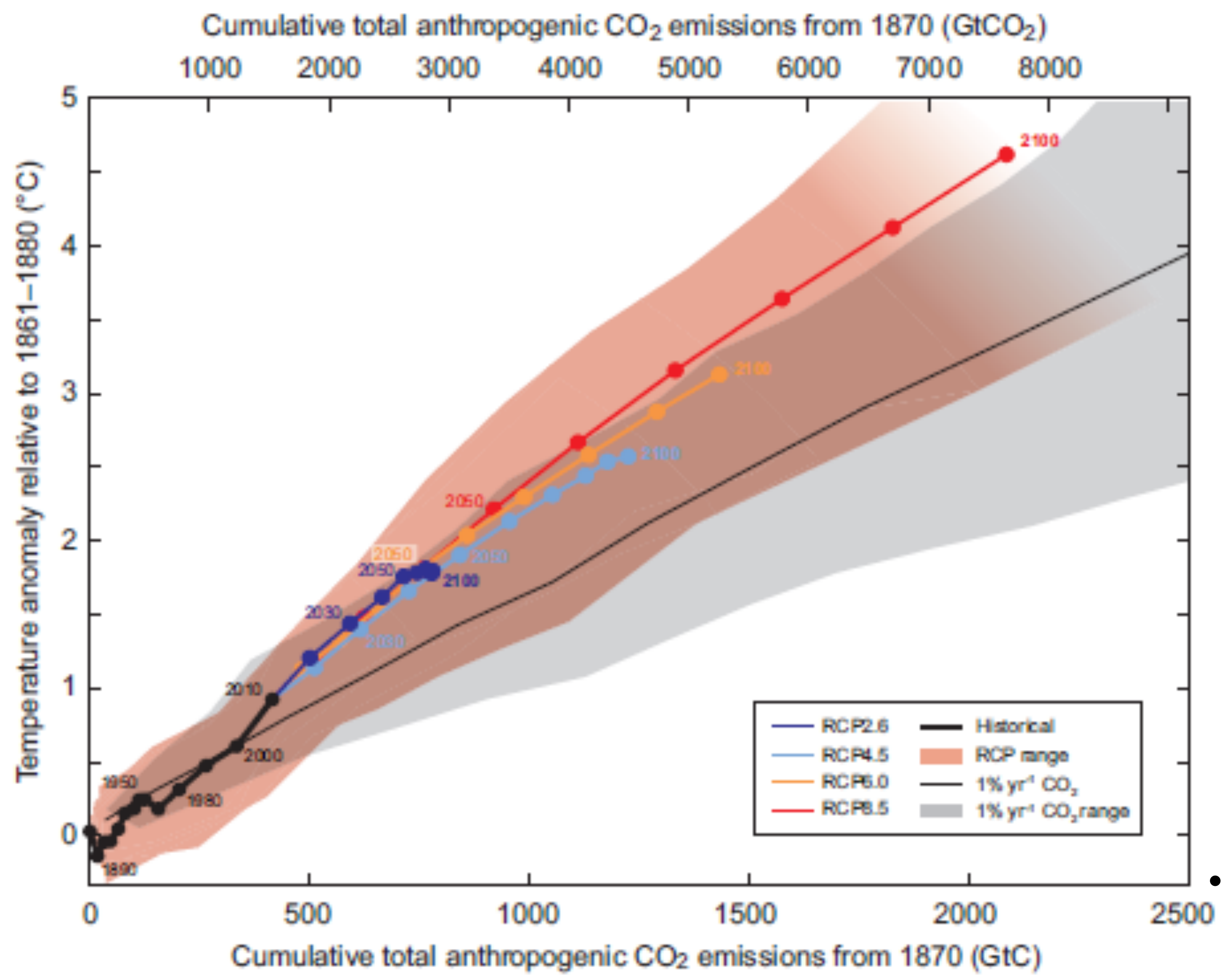


- Linearity between temperature increase (y) and cumulative CO2 emissions (x):
  - every 1000 GtCO2 = + .5°
- Carbon budget associated with temperature targets: **carbon budget of 565 Gt to keep temperature increase below 2ºC**
- Uncertainty on specific boundaries yet good approximation
- Interactive website: https://bit.ly/2aj5RN6

EFMD EQUIS ACCREDITED · AACSB ACCREDITED · ASSOCIATION AMBA ACCREDITED

Unburnable carbon (Carbon Tracker 2013)

- Available carbon budget: 900 $GtCO_2$ for 80% probability to stay below 2°C, 1075 $GtCO_2$ for 50% probability:
  - carbon budget for the second half of the century: only 75GtCO
- 60 to 80% of publicly listed fossil fuel reserves considered "unburnable" if the world is to comply with the Paris Agreement
  - Listed coal, oil and gas assets that are already developed are nearly equivalent to the 80% 2°C budget to 2050 of 900$GtCO_2$.
  - If listed companies develop all assets, potential reserves would exceed the budget to 2050 to give only a 50% chance of achieving the 2C of 1075$GtCO_2$.
- Top 200 oil and gas and mining companies have allocated $674bn in 2012 for fossil reserves R&D and devel.

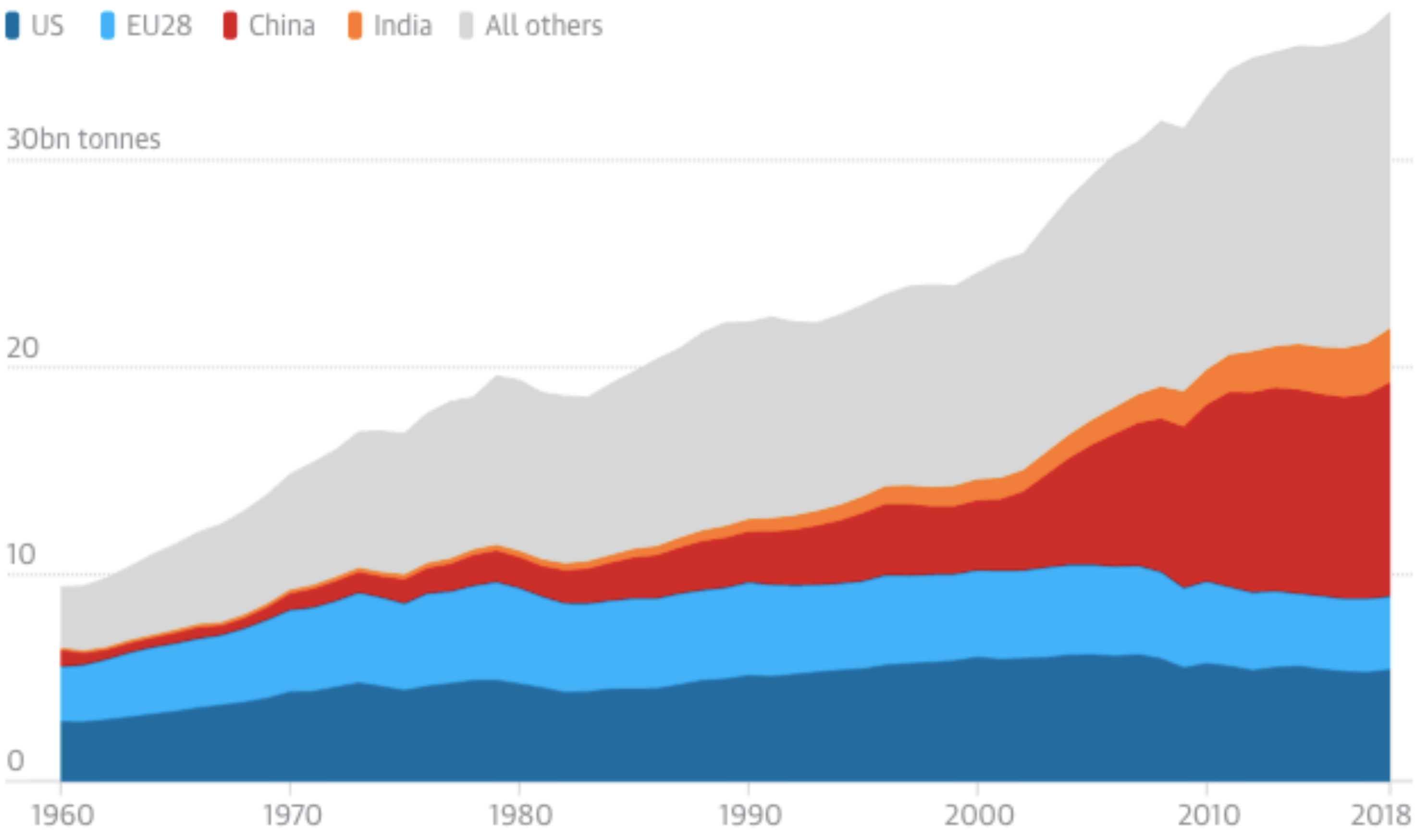
Carbon Tracker 2013. Unburnable Carbon 2013: Wasted capital and stranded assets. *conjunction with the Grantham Research Institute of Climate Change and the Environment. www. carbontracker. org*.

Unburnable carbon leads to stranded assets

- 200 fossil fuel companies' market value of $4trn for which HSBC suggests that equity valuations could be reduced by 40/60% in 2C scenario
- Potential cost for the fossil fuel industry: $28 trillion in revenues over next 2 decades (Carbon Tracker, 2013a; Kepler Cheuvreux, 2014).
- This would likely be reflected in lower share prices and could lead to financial instability as a result of significant losses (Battiston ea. 2017)
  - Interconnectedness in the financial system could amplify losses and lead to systemic risk (Battiston ea. 2017, ESRB 2016)
- *Thus, the financial system needs to adapt to ensure it can reflect the growing risk of wasted capital and stranded assets…(more later)*

Are we on a track for the PA? No: global carbon emissions in 2018 hit an all-time high of 37.1bn tonnes

- CO_2 emissions will rise by 2.7% in 2018, up on 1.6% rise in 2017
- Who? China + 4.7%, US + 2.5% India + 6.3% in 2018.
- EU's emissions are near flat (but different contribution by country…)
- Why? Transport (growing number of cars on the roads) and energy (renaissance of coal use)
- New coal investments to add 330 Gt of CO_2 to the atmosphere. Added to existing infrastructure, this would use up all of the world's remaining carbon budget



Guardian graphic. Source: University of East Anglia, Global Carbon Project

Carbon stranded assets

- **2 structural conditions for asset stranding** in economy and finance:
  - Diverting capital assets away from carbon-intensive industries must be *costly or impossible in the short term*,
  - Investors may not price policy/technology shocks in their decisions by divesting (investing in) from contracts issued by high-carbon (low-carbon) firms
- **Economy**: fossil companies hit by an unanticipated drop in demand for their products->their economic performance shrinks-> cascading losses in business value chain->write-offs (Rozenberg et all. 2014)
- **Finance**: economic losses negatively affect financial returns of fossil capital stocks-> drop in market valuation and value of financial contracts -> cascading losses on portfolios of investors that are exposed to these financial contracts.

Rozenberg, J., Vogt-Schilb, A. and Hallegatte, S., 2014. *Transition to clean capital, irreversible investment and stranded assets*. The World Bank.

Four sources of assets stranding

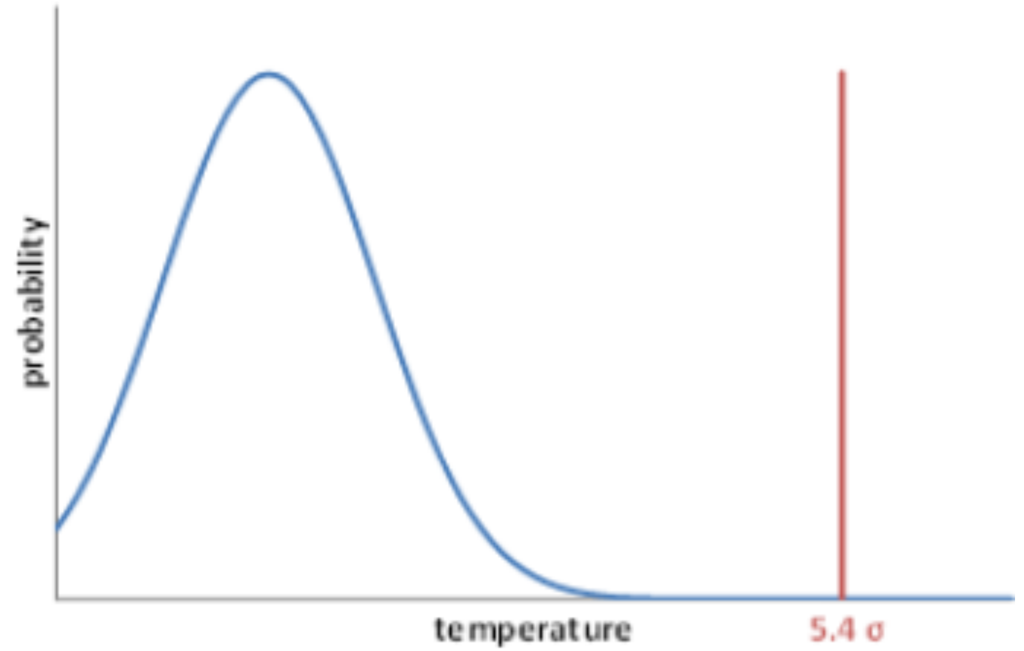
- **abandoned carbon**: a substantial part of fossil fuel reserves is simply never to be touched if temperature is to stay below 1.5 or 2 degrees Celsius.
- **abandoned capital**: some infrastructure and capital invested in fossil fuel industry will become useless once the economy switches to renewable energy.
- **anticipated stranded asset**: since prices of fossil fuel assets respond long before their industry closes shop or climate policy is enacted, valuation of these assets changes once unanticipated future changes are anticipated (?!).
- **realized stranded asset**: some policy changes are not anticipated with certainty and announcements are subject to doubt about their actual implementation. If this is so, the initial anticipation effect at the time of announcement will soften and realized stranding can differ.

van der Ploeg, F. and Rezai, A., 2020. The risk of policy tipping and stranded carbon assets. *Journal of Environmental Economics and Management*, *100*, p.102258.

Climate risks:
this time risk is different for finance!

Non-normal climate data evidence

- Western European summer 2003 was 5.4σ above mean temperature for 1864-2000
  - With normal distribution, 5.4σ summer would occur once every 30 mil. years
  - But Eastern Europe had similar heat wave in 2010: if such events happen every 7 years, temperatures are not normally distributed
  - Power law, which explains how likely extreme events are to occur, better fit to extreme events



Ackerman, F., 2017. *Worst-Case Economics: Extreme Events in Climate and Finance*. Anthem Press.

Climate is not the Normal type of risk economists are used to

1. **Climate deep uncertainty**: largest shocks expected to occur in mid-term but exact localization and magnitude unknown (Weitzman 2009)

2. **Non-linearity of impacts:** shocks probability distribution can't be inferred from historical data, nor proxied by *N* (Ackerman 2017)
   - But traditional pricing models neglect tail risk and incomplete markets

3. **Endogeneity:** climate policy decisions and financial actors' expectations of future policy leads to uncertainty and multiple equilibria

4. **Financial complexity**: interconnectedness could lead to mispricing with systemic effects (Battiston et al. 2016)

- *We need to go beyond green/brown factors and **embrace complexity (vs greenwashing)***

Monasterolo, I., Roventini, A., and Foxon, T. (2019). Uncertainty of climate policies and implications for economics and finance: an evolutionary economics approach. *Ecological Economics,* 163, 1-10

Endogeneity and circularity of risk

- Main difficulty to assess and manage climate financial risk comes from the fact that is **endogenous** and involves **multiple scenarios** (Battiston 2019):
  - **Endogeneity of risk:** the transition depends on governments and firms' investment decisions. But both decisions depend on risk perception:
  - **Risks differ across the possible transition scenarios**. But the occurrence of the scenarios depends on the perception of decision makers, including financial regulators, about the risks involved (Battiston ea. 2017).
    - These decisions depend on financial actors' **expectations** of climate policies
    - **Circularity** introduces new sources of uncertainty related to constraints and opportunities of the financial sector in mitigation scenarios
- Such endogeneity of risk hampers a smooth low-carbon transition

ESG vs climate risk

- **ESG** is not a good proxy of **climate risk**:
  - *Lot of S and G, little E*: fragmented, not consolidated data (e.g. Scope 3, see Busch ea. 2018, Berg ea. 2019)
  - Proprietary methodologies, **not transparent**: VW vs Tesla
  - **Backward-looking** assessment (vs forward looking climate risk)
  - No info on **technology risk** (current, future -> CAPEX)
  - Investment and **ownership chains** not considered in criteria

Thus, assessing climate risks requires to rethink financial risk

- Climate risk entails **new types of risks for finance**

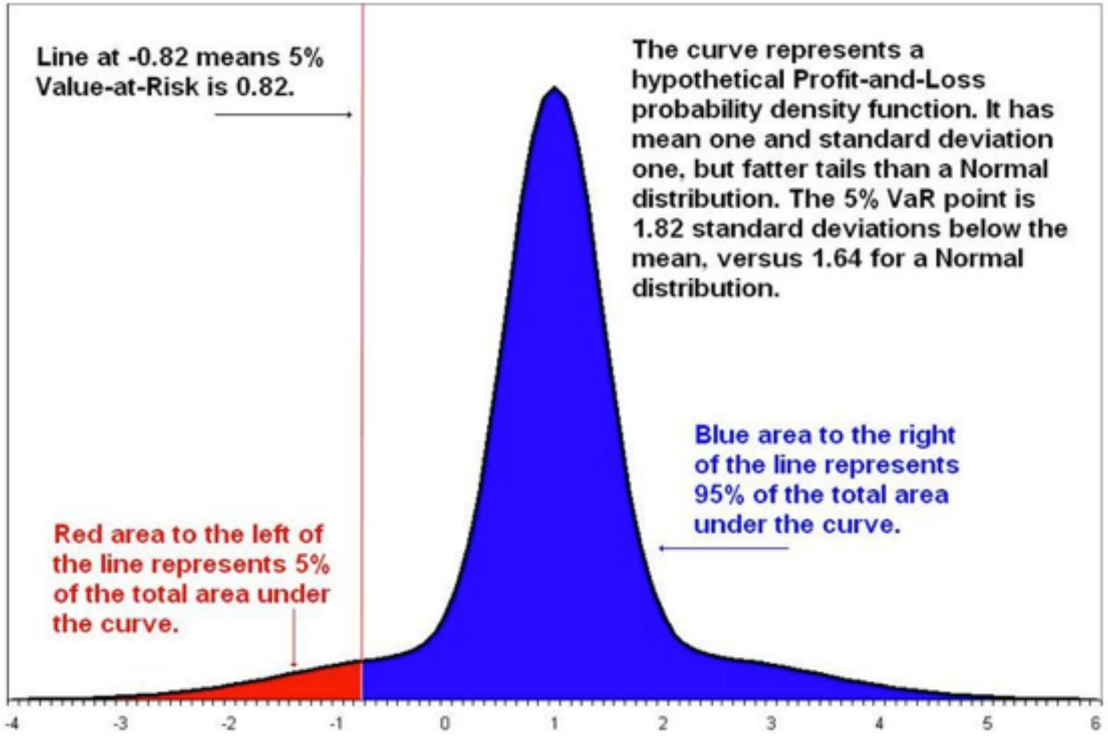
- Traditional approaches to financial pricing (e.g. used by rating agencies) and pure scenario-based stress-test are **inadequate to incorporate the nature of climate risks** and the associated **financial risks** (balance sheet interconnectedness, macro-financial feedbacks)

- Aligning finance to climate targets requires new, transparent methodologies to price **forward-looking** climate risks (opportunities) in financial contracts and in investors' portfolios

Battiston S, Monasterolo I. 2019. A climate risk assessment of sovereign bonds' portfolios. In collaboration with the Austrian National Bank (OeNB) working paper available at SSRN #3376218

Risk type 1: if we know what we don't know

- Value-at-Risk (VaR) used by central bankers to set capital requirements: value to keep aside to avoid massive losses in 95% of cases
- Stands on normal distribution of shocks
- But in presence of fat tails, we can't assume normality
- But models ignore this assuming a linear shock transmission from climate to prices

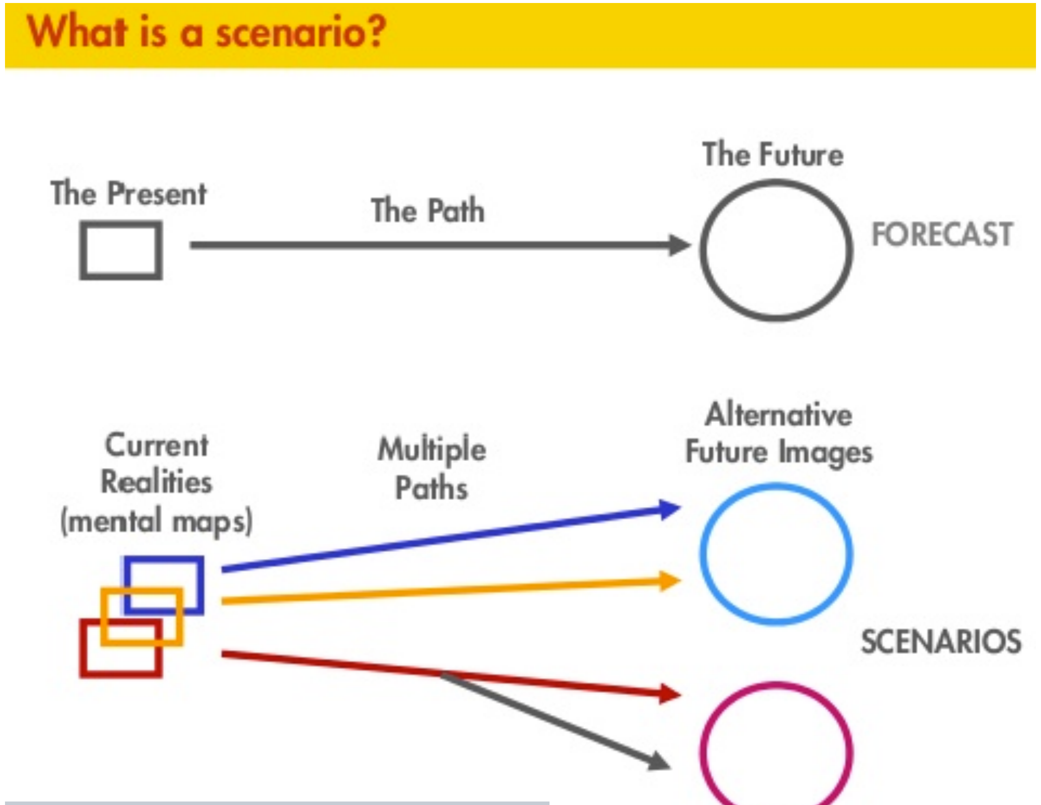


Picture source: wikipedia

Risk type 2: if we don't know what we don't know

- Several situations in which we don't know the distribution of shocks, thus we need to work with *scenarios*

- Scenario analysis can help (doesn't rely on probability distribution):
  - Decide what extreme climate scenarios could be feasible and relevant for business
  - Compute losses conditioned to each scenario
  - Identify portfolios' rebalancing strategies to mitigate risk of losses under each scenario



Picture source: *Royal Dutch Shell*

Climate physical and transition risks

Climate change and financial stability: where does financial risk come from?

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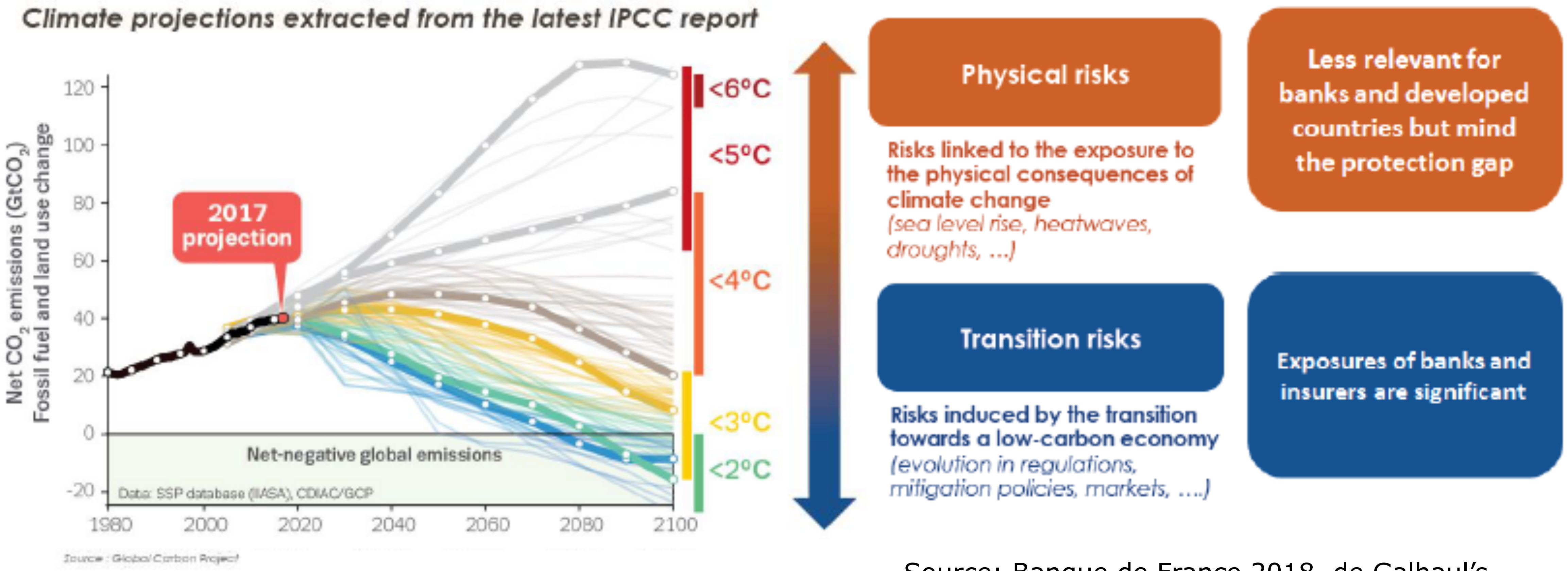
- **2 channels** of climate risk transmission to finance (Carney 2015):
  - **Physical**: risk of damages to physical assets, natural capital and/or human lives resulting into output losses, as a result of climate induced weather events. Based on the available scientific information
    - Insurance, banks: losses on value of financial contracts owned and traded
    - Government: lower GDP growth ->lower fiscal revenues -> impact on eco. competitiveness, budget balance, creditworthiness
  - **Transition**: policy, tech., regulatory shocks:
    - Losses on carbon-intensive assets -> investors' portfolios -> cascading effect on their investors in the financial network
- 2 channels are connected (yet treated separately), leading to **stranded assets**

Carney, M., 2015. Breaking the Tragedy of the Horizon–climate change and financial stability. *Speech given at Lloyd's of London*, *29*, pp.220-230.

Physical risks more visible but transition risks may be more financially relevant



Source: Banque de France 2018, de Galhaul's BIS presentation

Climate physical risks for financial institutions

Adverse consequences include:

- the destruction of immobilized productive capital, with negative implications on firms’ performance and values of securities and loans
- drops in productivity, employment and Gross Domestic Product (GDP) and sovereign credit risk
  - also via loss of arable land productivity
    - with implications on food commodities’ production and prices, famine and social unrest; relocation of millions of people living in areas exposed to climate physical risks, even within developed countries.
- drops in properties’ values, with implications for banks and insurance companies

Examples of materiality of climate risk

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BUSINESS

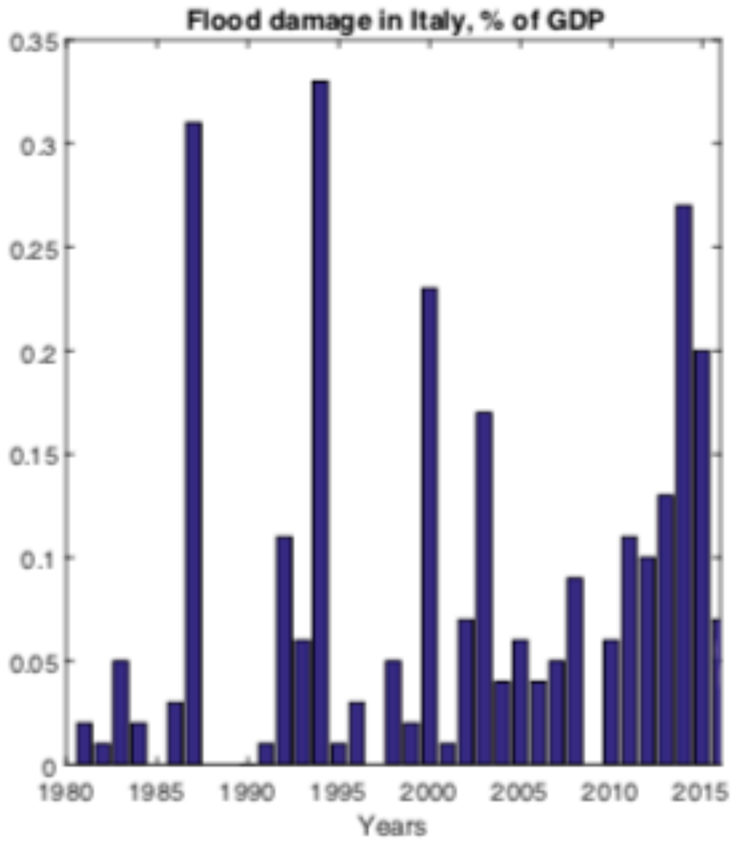
PG&E: The First Climate-Change Bankruptcy, Probably Not the Last

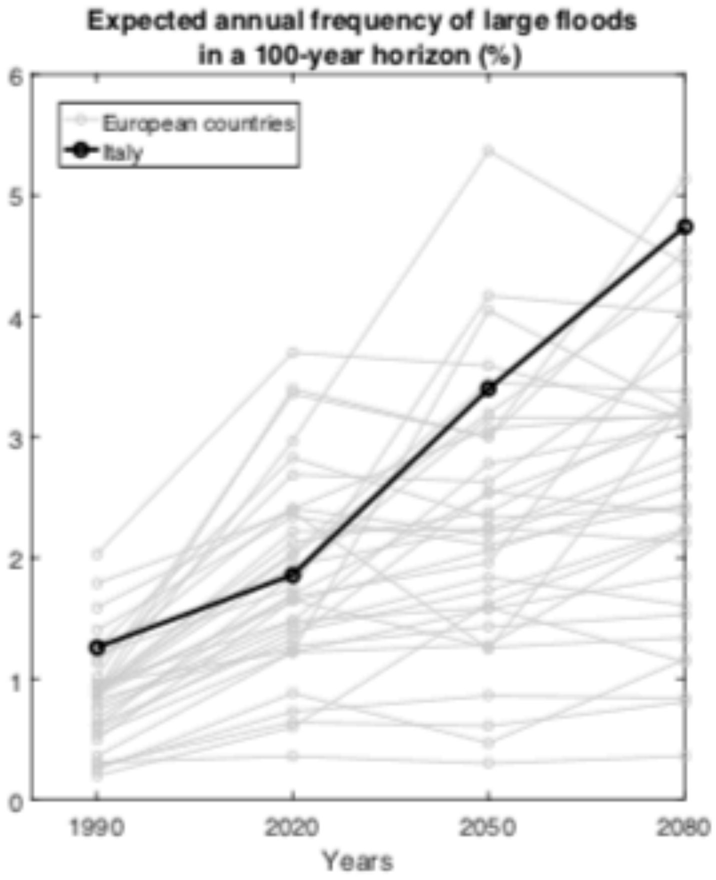
The fast fall of PG&E after California's wildfires is a jolt for companies considering the uncertain risks of a warming planet

By Russell Gold

Jan. 18, 2019 9:00 am ET

Climate physical risks for financial institutions. Example from flood damage projections in Italy





Left panel: Flood damage in Italy as a percentage of GDP. Data source: ISPRA.

Right panel: expected annual frequency of large floods in a 100-year horizon by European country, in %. Black line: Italy; grey lines: the other 36 European countries in the sample.

Source: Ivan Faiella, Filippo Natoli, Climate change and bank lending: the case of flood risk in Italy, 2019, Bank of Italy, working paper.
Data source: Alfieri et al. (2015).

Physical risk versus transition risk

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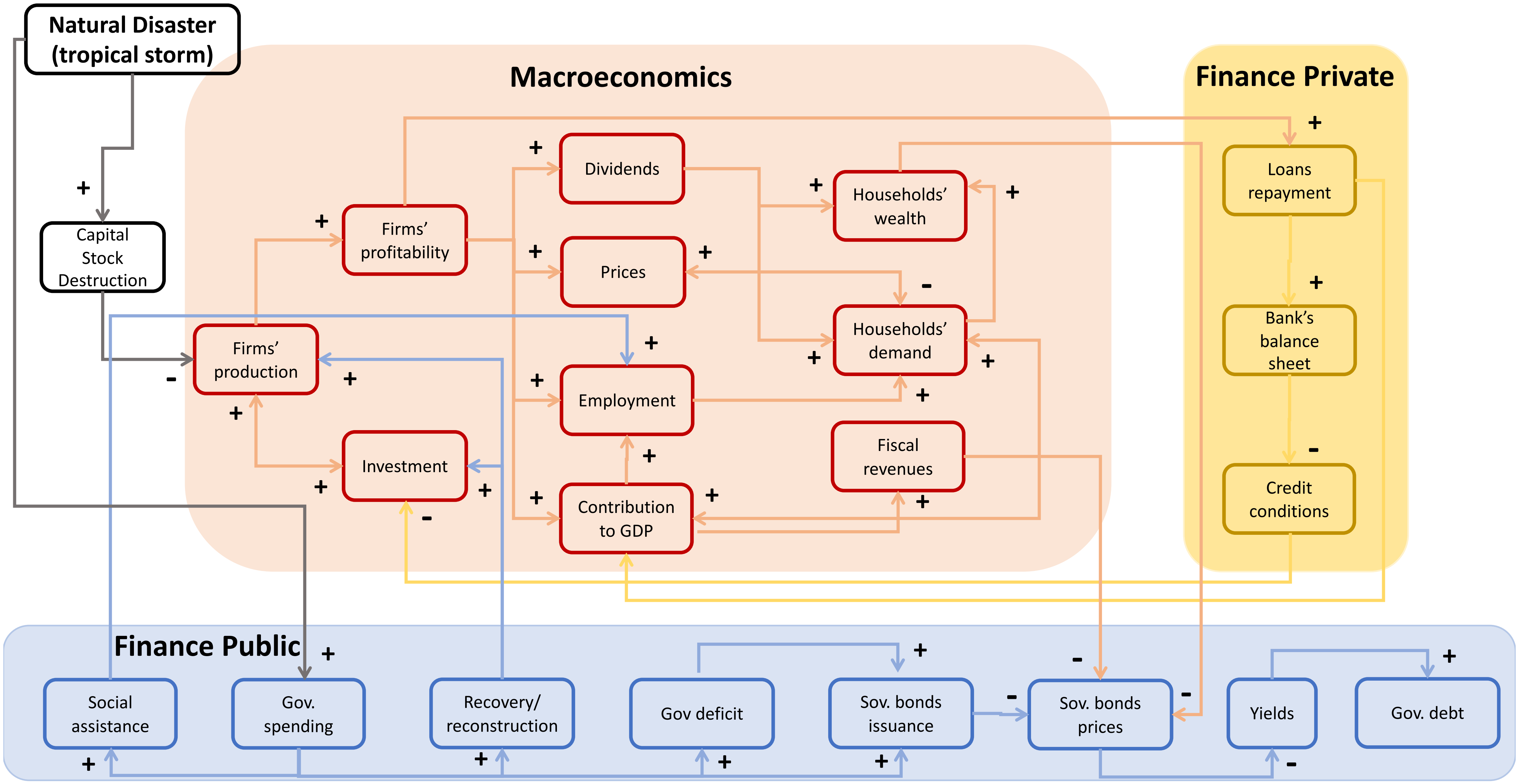
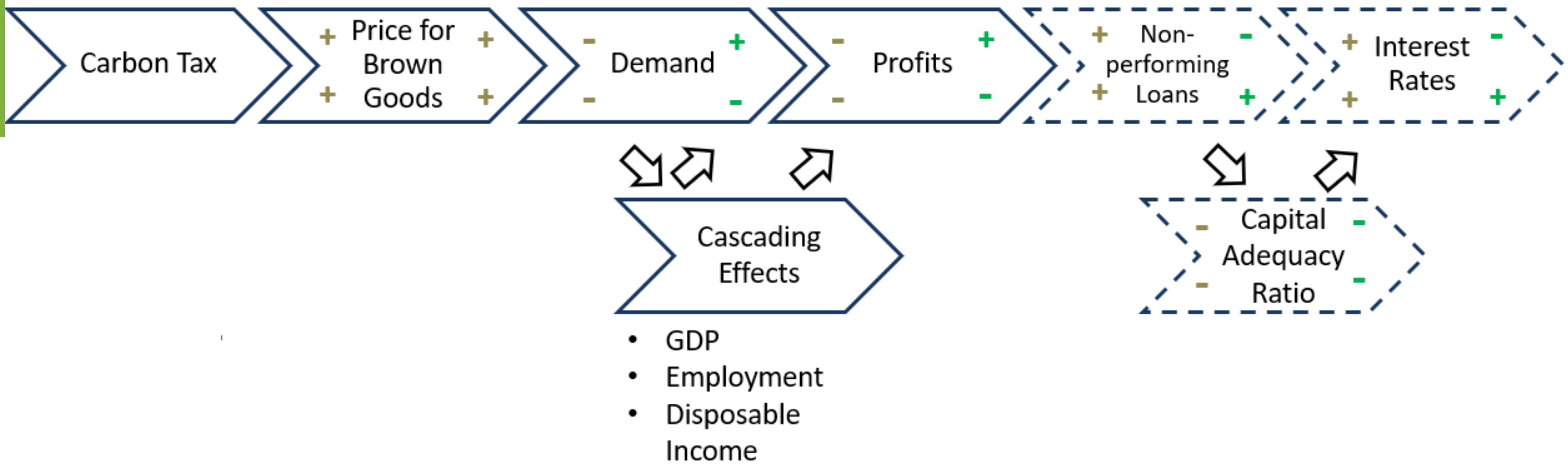
- **Physical risks:** impacts of climate change on physical assets are interconnected:
    - Effect of droughts and high-intensity rainfalls reinforce each other via soil drying and soil erosion
    - Commonly said that that in the EU and UK we do not need to worry about physical risk in the short term. Not entirely true.
- **Transition risks:** unanticipated changes in asset values resulting from not aligning smoothly to a 2 degree C trajectory. We tend to think:
    - market players are good at anticipating price changes and it is unlikely that policy makers would agree to pass climate policies that could entail risks.
    - However, the events of the last 3 years show that market players may collectively make wrong predictions and policies that entail new risks are sometimes adopted, and unexpectedly so.

NATURAL DISASTERS (TROPICAL STORM) RISK TRANSMISSION MAP



Monasterolo et al. 2020. Compound COVID-19, climate and financial risk: what role for public policy? Working paper, forth.

Climate transition risk: unanticipated carbon tax



- CT contributes to decrease brown firms' profitability affecting their ability to repay loans
- CT is beneficial for the Green capital good firm, being more price competitive and more attractive for the consumption good producer.
- However, lower demand and a green capital productivity prevent its growth to fully compensate brown's losses leading to lower GDP growth
- Lower firms' profits might lead to NPLs increase thus affecting bank's profits and saving, which lead to a lower Capital Adequacy Ratio (CAR).

Dunz, N., Naqvi, A., Monasterolo, I. (2019). Climate Transition Risk, Climate Sentiments, and Financial Stability in a Stock-Flow Consistent approach. *Forthcoming on Journal of Financial Stability*. SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3520764

Climate-aligned policies

Most debated climate-aligned policies

- Market-based solutions
  - Emissions Trading Schemes
  - Carbon pricing
  - Carbon tax
- Monetary policies
  - Green Quantitative Easing (via green bonds purchase)
  - Greening collaterals
- Financial regulation
  - Revision of microprudential regulation: green supporting factor vs brown penalizing factor

Carbon pricing

- IMF: “Carbon pricing is the most effective policy for reducing emissions,” says Christine Lagarde, managing director of International Monetary Fund
- Putting a price on carbon at a global scale could unleash innovation and provide the incentives that industries and consumers need to make sustainable choices (António Guterres, UN Secretary-General)
- Carbon pricing reinforces the full realization of the nationally determined contributions and is an essential key for a strong, real, useful implementation of the Paris Agreement (Patricia Espinosa, former Executive Secretary of UNFCCC)

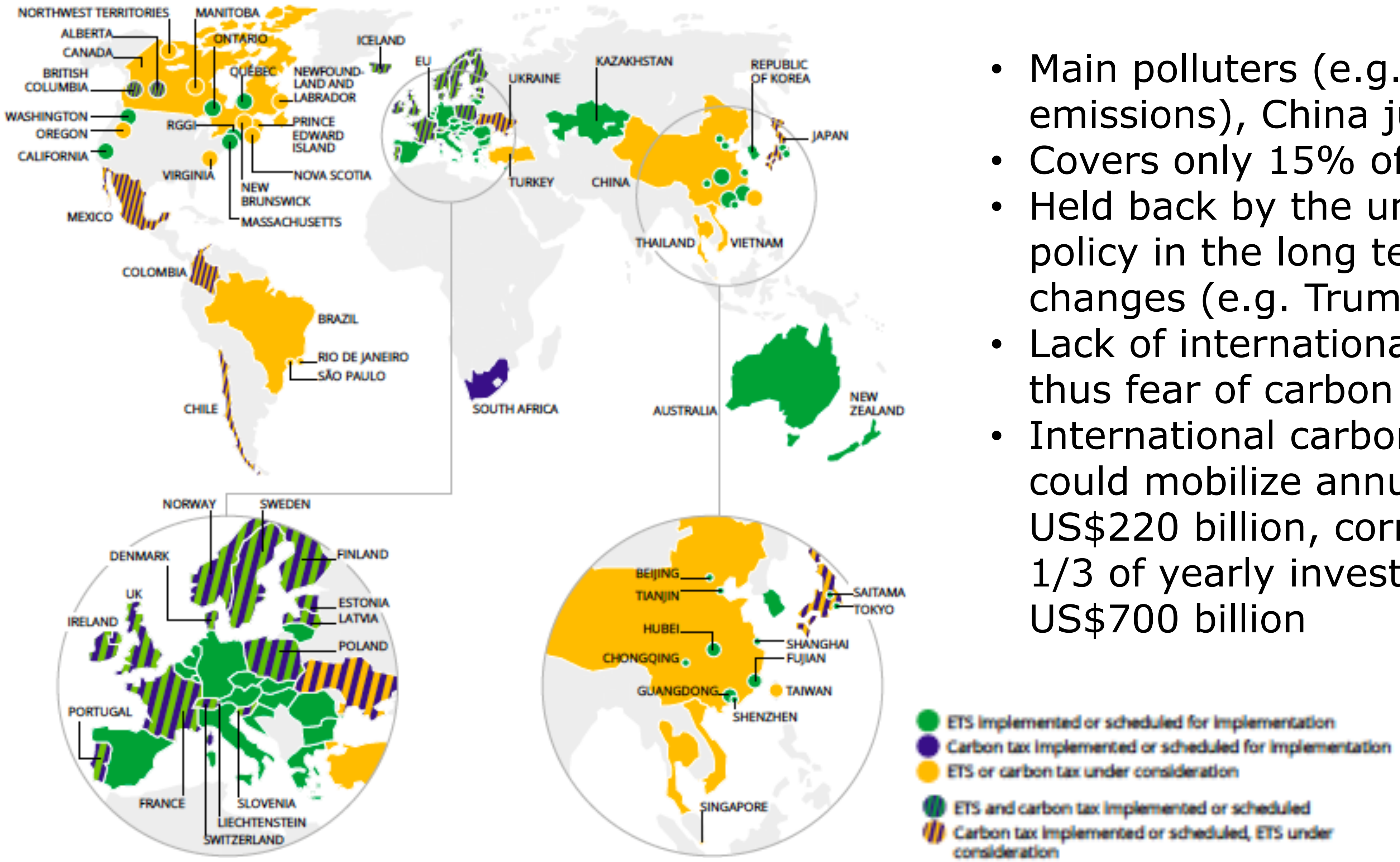
Well-designed carbon price key for reducing emissions: the Stiglitz report

- Carbon prices to foster the changes needed in investment, production, consumption patterns, and to induce technological progress that can bring down future abatement costs.
- **Ways to introduce a carbon price:**
  - GHG emissions priced explicitly through a carbon tax
  - Carbon pricing implemented by embedding notional prices in financial instruments & incentives to foster low-carbon programs/ projects (Clean Development Mechanism)
  - Explicit carbon pricing complemented by shadow pricing in public activities/internal pricing in firms.
  - Reducing fossil fuel subsidies because they similar to *negative* price
- **All countries to implement climate policy packages**

Key take-home messages from Stiglitz report

- Explicit carbon-pricing instruments can raise revenue efficiently because they help overcome a key market failure: the climate externality.
- Carbon pricing alone may not be sufficient to induce change at the pace and on the scale required, may *need to be complemented by other well-designed policies tackling market and government failures*
- Countries may choose different instruments to implement their climate policies, depending on national and local circumstances and on the support they receive.
- *Based on industry and policy experience, and literature reviewed, the explicit carbon-price level consistent with achieving the Paris temperature target is at least US$40–80/tCO2 by 2020 and US$50–100/tCO2 by 2030, provided a supportive policy environment is in place.*

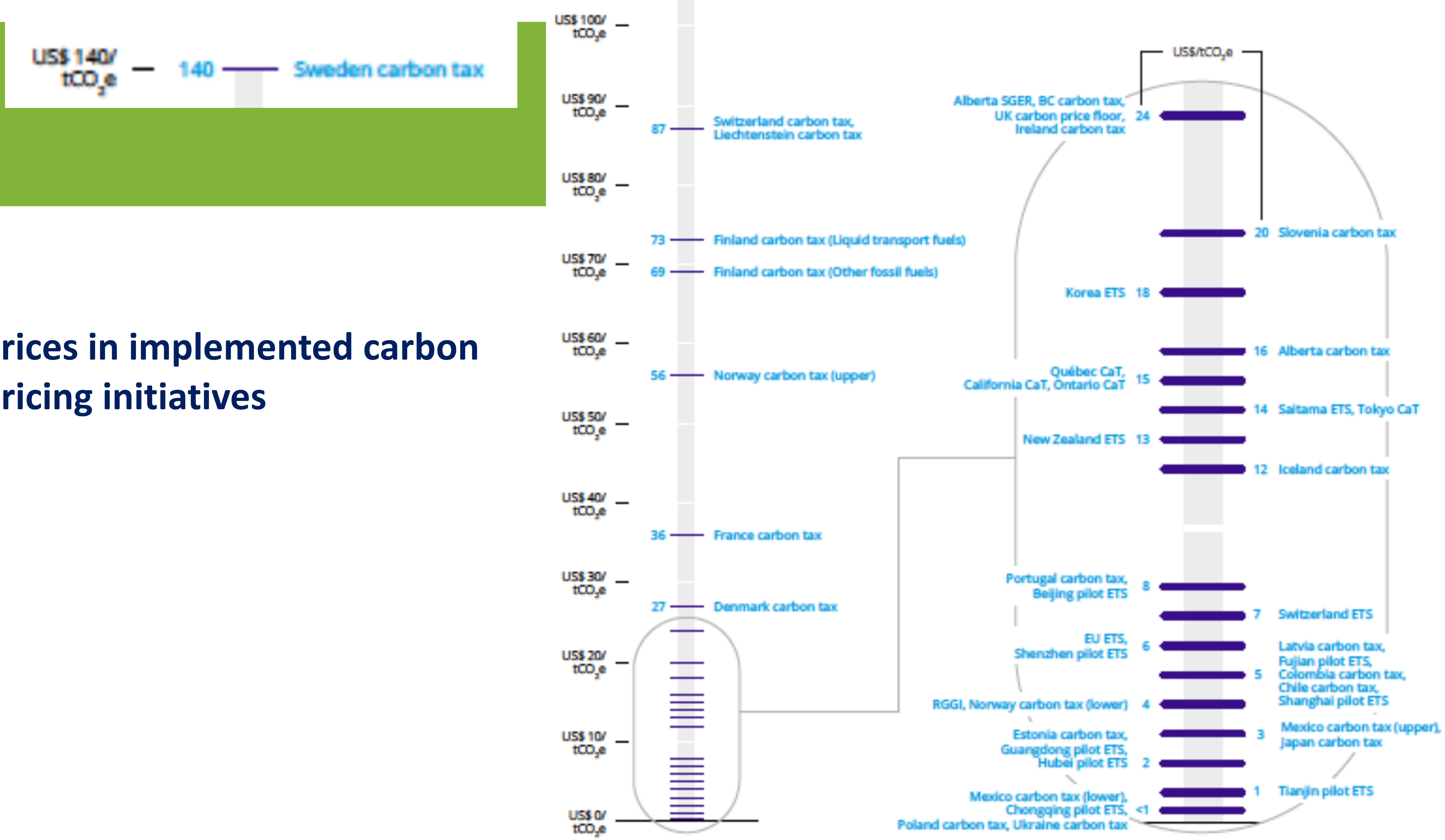
Global Growth of Carbon Pricing: issues at stake



World Bank Group: State and Trends of Carbon Pricing 2017.

- Main polluters (e.g., USA:25% of tot emissions), China just at initial phase
- Covers only 15% of all emissions
- Held back by the uncertain of climate policy in the long term, due to policy changes (e.g. Trump)
- Lack of international coordination and thus fear of carbon leakage
- International carbon market by 2030 could mobilize annual resource flows of US$220 billion, corresponding to about 1/3 of yearly investment needs of US$700 billion

Prices in implemented carbon pricing initiatives



Second best? Greening monetary policies and prudential regulation

What is a Quantitative Easing?

- Asset purchase program: Central banks (CBs) issue newly created reserves and use them to buy pre-existing financial assets, mainly government/corporate bonds:
  - ECB and national CBs have started the purchasing of up to 60 billions worth of financial securities from the secondary market every month from March 2015-2017.
- QE's goal: increase *private* spending to achieve price stability (2% inflation)

- How? *Anchoring expectations thorugh assets prices signalling (Draghi, 2015):*
  - Buying considerable amount of long term securities shows the market that the CB is committed to keeping interest rates low.
  - Portfolio rebalancing channel: substitute bonds with cash, to give banks incentives to lend to private sector, households, companies.

Towards a green Quantitative Easing (QE) for the ECB?

- Growing support for greening monetary policies (Battiston & Monasterolo 2019, De Grawe 2019, Monasterolo & Raberto 2018, Schoenmaker 2019)
- A question of mandate: could the ECB go green if it wanted to?
  - **Primary**: preserve price and financial stability (Art 127(1) of the Treaty).
  - **Secondary** : support economic growth in alignment with EU policies...which include EU2030 targets!
- ECB's QE (*whatever it takes*): 2.7 trn EUR injected in the Euro Area, including bonds issued by 237 companies for 177 Md€.
- ECB will replace the bonds that will reach their maturity with other eligible bonds. Thus, the composition of the CSPP concerns not only the past but also the future

Greening QE via green bonds?

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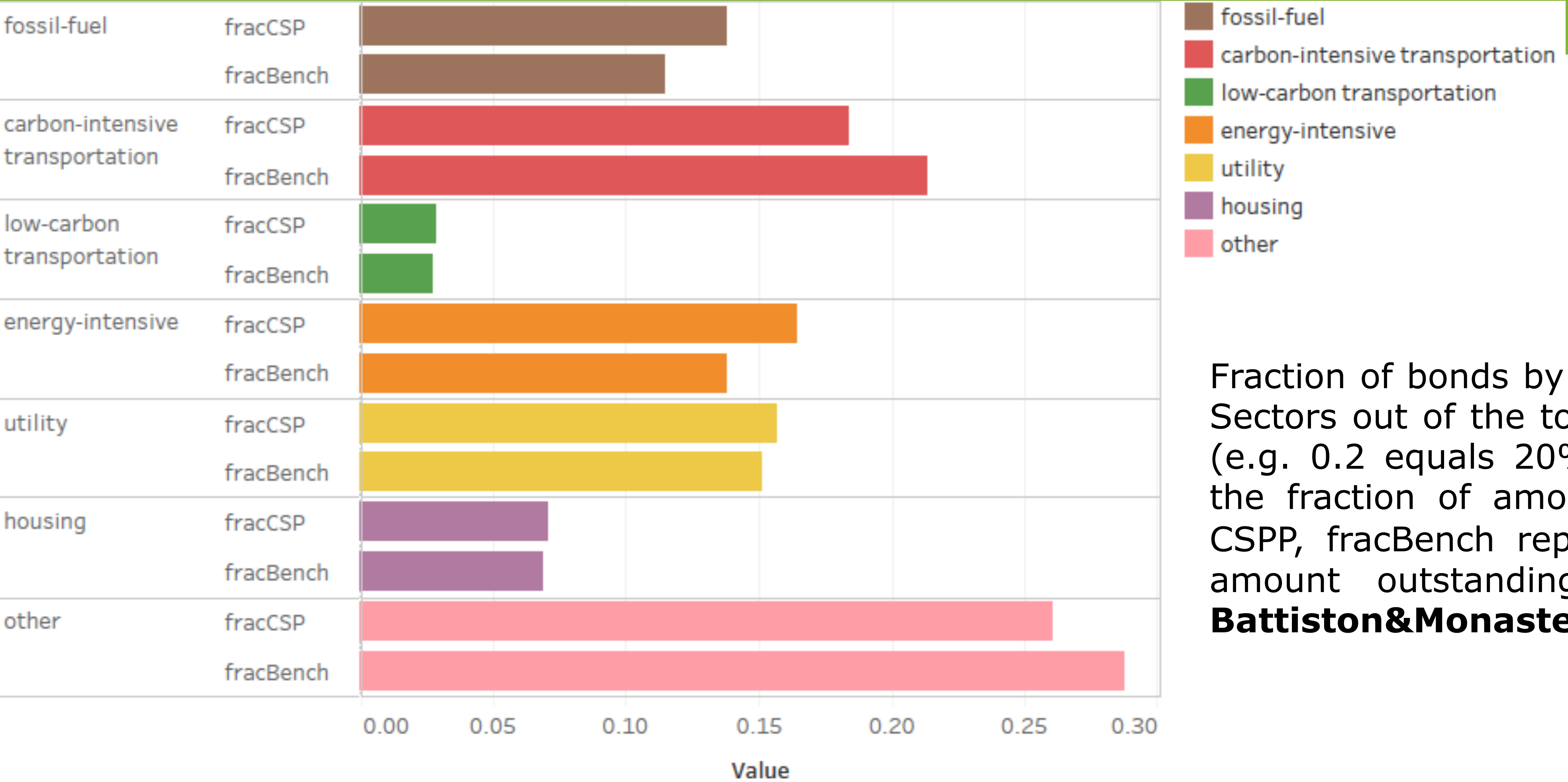
- *A green QE could be implemented via the purchase of green bonds* (issued by corporations, governments and national development banks and European Investment Bank) to signal the market
- But within CSPP, 6 National Central Banks purchased corporate bonds issued by Euro-Area corporations. But they
- Concern about the direct (purchase)/indirect (market signaling) implications on the carbon intensity of the Euro Area economy and thus on its misalignment with the EU2030 climate and energy targets

But what did the ECB purchase? CSPP sector composition vs market benchmark



Fraction of bonds by Climate Policy Relevant Sectors out of the total amount outstanding (e.g. 0.2 equals 20%). FracCSP represents the fraction of amount outstanding of the CSPP, fracBench represents the fraction of amount outstanding of the benchmark. **Battiston&Monasterolo 2019a**

Battiston, S. and Monasterolo, I. (2019a). How could the ECB's monetary policy support the sustainable finance transition? Input to the Positive Money and Veblen's policy report "Aligning Monetary Policy with the EU's Climate Targets". https://www.finexus.uzh.ch/en/news/cspp_sustainable_finance.html

Green supporting factor

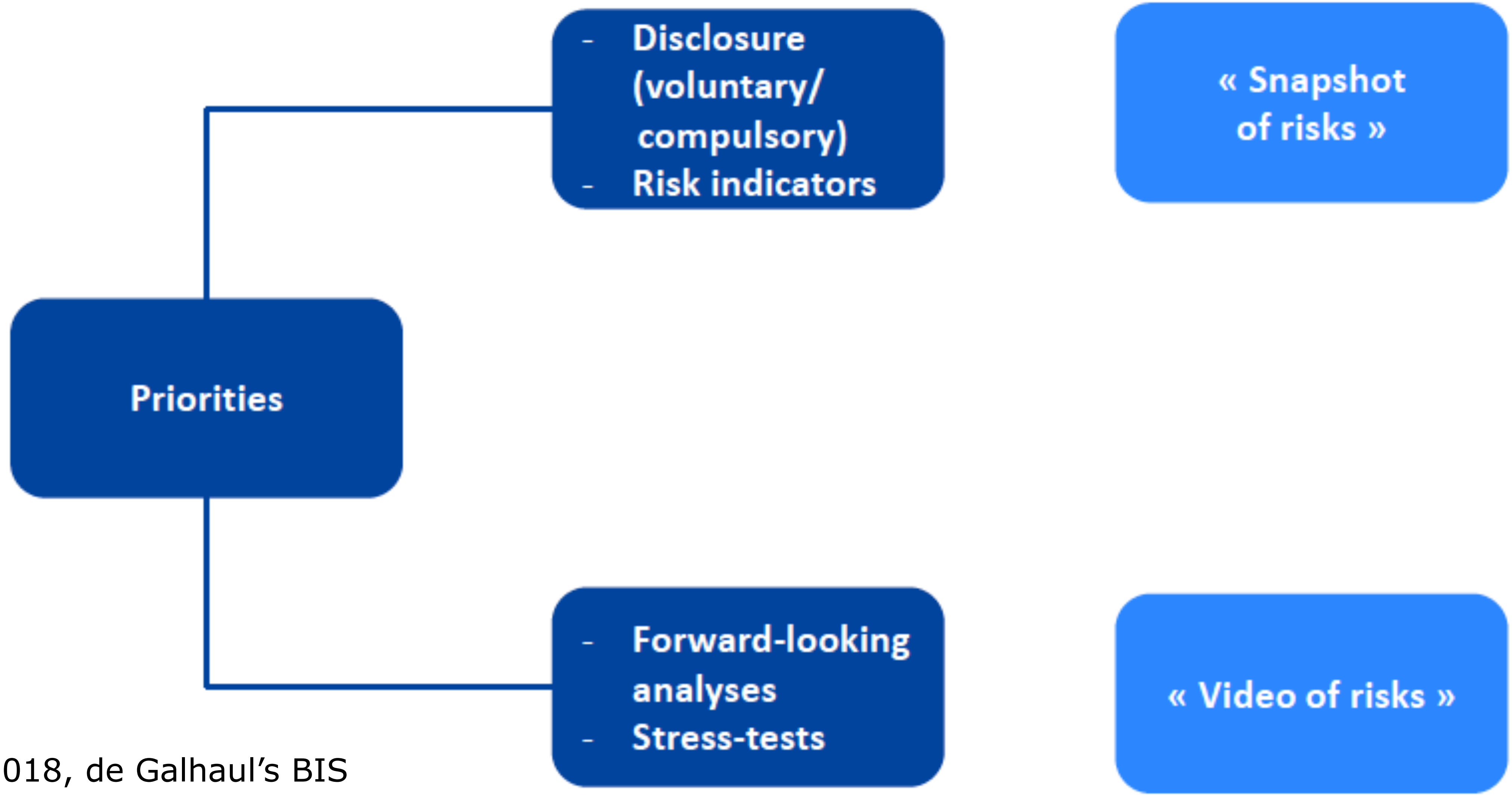
- Dombrovskis (2018): "To incentivize (green) lending, we are looking to **amend capital charges for banks to boost green investments and loans by introducing a so-called green supporting factor (GSF)**. This could be done by **lowering capital requirements for certain climate-friendly investments**.
- Proposal: reduce risk weights on green investments by 25% for investments <€1.5 million, by 15% for portion exceeding €1.5 million.
- **What implications for financial stability?**
  - Basel III Pillar 1 defines a minimum amount of capital of 4.5% of risk-weighted assets, and an additional capital conservation buffer of 2.5% to preserve banks' stability
  - Basel III Pillar II introduces financial supervisory authorities to adjust capital reserve requirements for individual institutions based on individual risk profiles, internal risk management frameworks, and potential concentration risk, eg. for so-called Systemically Important Financial Institutions (SIFIs).

GSF: risk or opportunity?

- Financial regulators, academics and NGOs criticized the GSF and proposed a brown penalizing factor, i.e. increasing capital requirements for banks exposed to carbon-intensive assets and companies
- Challenges for implementing GSF:
  - Lack of standardized green taxonomy to define what is green (asset, investment), the risk associated to the "shades of green" (EC working on it but no agreement among Member States)
  - Are we considering banks' climate sentiments, i.e. expectations about the policy?
    - European Banking Authority (EBA) from March 2016 found no evidence that the SME [Supporting Factor] provided additional stimulus for lending
- For a review: Dunz, N., Naqvi, A., Monasterolo, I. (2019). Climate Transition Risk, Climate Sentiments, and Financial Stability in a Stock-Flow Consistent approach. *Forthcoming on Journal of Financial Stability*. SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3520764

Assessing climate-related financial risks in investors' portfolios

Tackling climate-related financial risks



Banque de France 2018, de Galhaul’s BIS presentation

Disclosure

- G20 FSB Task Force Climate-Related Financial Disclosure (TCFD): 4 recommendations on climate-related financial disclosures for financial investors:

TCFD 2017 Final report, https://bit.ly/2TGfihl

Governance	Strategy	Risk Management	Metrics and Targets
Disclose the organization's governance around climate-related risks and opportunities.	Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material.	Disclose how the organization identifies, assesses, and manages climate-related risks.	Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material.
Recommended Disclosures	**Recommended Disclosures**	**Recommended Disclosures**	**Recommended Disclosures**
a) Describe the board's oversight of climate-related risks and opportunities.	a) Describe the climate-related risks and opportunities the organization has identified over the short, medium, and long term.	a) Describe the organization's processes for identifying and assessing climate-related risks.	a) Disclose the metrics used by the organization to assess climate-related risks and opportunities in line with its strategy and risk management process.
b) Describe management's role in assessing and managing climate-related risks and opportunities.	b) Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning.	b) Describe the organization's processes for managing climate-related risks.	b) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks.
	c) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario.	c) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management.	c) Describe the targets used by the organization to manage climate-related risks and opportunities and performance against targets.

However, disclosure is not moving fast

- 2018: TCFD's survey of disclosures by over 1,700 firms:
  - The majority of the firms surveyed disclose information aligned with at least one of the TCFD recommended disclosures.
  - While many companies describe climate-related risks and opportunities, **few disclose the financial impact of climate change on the company**.
  - **A minority of companies disclose forward-looking climate targets** or the resilience of their strategies under different climate-related scenarios, including a 2°C or lower scenario, which is a key area of focus.
  - **Disclosures vary widely across industries.** More non-financial companies reported their climate-related metrics and targets than financial companies. But financial companies were more likely to disclose how they had embedded climate risk into overall risk management.
  - **Disclosures are often made in sustainability reports** or spread across financial filings, annual and sustainability reports.

And it might not be enough alone

- **Evidence that markets and investors are mispricing climate risks:**
  - De Greiff ea (2018): climate mispricing in banks’ loans after Paris Agreement
  - Morana & Sbrana (2018): mispricing of catastrophe bonds
  - Monasterolo & DeAngelis (2018): stock market indices’ reactions to the PA
- **Science-based, transparent metrics and methods needed** to price climate risks in the present value of investors’ portfolios (Monasterolo ea. 2017)
- **Policy and regulatory framework for sustainable finance**:
  - Green taxonomy
  - Green bonds’ standards
  - **Metrics for disclosure**

Sustainable finance (HLEG 2018)

- Sustainable finance is about **two imperatives:**
  - **Improve the contribution of finance to sustainable and inclusive growth**, in particular funding society’s long-term needs for innovation and infrastructure, and accelerating the shift to a low-carbon and resource efficient economy.
  - **Strengthen financial stability and asset pricing**, notably by improving the assessment and management of long-term material risks and intangible drivers of value creation – including those related to environmental, social and governance (ESG) factors.
- Sustainable finance means **‘better development’ and ‘better finance’** – development that is sustainable in each of its economic, social and environmental dimensions; and a financial system that is focused on the longer term as well as material **ESG** factors.

High Level Experts Group on Sustainable Finance: towards sustainable finance (2018)

EU HIGH-LEVEL EXPERT GROUP ON SUSTAINABLE FINANCE

Final Report 2018
by the High-Level Expert Group on Sustainable Finance
Secretariat provided by the European Commission

- **Action Plan on Sustainable Finance**
- **2030 Climate energy framework**
- **2050 Climate roadmap**

From EU Commission HLEG Sust Fin report:

- "We are now moving towards a low-carbon society"
- **"The low-carbon transition is here to stay"**
- **"The EU is already leading this shift"**
- Regulatory changes to mobilise the funding capacity of private capital
- Investment challenge: need €180B Euros yearly

BUT:
How/when will investors internalize the transition?
How/when will countries internalize the transition?

EC Action Plan on Sustainable Finance

- European Commission’s Sustainable Finance Action Plan (SFAP) to redirect finance towards sustainable investments in alignment with EU2030 targets
- But its implementation brings both opportunities and challenges:
  - Economic competitiveness and financial risks for Member States with high-carbon GDP (e.g. Poland, EU accession countries in Western Balkans)
  - Assets price volatility’s implications for credit market and financial stability
- Markets are not pricing climate risks adequately nor driving the transition:
  - After the Paris Agreement: higher risk premia for carbon-intensive assets but no clear effect on risk-adjusted returns (Monasterolo & de Angelis 2018)
  - Corporate bonds’ carbon-intensive long-term maturities (Battiston & Monasterolo 2019)

The EC Sustainable Finance Action Plan

- Goal: scale up private investments and capital markets to achieve the EU2030 targets and fill the investment gap
- Adopted on 8 March 2018: Comprehensive approach, Sets out 3 main objectives and 10 actions to be delivered

1. Reorientation of capital flows towards sustainable investment

2. Integration of ESG risks into risk management and decision-making

3. Fostering transparency and long-termism

EC Action Plan on Financing Sustainable Growth

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One comprehensive strategy | Three main objectives | Ten Actions

1. **Reorienting capital flows** towards sustainable investment
2. **Mainstreaming Sustainability into risk Management**
3. **Fostering transparency** and **Long-termism**

Actions

1 Establish EU taxonomy for Sustainability	COM is progressively developing the EU taxonomy. The technical details (screening criteria)are developed by the Technical Expert Group (TEG) that will deliver their report by Q2 2019.
2 Create Standards and Labels	COM explores the use of the EU Eco-Label framework for green financial products. By Q2 2019, the TEG will prepare a report on an EU Green Bond Standard building on current best practices. On the Eco-label, JRC has launched an open consultation (open until 25 January 2019).
3 Foster Investment in Sustainable Projects	COM explores measures that will improve the efficiency and impact of instruments aiming at investment support. A mapping on investment gaps and financing took place in Q3 2018, best practices for sustainable investments were exchanged on (inter-)national and EU level in Q4 2018.
4 Incorporate Sustainability in Investment Advice	COM will ensure that advisors will take into account the sustainable preference of clients. Draft delegated acts were published for Feedback in May 2018. COM reviewed stakeholder feedback and published the final version of the delegated act.
5 Develop Sustainability Benchmarks	COM will increase the transparency of sustainability benchmarks. The TEG is currently assisting the Commission in developing minimum standards for low-carbon benchmarks and minimum disclosure requirements for ESG benchmarks. It will deliver a report by Q2 2019.

One comprehensive strategy | Three main objectives | Ten Actions

1. **Reorienting capital flows** towards sustainable investment
2. **Mainstreaming Sustainability into risk Management**
3. **Fostering** transparency and **Long-termism**

Actions

6 **Integrate ESG in Ratings and Market Research**	COM will launch a public survey in Q1 2019 to explore how to better integrate sustainability factors in the credit rating assessment. ESMA will report to COM by Q2 2019 and launch a formal consultation on CRA in February 2019. A progress report by COM is due Q3 2019.
7 **Clarify institutional investors and asset managers duties**	COM is working on how to clarify the duties of asset managers, pension funds and insurance companies to ensure they consider ESG factors in their investment decision process and are more transparent towards end-clients.
8 **Incorporate sustainability in prudential requirements**	COM will explore the feasibility of a green supporting factor when it is justified from a risk perspective to safeguard financial stability.
9 **Strengthen Sustainability Disclosure & Accounting**	COM is evaluating the current reporting requirements for companies. The TEG assists COM in integrating TCFD recommendations in the Non-Binding Guidelines, which will be updated by Q2 2019. COM will further analyze the impact of accounting rules (IFRS standards) on sustainable and long-term investments.
10 **Foster Sustainable Corporate Governance**	COM is exploring how improved corporate governance can enhance sustainability and is collecting evidence from the ESAs on short term market pressure arising from capital markets.

Source: European Commission: Action Plan on Financing Sustainable Growth (2018).

Sustainability taxonomy

What is the Taxonomy?

A list of economic activities that are considered environmentally sustainable for investment purposes.

What is set out in the Proposal?

The framework to develop the taxonomy. For an economic activity to be on the list, it has to comply with four conditions:

(a) **Substantially contribute** to at least one of the six environmental objectives as defined in the proposed Regulation*

+

(b) **Do no significant harm** to any of the other six environmental objecties as defined in the proposed Regulation*

+

(c) Comply with **minimum social safeguards**

+

(d) Comply with quantitative or qualitative **Technical Screening Criteria**

*The six environmental objectives as defined in the proposed Regulation are: (1) climate change mitigation; (2) climate change adaptation; (3) sustainable use and protection of water and marine resources; (4) transition to a circular economy, waste prevention and recycling; (5) pollution prevention and control; (6) protection of healthy ecosystems.

European Commission: Proposal on the establishment of a framework to facilitate sustainable investment (2018).

Central banks and financial regulators' Network on Greening of the Financial System (NGFS)

- In responding to environmental and climate challenges, there are opportunities and vulnerabilities for financial institutions and the financial system as a whole.
- Network's role: help strengthening the global response to meet the Paris Agreement and to enhance the **role of the financial system to manage risks and to mobilize capital** for green and low-carbon investments

Founded end of 2017 in Paris.

Chair: Frank Elderson (DNB), *Secretariat*: Banque de France

Members		Obervers
BaFin	Bank of England	BIS
Banco de España	Banco de Mexico	EBRD
Bank of Finland	Bank Al Maghrib	OECD
Banque centrale du Luxembourg	Japan Financial Services Agency	Sustainable Insurance Forum
Banque de France	Monetary Authority of Singapore	World Bank
Banque nationale de Belgique	People's Bank of China	
De Nederlandsche Bank	Reserve Bank of Australia	
Deutsche Bundesbank	Swedish Finansinspektionen	
European Central Bank		
Oesterreichische Nationalbank		

Workstream 1	Workstream 2	Workstream 3
Microprudential/Supervisory	**Macrofinancial**	**Scaling up green finance**
• Comparison of regulatory and supervisory practices • Monitor national und international initiatives • Integrate climate-related risks into financial supervision	• Analysis of transmission of climate-related risks into real economy and financial system • Quantify effects of physical risks and transition risks (baseline scenarios and tail risks)	• Support Green-Finance-Market • Standardized classification of green assets • Standardized reporting of climate-related risks • Define and promote best practices • Information for financial industry
Chair: Ma Jun (PBOC)	Chair: Sarah Breeden (BoE)	Chair: J. Wuermeling (Buba)

- Mapping of supervisory practices for integrating environmental (climate) risks into micro-prudential supervision
- Environmental information (climate risk) disclosure by financial institutions, options to encourage disclosure

- How can climate change and the transition impact upon the macroeconomy and financial stability?
- Examples of good practices?
- Gaps in collective knowledge? What are the priority questions which need answering?

- Greening the activities of Central Banks and supervisors
- Understanding/monitoring the market dynamics of green finance
- Central banks/supervisors as catalysts for greening the financial system

Climate risks and financial stability

Climate and financial stability risk: issues at stake

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1. **Investments** are largely **misaligned** to the climate targets (IPCC 2018). **Policies** advocated but implementation uncertain

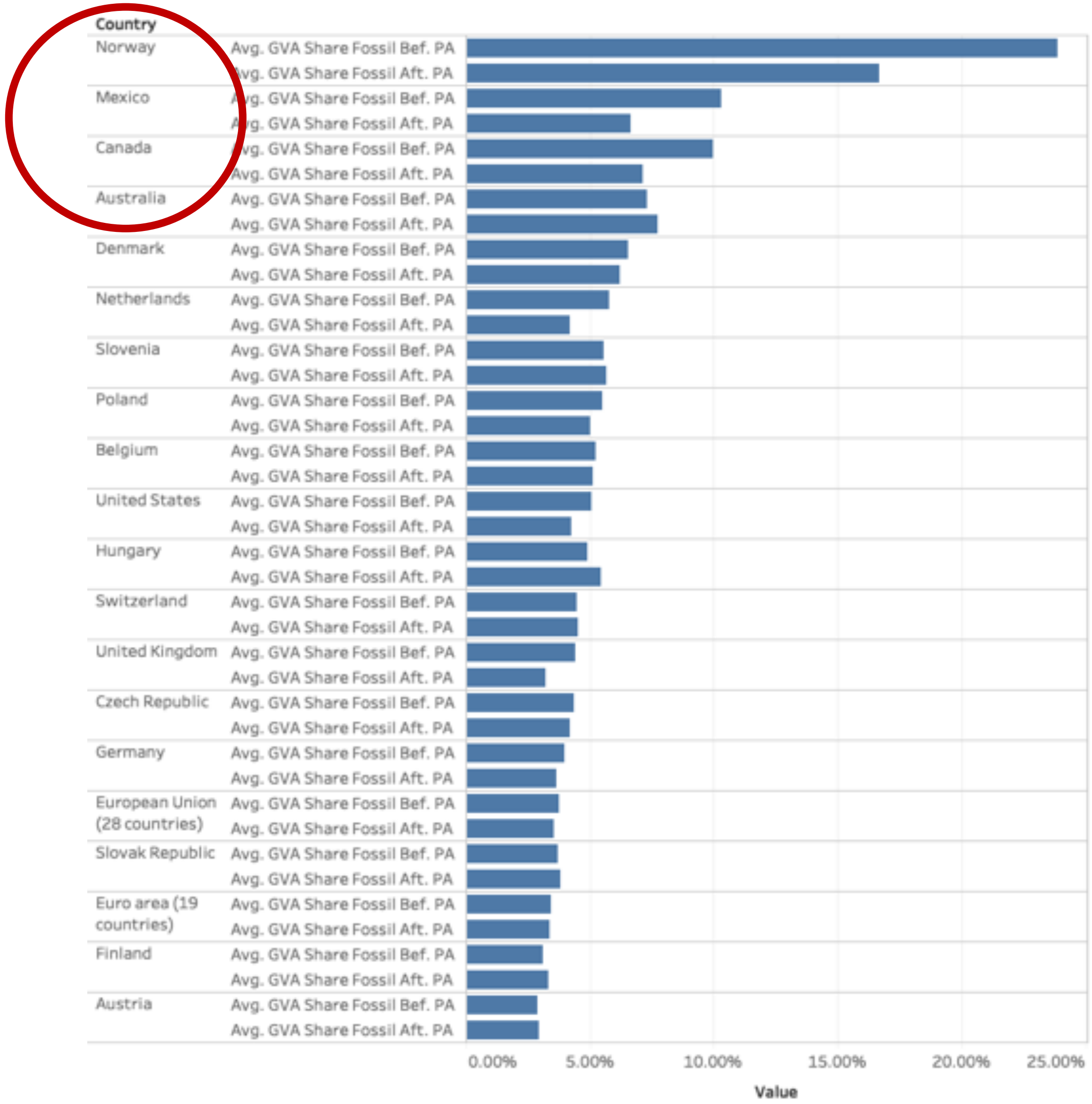
2. **A disordered transition** (late, unanticipated policies) could drive new risks for financial stability: **climate Minsky Moments** (NGSF 2019)

3. Investors are not pricing climate **risks** in their portfolios (Monasterolo & de Angelis 2019): increasing (trading) exposures to **carbon stranded assets**

4. **Assessing the materiality of climate risks in financial contracts and portfolios** is key to inform investors and supervisors' prudential measures

5. We provide **transparent climate financial risk metrics** that can be integrated in traditional supervisory tools

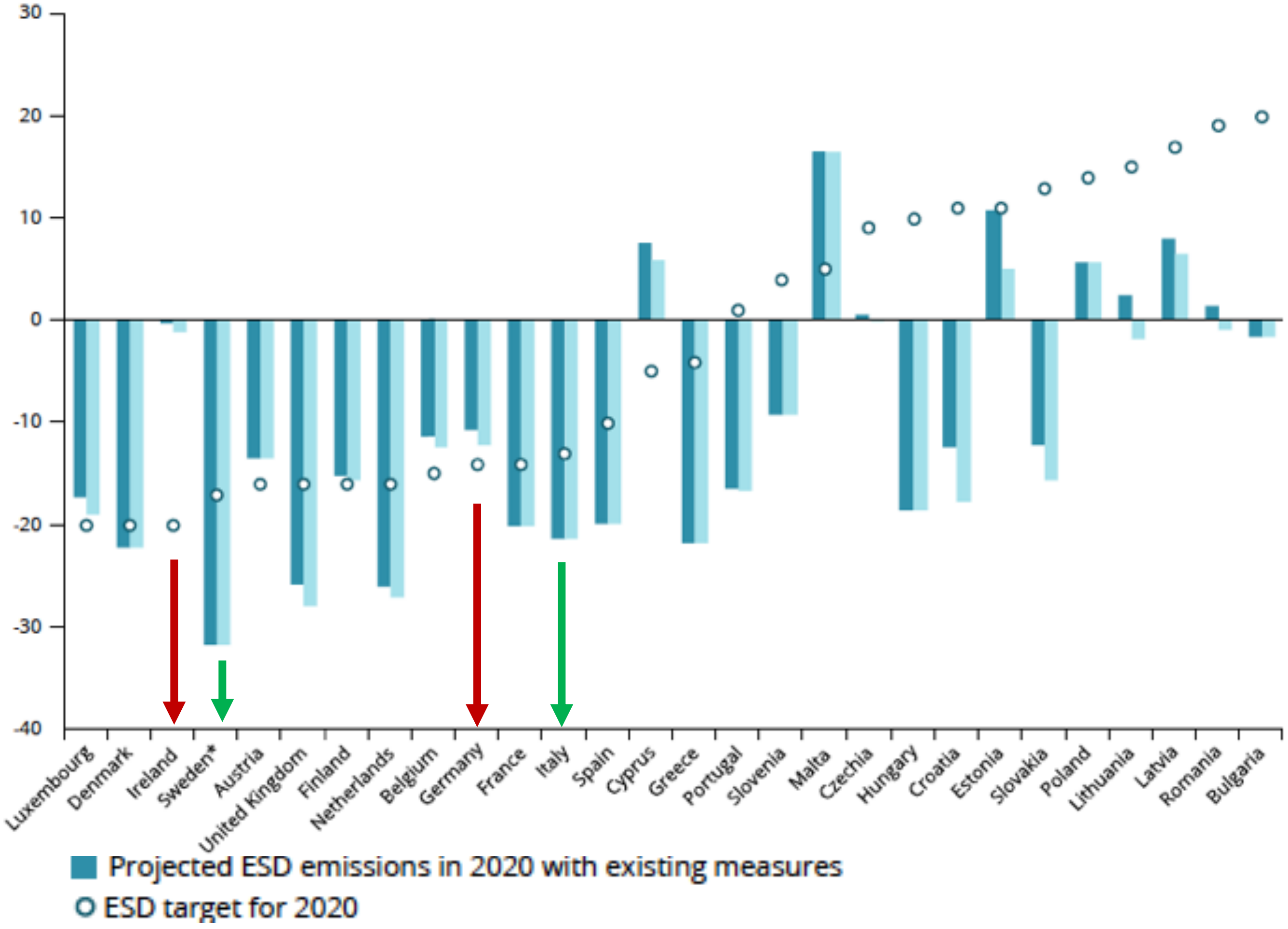
Why risk? Fossil fuels still represent a large share on Gross Value Added, even after Paris



- Achieving the climate targets requires to decarbonize the economy. But…
- Average share of fossil fuels on Gross Value Added (GVA) by OECD country reaches 18% after the Paris Agreement (OECD data).
- **To what extent are investors exposed to "carbon stranded assets"?**

Thus, most economies are misaligned to the climate targets

Projected EU member states' progress



- Heterogeneity in degree of alignment to EU2020 targets (not enough to stay within 2°C)
- **Risk pricing** has implications for risk management and creditworthiness:
  - ➢ If I were a **pension fund,** should I keep my exposures or divest from bonds of misaligned (thus riskier) countries?
  - ➢ To what extent risk repricing affects country's economic performance, **refinancing conditions and solvability**?

In this context, a disorderly transition can drive financial risks

- Reaching **climate targets** requires undertaking a low-carbon energy transition by 2030, which could be:
  - **Orderly:** climate policies are introduced in a stable and predictable way -> investors *can* anticipate and price it
  - **Disorderly:** government delays the policy introduction -> investors cannot fully anticipate the policy introduction/impact and thus price it
    - could lead to sudden portfolio adjustment (when policy occurs) -> asset **price volatility** (Monasterolo et al. 2017)
    - If large (and correlated) asset classes and systemic investors involved, there could be implications on **systemic risk** (Battiston et al. 2017)

Battiston, Mandel, Monasterolo 2019, CLIMAFIN Handbook: Pricing climate financial risk Part 1
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3476586

Central banks and financial supervisors started to worry about the climate…

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Mark Carney tells global banks they cannot ignore climate change dangers

Financial sector warned it risks losses from extreme weather and its stakes in polluting firms

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Climate Changed

ECB Says Mispricing Climate Change May Hurt Financial Stability

By Piotr Skolimowski
29 May 2019, 01:00 GMT-7

Network for Greening the Financial System
First comprehensive report

A call for action
Climate change
as a source of financial risk

April 2019

Italy central bank to spurn firms that don't go green

The Bank of Italy plans to adopt investment criteria which reward companies that take action on climate change, joining other central bank...

reuters.com

And climate financial risk was on the top of 2019's IMF annual meeting

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IMF Will Include Climate in Country Analysis, Georgieva Says
bloomberg.com

11:58 AM · Oct 17, 2019 · Twitter Web App

IMF Managing Director K. Georgieva: IMF gearing up to integrate climate risks in surveillance duty, including **climate stress-tests, climate risk pricing**

What if we start to price investments' (mis)alignment?

- Countries' (mis)alignment can drive sovereign risk re-pricing:
  - How the **energy technology path** (low/high-carbon) of an economy affects its sovereign's bond yields, i.e. what is the **climate spread** of Australia vs Sweden?

- Risk pricing has implications for **risk management and sov. creditworthiness:**

➢ If I were a **pension fund,** should I keep my exposures or divest from bonds of misaligned (thus riskier) countries?

➢ To what extent risk repricing affects country's economic performance, refinancing conditions and **solvability**?

Three questions for you

1. **What do we need to know to price climate risks/opportunities in the value of financial contracts?**
   - How future climate policy shocks shift investors' default probability?
   - What is the price of climate risk (spread) for a country and investor?

2. **Do we have the models to do it?**

3. How could we use information from climate risk assessment to **inform risk management and prudential regulation**?

The CLIMAFIN tool

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- First approach to combine **forward-looking climate transition** risks based on **climate models** used by IPCC, with **climate financial risk metrics** now used by scholars and practitioners (Battiston et al., 2017)
- CLIMAFIN allows risk averse investors and supervisors with a financial stability mandate to assess quantitatively climate-related financial risk:
  - Identify channels by which a disorderly transition affects issuer's **default probability and creditworthiness, and sovereign fiscal revenues**
  - **Price** forward-looking climate risks in financial contracts and portfolios
- *No need to reinvent the wheel but need to consider **climate risk nature***

Battiston, Mandel, Monasterolo 2019, CLIMAFIN Handbook: Pricing climate financial risk, Part 1
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3476586

From Stress-test to Climate Stress-test

- **Classic stress-tests** consider scenarios where a shock consists in changes in macro-economic variables across two equilibrium states of the economy
- **Climate Stress-test**: we consider transition from a business-as-usual (*BAU*) to a policy (2°C target) trajectory (P): temporary out-of-equilibrium evolution
  - Shocks are obtained from differences in sectors' output between the two trajectories (*BAU* and *P*) for the same Integrated Assessment Model
  - Shocks shift the **Probability of Default** on financial contracts and revaluation of losses in investors' portfolios
  - Calculate **Climate Value at Risk** on portfolio and the worst-case losses, considering second (and >) round losses.

Climate Value at Risk and beyond

- In 2017 we introduced **Climate Value at Risk** (VaR) and Climate Expected Shortfall because metrics familiar to investors (Battiston ea. 2017)

- Yet, a main problem applies: VaR depends linearly on the Probability of Default (PD) of underlying assets (small errors have small consequences)

- But Probability of Default (**PD) of leveraged investor depends non-linearly with PD of underlying assets implying small errors can have big consequences**

- But VaR does not consider leverage. This means we need to go beyond Var

- **Climate risk can be systemic risk:** climate risk assessment requires expertise in PD analysis in **interconnected financial actors**, **leverage financial agents** with **overlapping portfolios**.

Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin (2017). A Climate stress-test of the EU financial system. *Nature Climate Change*, 7, 283–288.

Getting the tools right: expertise, incentives and motivation

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- Results show that climate risk is a matter of **public safety**. Financial actors are largely exposed to climate risks without taking adequate action. Governments cannot afford them.
- Thus, potential **conflict of interest**: financial industry has incentive to underestimate climate-financial risks (eg. ESG) to avoid tighter regulation
- The **regulators' mission** is to mitigate financial risk thus protecting consumers and providing a solid floor for governments' climate policy
- **Interdisciplinary scientific expertise needed**: climate economics and policy but also systemic financial risk and pricing
- This is why we need financial supervisors to team up with academia in idetification of feasible scenarios and their **transparent** assessment

This happens when you get pricing wrong

- Rating agencies business model: potential conflict of interest undermines the credibility of climate risk assessment, like in the last financial crisis

Until six days **before Lehman Brothers collapsed** five years ago, the **ratings** agency Standard & Poor's maintained the firm's investment-grade **rating** of "A". Moody's waited even longer, downgrading **Lehman** one business day **before** it **collapsed**. Sep 13, 2013

www.theguardian.com › business › sep › lehman-brothers-was-capitalis...

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Business

Bringing Down Wall Street as Ratings Let Loose Subprime Scourge

Elliot Blair Smith

24 September 2008, 06:00 CEST

CLIMAFIN's 5 modules

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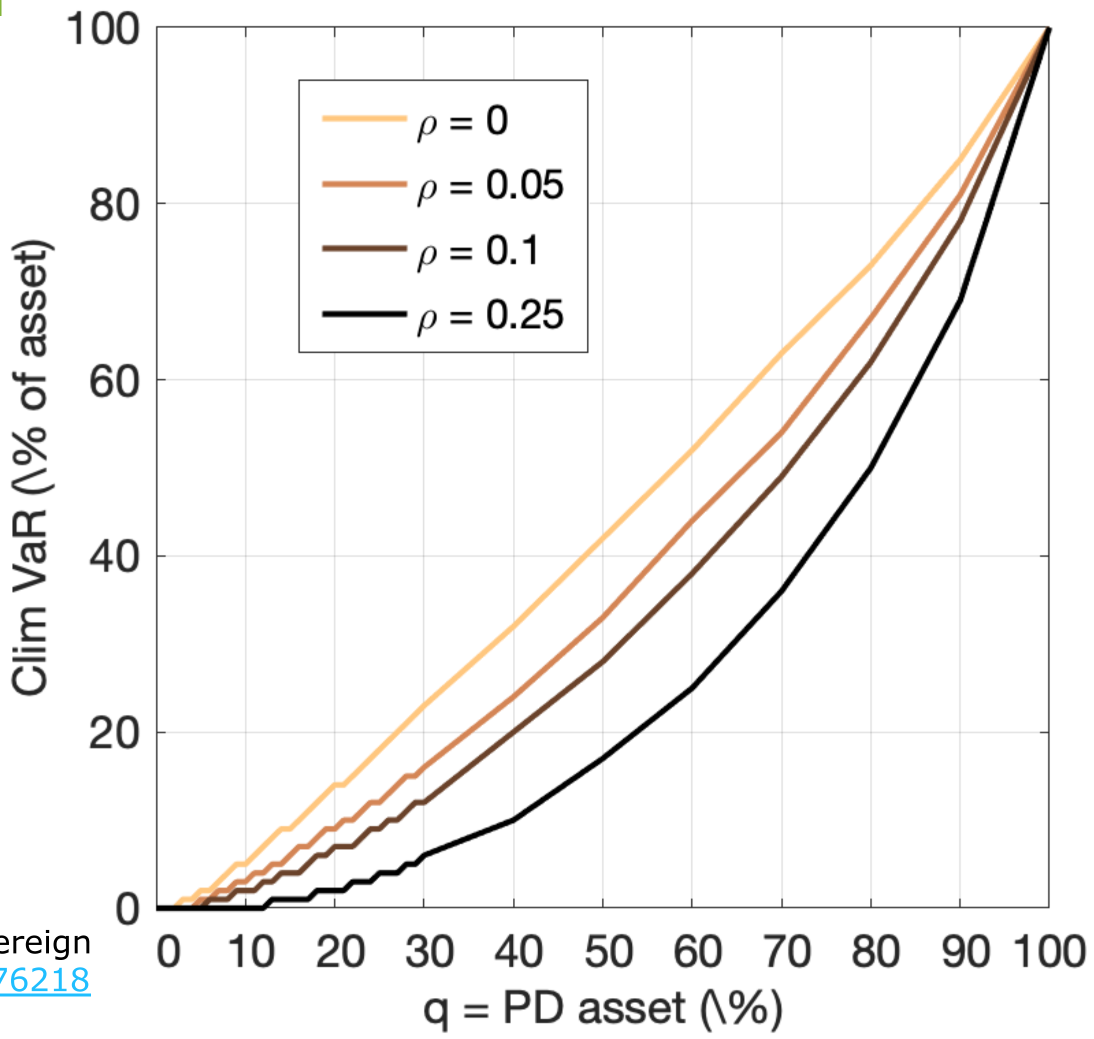
1. Identify financial contracts exposed to climate transition risks based on issuer's sector, technology (share of electricity from fossil/ renewable)
2. Identify **Climate Policy Shock Scenarios** based on energy transition (IPCC 2018), estimate shocks in sector output as a relative difference between the two trajectories (BAU and P).
3. Compute **adjustment on the Probability of Default (PD)** conditioned to the shock scenario, and **Climate Spread** for individual bonds
4. Compute adjustment on **Climate VaR** (worst-case loss) conditional to a **Climate Policy Shock Scenarios**
5. **Climate Stress-test** based on financial valuation in network models (NEVA) to assess largest individual/systemic losses

Battiston, Mandel, Monasterolo 2019, CLIMAFIN Handbook: Pricing climate financial risk, Part 1
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3476586

Value-at-Risk not sensitive to asset PD …

- Consider a financial investor financed
  - with leverage (e.g. 20), with a portfolio of corporate bonds
  - with individual PD q and
  - with correlation rho

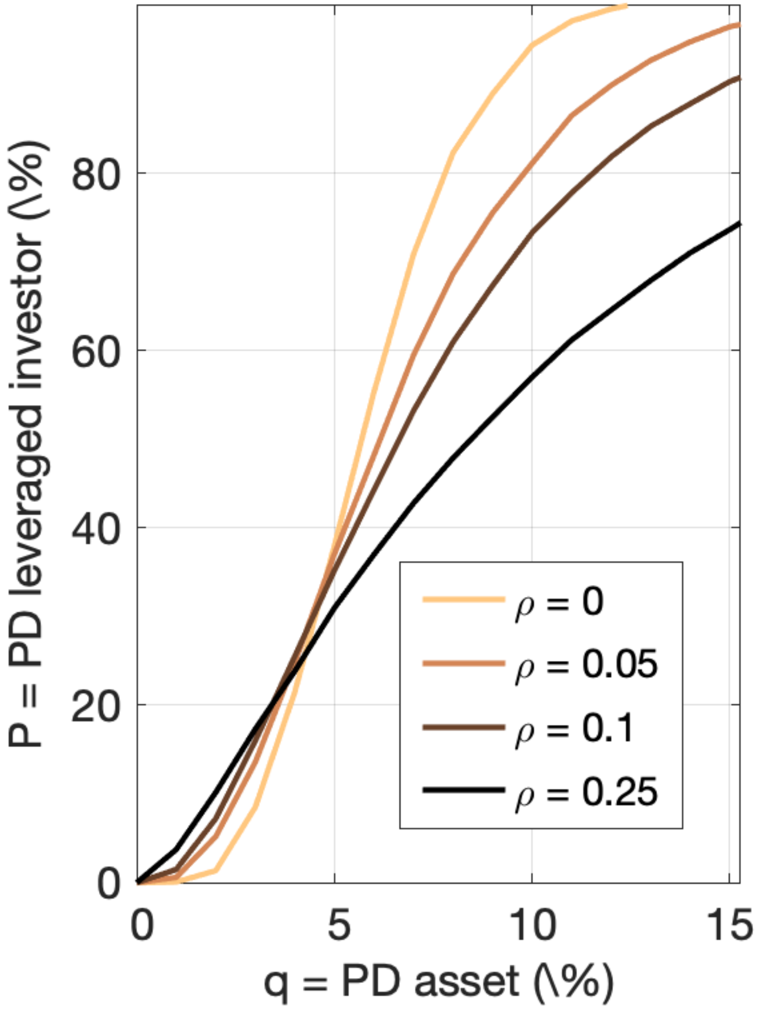
- Small change in PD imply small changes in VaR.
- <u>Is this the whole story?</u>

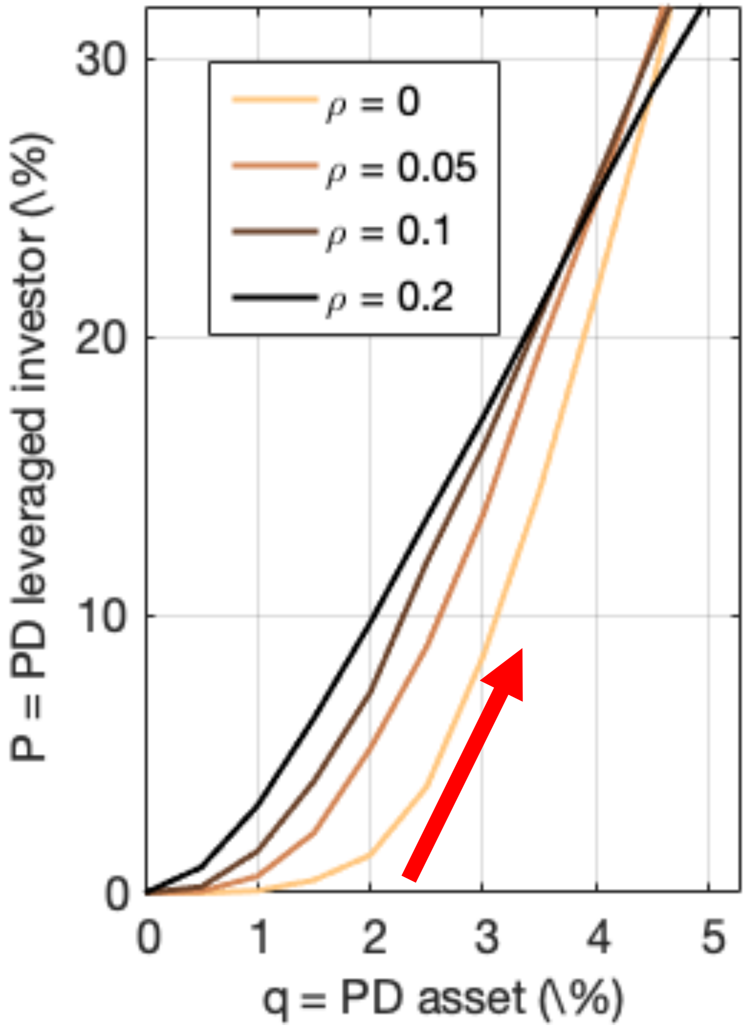


Battiston, S., Monasterolo, I. (2019). A climate risk assessment of sovereign bonds' portfolios. Forthcoming as OeNB working paper, see SSRN #3376218

…but investors' PD highly sensitive to asset PD

- Consider a financial investor financed
  - with leverage (e.g. 20), with a portfolio of corporate bonds
  - with individual PD q and
  - with correlation rho
- Small change in PD imply large changes in investor's PD
- <u>Financial stability highly sensitive to climate policy shock scenario</u>

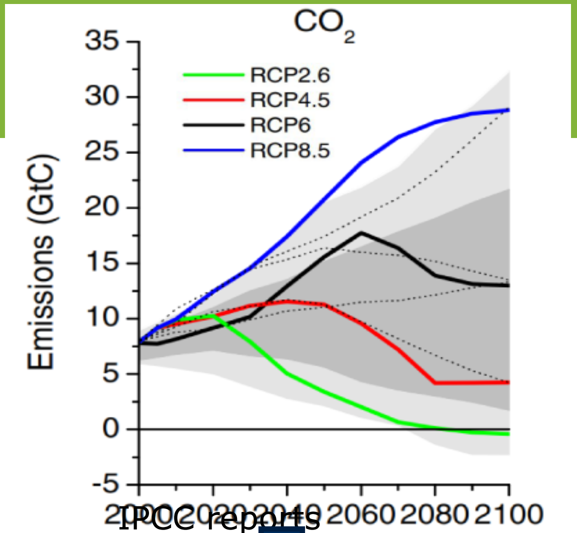




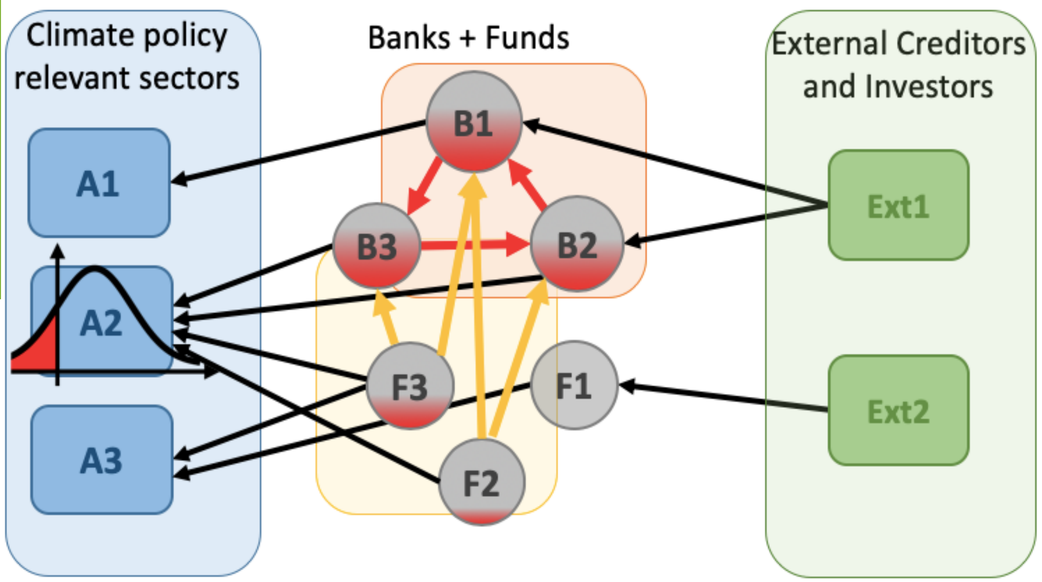
Battiston, S., Monasterolo, I. (2019). A climate risk assessment of sovereign bonds' portfolios, [SSRN #3376218]

Framework for Climate Stress-testing

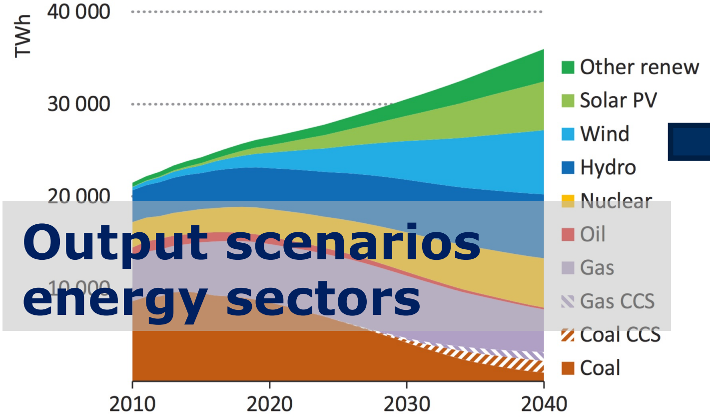
Climate policy scenarios



IPCC reports

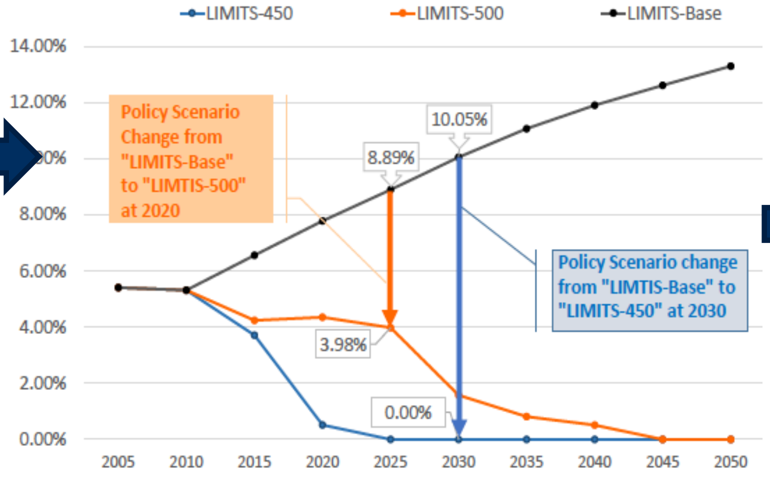


Output scenarios energy sectors

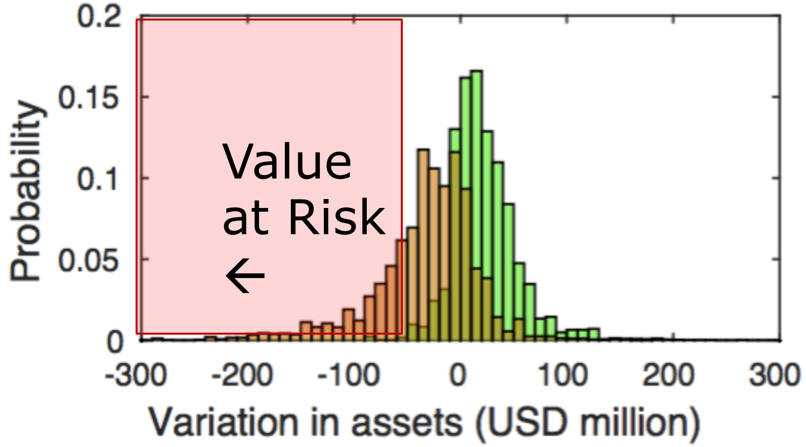


[source: LIMITS Kriegler ea. 2013]

Disorderly transition



Adjustment of gain/losses distr. → Value at Risk



Identify the climate scenarios and define the climate transition risk trajectories

Climate policy scenarios

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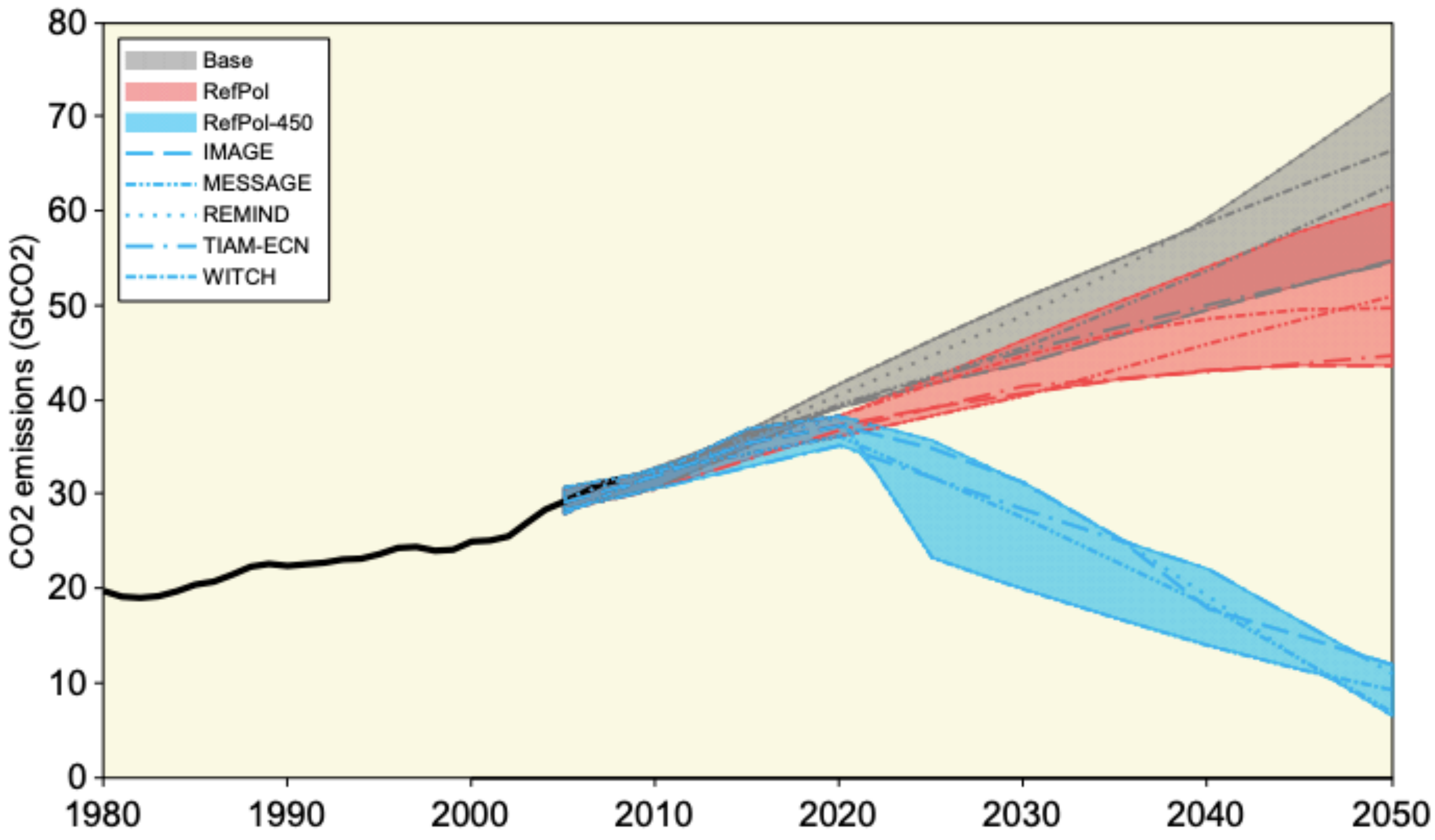

Example from LIMITS: Global CO2 emissions from fossil fuel combustion and industrial processes across the various models in the Base, RefPol, and RefPol-450 scenarios.

Several established models with different strengths/focus (e.g. land use/energy)

- e.g. AIM, REMIND, IMAGE, WITCH, GCAM. GLOBIOM, MESSAGE

Source of figure: D. McCollum, Y. Nagai, K. Riahi, G. Marangoni, K. Calvin, R. Pietzcker, J. van Vliet, B. van der Zwaan: Energy investments under climate policy: a comparison of global models (.pdf), Vol. 04/Issue 04, Climate Change Economics, World Scientific

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Climate policy scenarios correspond to energy investment mix

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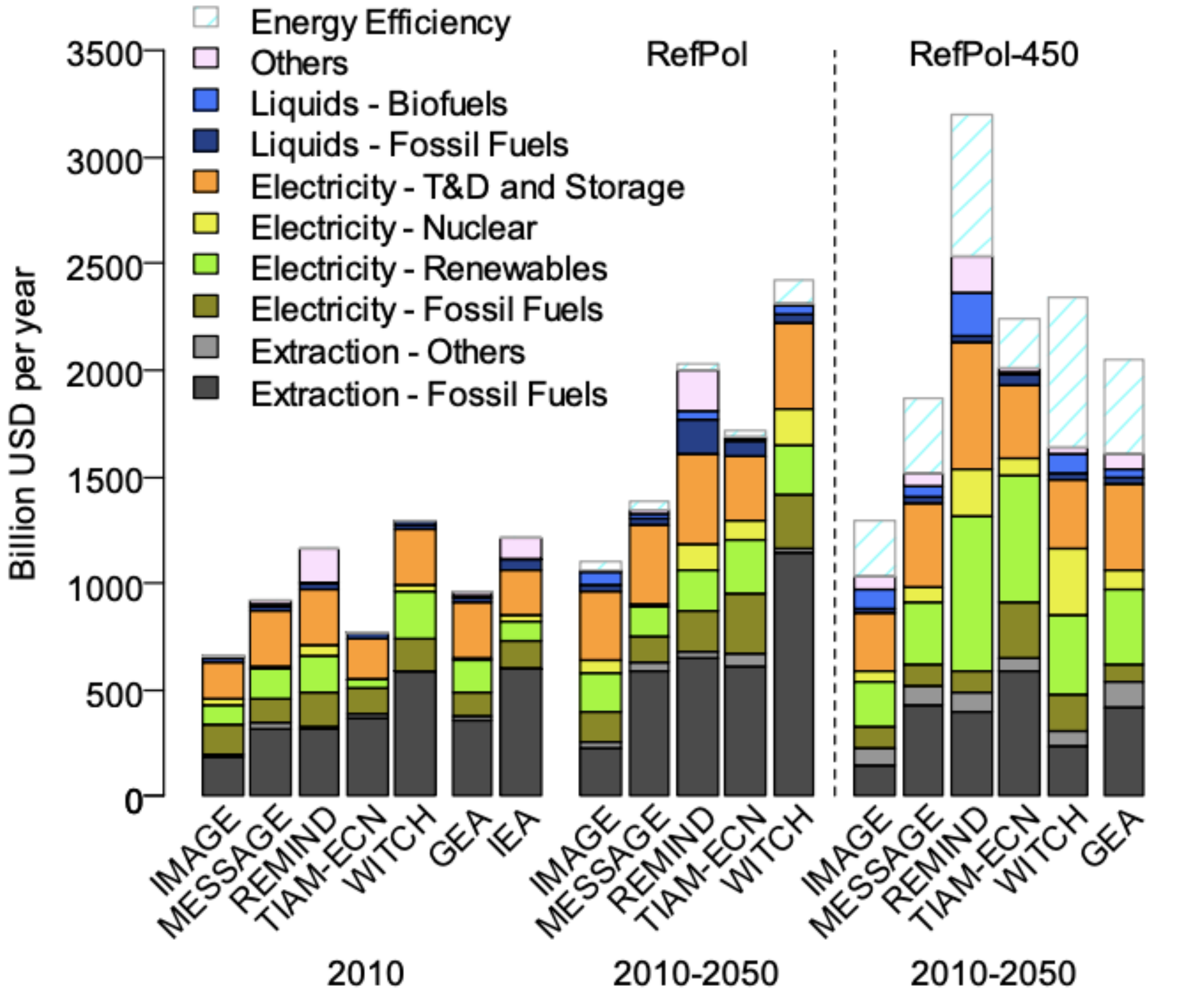

From Mc Collum ea. 2014: Global annual energy investments (both supply- and demand-side) across models/sectors in RefPol and RefPol-450 scenarios. GEA = estimates from the International Energy Agency (IEA 2012b) and Global Energy Assessment (Riahi et al.

Most **model projections foresee substantial reduction** of investments in **fossil fuel sectors** wrt to Business as usual scenario

Source of figure: D. McCollum, Y. Nagai, K. Riahi, G. Marangoni, K. Calvin, R. Pietzcker, J. van Vliet, B. van der Zwaan: Energy investments under climate policy: a comparison of global models (.pdf), Vol. 04/Issue 04, Climate Change Economics, World Scientific

How to formalize transition scenarios?

		Strength of response (based on whether climate targets are met)	
		Met	**Not met**
Transition pathway	**Disorderly**	**Disorderly** Sudden and unanticipated response is disruptive but sufficient enough to meet climate goals	**Too little, too late** We do not do enough to meet climate goals, the presence of physical risks spurs a disorderly transition
	Orderly	**Orderly** We start reducing emissions now in a measured way to meet climate goals	**Hot house world** We continue to increase emissions, doing very little, if anything, to avert the physical risks

Transition risks ↑

Physical risks →

(*)Source: Network for Greening the Financial System - NGFS 2019

Building shock distributions on forward-looking trajectories (negative/positive)

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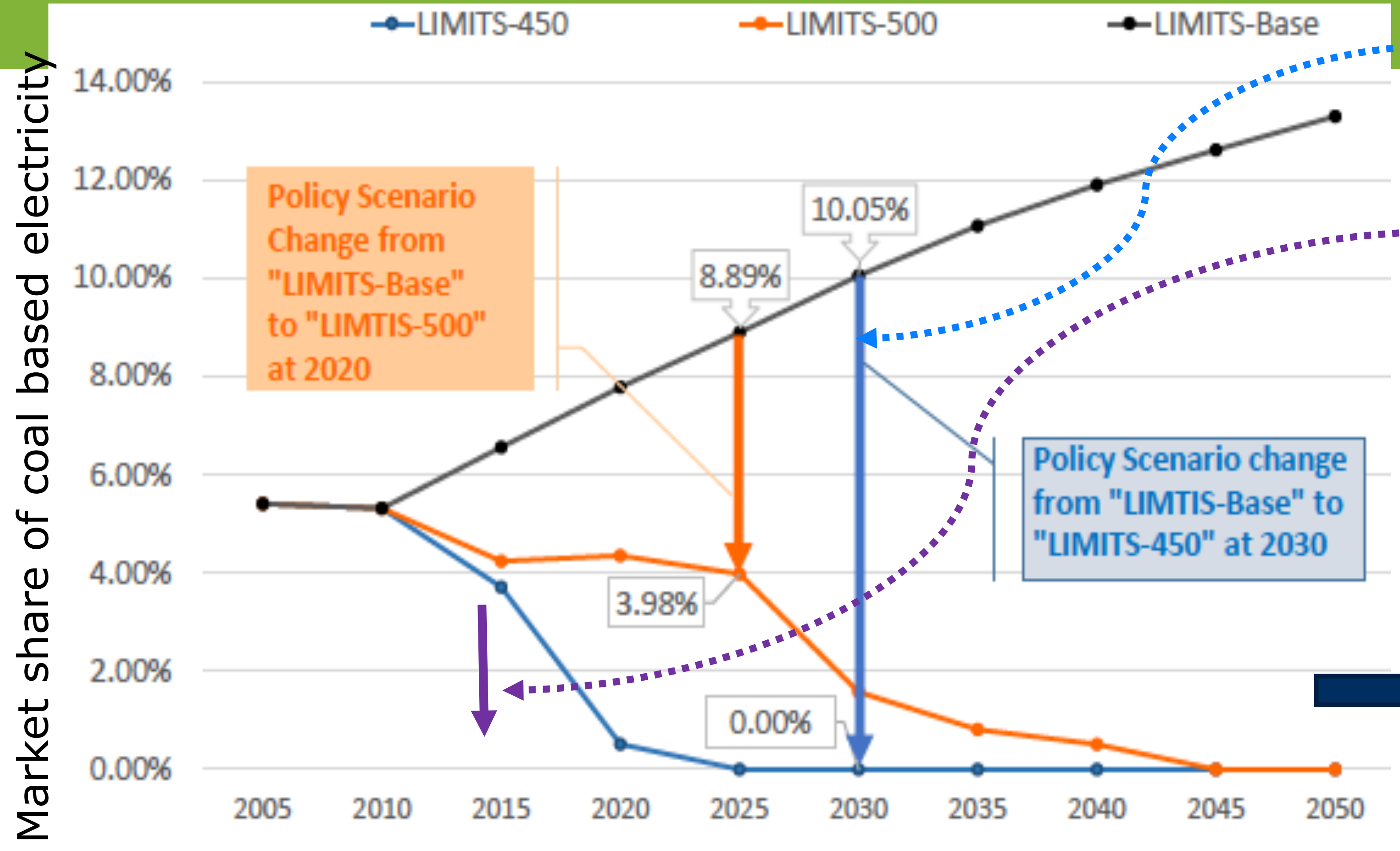
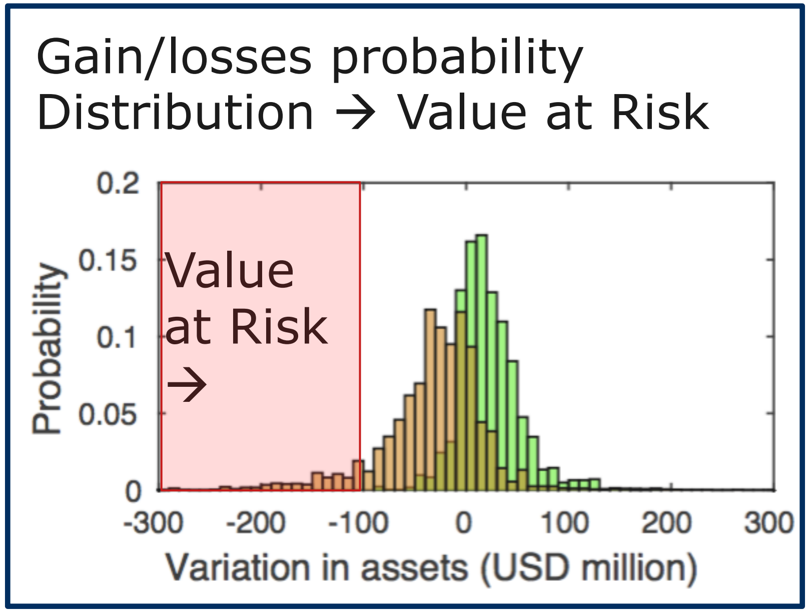


Cross-sectional: across climate trajectories (this presentation)

Longitudinal: along trajectories (every 5 y time step)



Trajectories for coal-based electricity sector: *market share under tight/mild policy scenarios (Monasterolo ea. 2018)*

Pricing forward-looking climate risks in financial contracts

Define properties of the information set of a risk averse investor

- Set of *Climate Policy Scenarios* P_l corresponding to GHG emission reduction target across regions (B = Business-as-Usual):

$$\textbf{ClimPolScen} = \{B, P_1, ..., P_l, ..., P_{n\text{Scen}}\}$$

- Set of economic output trajectories for each country j, sector k under each scenario P_l, estimated with each climate economic model M_m:

$$\textbf{EconScen} = \{Y_{1,1,1,1}, ..., Y_{j,k,P_l,M_m,...}\}$$

- Set of **forward-looking** *Climate Policy Shock Scenarios* (disorderly transition $B \to P_l$):

$$\textbf{TranScen} = \{B \to P_1, ..., B \to Pl, ..., B \to P_{n\text{Scen}}\}$$

- Set of *Climate Policy Shocks* on economic output for j, k under transition scenario $B \to P_l$, estimated with model M_m

$$\textbf{EconShock} = \{..., \frac{Y_{j,k,P_l,M_m} - Y_{j,k,B,M_m}}{Y_{j,k,B,M_m}}, ...\}$$

Define the investor's risk management strategy under climate deep uncertainty

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1. Account for investor-specific **risk aversion** level (varying subsets of investor information set InfoSetClimRisk)
2. Account for **counterparty risk** adjusted for **climate policy shock** scenarios (e.g. probability of default PD, spread)
3. Account for metrics relevant for financial regulation e.g. *risk measure* such as **Value-at-Risk**

Climate VaR Mng Strategy

- Risk averse investor aims to minimize her Climate Value-at-Risk (*Climate VaR*) under investor information set *InfoSetClimRisk* (i.e. policy shocks, econ scenarios, climate models)
- **Climate VaR Management Strategy** aims to minimize the worst-case losses of the portfolio across the forward-looking Climate Policy Shock Scenarios:

$$\textbf{ClimVaRStr} = \min_{\text{Portfolios}} \{ \max_{\text{Shocks}} \{ \text{VaR}(\text{Ptfolio}, \text{Adj.PD} \,|\, \text{Policy Shock}) \} \}$$

Defaultable sovereign bonds

Portfolio of zero-coupon defaultable sovereign bonds

- Risky (defaultable) bond of country j issued at t_0 with maturity T
- Bond value at T:

$$v_j(T) = \begin{cases} R = (1 - LGD) & \text{if j defaults (with prob. } q_j) \\ 1 & \text{else (with prob. } 1 - q_j) \end{cases}$$

  where $R < 1$ bond recovery rate, rLGD Loss-given-default (in %)
- Expected value of bond: $\mathbb{E}[v_j] = (1 - q_j) + q_j\, R_j = (1 - q_j(1 - R_j))$
- Discounted expected value of the bond, with: y_j bond j yield (under risk neutral measure) and y_f risk free rate

$$e^{-y_f\, T}\, \mathbb{E}[v_j] = e^{-y_f\, T}\, (1 - q_j(1 - R_j)) = e^{-y_j\, T}$$

- Bond spread defined as: $s_j = y_j - y_f$, with $e^{-s_j\, T} = 1 - q_j(1 - R_j)$
- Useful fact about spread, with rLGD = relative LGD:
  $s_j \approx \frac{1}{T}\, q_j(1 - R_j) = \frac{1}{T}\, q_j\, \text{rLGD}_j$ (for small s_j)

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Sovereign default conditions

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Sovereign fiscal revenues: shocks and default condition

- Sovereign i balance sheet: $A_j(t_0)$, $A_j(T)$ **net fiscal asset** at t_0 and maturity; $L_j(T)$ liability.
  - Default condition (e.g. Gray-Merton-Bodie 2007)

$$A_j(T) = A_j(t_0)(1 + \eta_j(T)) < L_j(T)$$

  - $\eta_j(T) \in \mathbb{R}$: **idiosyncratic shock** (e.g. aggregate productivity), $\phi(\eta_1, ..., \eta_j, \eta_n)$ **joint probability distribution** (possibly correlated)
- We add climate policy shock ξ_j on j's fiscal assets ("jump" up/down), assuming idiosyncratic shock η_j and policy shock ξ_j are **independent**
- New sovereign default condition:

$$A_j(T) = A_j(t_0)(1 + \eta_j(T) + \xi_j(P)) < L_j(T)$$

$$\iff \eta_j(T) \leq \theta_j(P) = L_j(T)/A_j(t_0) - 1 - \xi_j(T, P)$$

  - $\theta_j(P)$ default threshold under scenario P
  - $\xi_j(P)$ **climate policy shock** $B \to P$, positive/negative: $\xi_j(P) > -1$, possibly correlated across j

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Change in sovereign default probability due to Climate policy shock

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Proposition. Δ default prob. with policy shock B→P

- Assuming
  - idiosynchratic shocks are **independent** from policy shock
  - policy shock on fiscal asset is proportional to shock on GVA via elasticity $\xi_j = \chi_j \, u_j^{\mathrm{GVA}}(P)$
- The **change** $\Delta q_j(P)$ in default probability of sovereign j under Climate Policy Shock Scenario B→P
  - increases with GVA shock magnitude $|u_j^{\mathrm{GVA}}(P)|$ if $u_j^{\mathrm{GVA}}(P) < 0$, and decreases viceversa (under mild condition on ϕ)
  - is proportional to the GVA shocks on climate relevant sectors (in the limit of small Climate Policy Shock):

$$\Delta q_j(P) \approx -\chi_j \left(u_{j,\mathrm{PrFos}}^{\mathrm{GVA}} \, w_{j,\mathrm{PrFos}}^{\mathrm{GVA}} + u_{j,\mathrm{ElFos}}^{\mathrm{GVA}} \, w_{j,\mathrm{ElFos}}^{\mathrm{GVA}} + u_{j,\mathrm{ElRen}}^{\mathrm{GVA}} \, w_{j,\mathrm{ElRen}}^{\mathrm{GVA}} \right).$$

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Sovereign bond value adjustment conditioned to climate policy scenarios

Definition. Climate policy shock bond value adjustment

- **Climate policy shock bond value adjustment** Δv_j^* is defined as the change in the discounted expected value of the bond, v_j^*, conditional to a Climate Policy Shock Scenario $B \to P$

$$\Delta v_j^* = v_j^*(q_j(P) - v_j^*(q_j(B)) = -e^{-y_f T} \Delta q_j(P) \text{LGD}_j$$

Proposition. Bond value adjustment and climate policy shocks

- Conditional to policy shock scenario $B \to P$, and assuming everything else the same regarding the issuer's balance sheet, then the bond value adjustment $\Delta v_j^*(P)$:
  - is negative and increases with magnitude of policy shock $|\xi_j(P)|$ if $\xi_j(P) < 0$
  - is positive and increases with magnitude of policy shock if $\xi_j(P) > 0$, with the constraint $v_j^* \leq 1$

Climate Sovereign Spread

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Definition. Climate spread on sovereign bonds

- **Climate spread** Δs_j is defined as the change in the spread s_j, conditional to Climate Policy Shock Scenario $B \to P$

$$\Delta s_j = s_j(q_j(P) - s_j(q_j(B))$$

Proposition. Climate spread and policy shock

- Conditional to policy shock scenario $B \to P$, the climate spread $s_j(P)$:
  - increases with magnitude of policy shock $|\xi_j(P)|$ if $\xi_j(P) < 0$
  - decreases with magnitude of policy shock if $\xi_j(P) > 0$
- For small GVA shocks $u_j^{\text{GVA}}(P)$ it holds:

$$\Delta s_j \approx -\frac{1}{T} \chi_j \times$$
$$\times \left(u_{j,\text{PrFos}}^{\text{GVA}} w_{j,\text{PrFos}}^{\text{GVA}} + u_{j,\text{ElFos}}^{\text{GVA}} w_{j,\text{ElFos}}^{\text{GVA}} + u_{j,\text{ElRen}}^{\text{GVA}} w_{j,\text{ElRen}}^{\text{GVA}} \right)$$

Result: Climate policy shock on OECD sovereign bonds

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- Forward looking shock on yield of 10-years, zero coupon sovereign bonds
- Policy shock occurs at year **2030** (mild/tight 2C-aligned climate policy scenarios based on carbon pricing of LIMITS IAMs)
- Shocks on yield derive from net shock on GVA of CPRS

Geo region	Models' region	WITCH: bond shock (%)	WITCH: yield shock (%)	GCAM: bond shock (%)	GCAM: yield shock (%)
AUSTRIA	EUROPE	1,3	-0,16	0,13	-0,02
AUSTRALIA	REST_WORLD	**-17,36**	**2,45**	n.a.	n.a.
BELGIUM	EUROPE	0,84	-0,1	0,03	0
CANADA	PAC_OECD	-5,21	0,67	-18,29	2,61
POLAND	EUROPE	**-12,85**	**1,75**	-2,49	0,32

- In a disorderly transition to a tight climate policy scenario, the financial solvability could be severely affected via **shocks on sovereign bonds value and spread** (E.g. -12,85%/ 1,75 for Poland).

2,45=245 basis points

Source: Battiston, S. and Monasterolo, I. (2019). A climate risk assessment of sovereign bonds' portfolio. Working paper available at SSRN: https://ssrn.com/abstract=3376218

Impact of climate policy shock on OeNB' portfolio

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Model	Policy Scenario	Country	Region	Portfolio Shock
WITCH	LIMITS-RefPol-450	Country 1	REST_WORLD	-0.367%
WITCH	LIMITS-RefPol-450	Country 2	REST_WORLD	-0.350%
WITCH	LIMITS-RefPol-450	Country 3	PAC_OECD	-0.329%
WITCH	LIMITS-RefPol-450	Country 4	NORTH_AM	-0.110%
WITCH	LIMITS-RefPol-450	Country 5	EUROPE	-0.078%
WITCH	LIMITS-RefPol-450	Aggregate	Aggregate	-1.234%
WITCH	LIMITS-RefPol-450	Country 6	EUROPE	0.005%
WITCH	LIMITS-RefPol-450	Country 7	EUROPE	0.016%
WITCH	LIMITS-RefPol-450	Country 8	EUROPE	0.018%
WITCH	LIMITS-RefPol-450	Country 9	EUROPE	0.021%
WITCH	LIMITS-RefPol-450	Country 10	EUROPE	0.083%
WITCH	LIMITS-RefPol-450	Aggregate	Aggregate	0.143%

EUROPE includes different countries (disclosure issues).
Battiston & Monasterolo (2019)

- -0,367: negative shock (%) on the value of the OECD country's sovereign bond **weighted** for the role of the country issuing it on OeNB's portfolio.
- **Total negative shocks** = 1,234% of OeNB portfolio -> financial distress does not apply to a central bank (in monetary sovereignty), but what about a commercial bank experiencing such losses?
- Shocks can be also positive where

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A climate risk assessment of the sovereign bond portfolio of European insurers

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- 1st collaboration btw. climate economists (IIASA), climate finance risk experts (WU, UZH), EU financial regulator (European Insurance and Occupational Pension Fund Authority (EIOPA):
  - Analyse the shock on the market share and profitability of carbon-intensive and low-carbon activities under climate transition risk scenarios
  - Define the climate risk management strategy under uncertainty for a risk averse insurer that aims to minimise her largest losses
  - Price the forward-looking climate transition scenarios in the probability of default of the individual sovereign bonds and in the bonds' climate spread
  - Estimate largest gains/losses on insurance portfolios conditioned to climate scenarios.

Battiston, S., Jakubik, P., Monasterolo, I., Riahi, K. and van Ruijven, B. 2019. Climate risk assessment of the sovereign bond portfolio of European insurers. In: EIOPA Financial Stability Report, pp. 69-89

Methodology

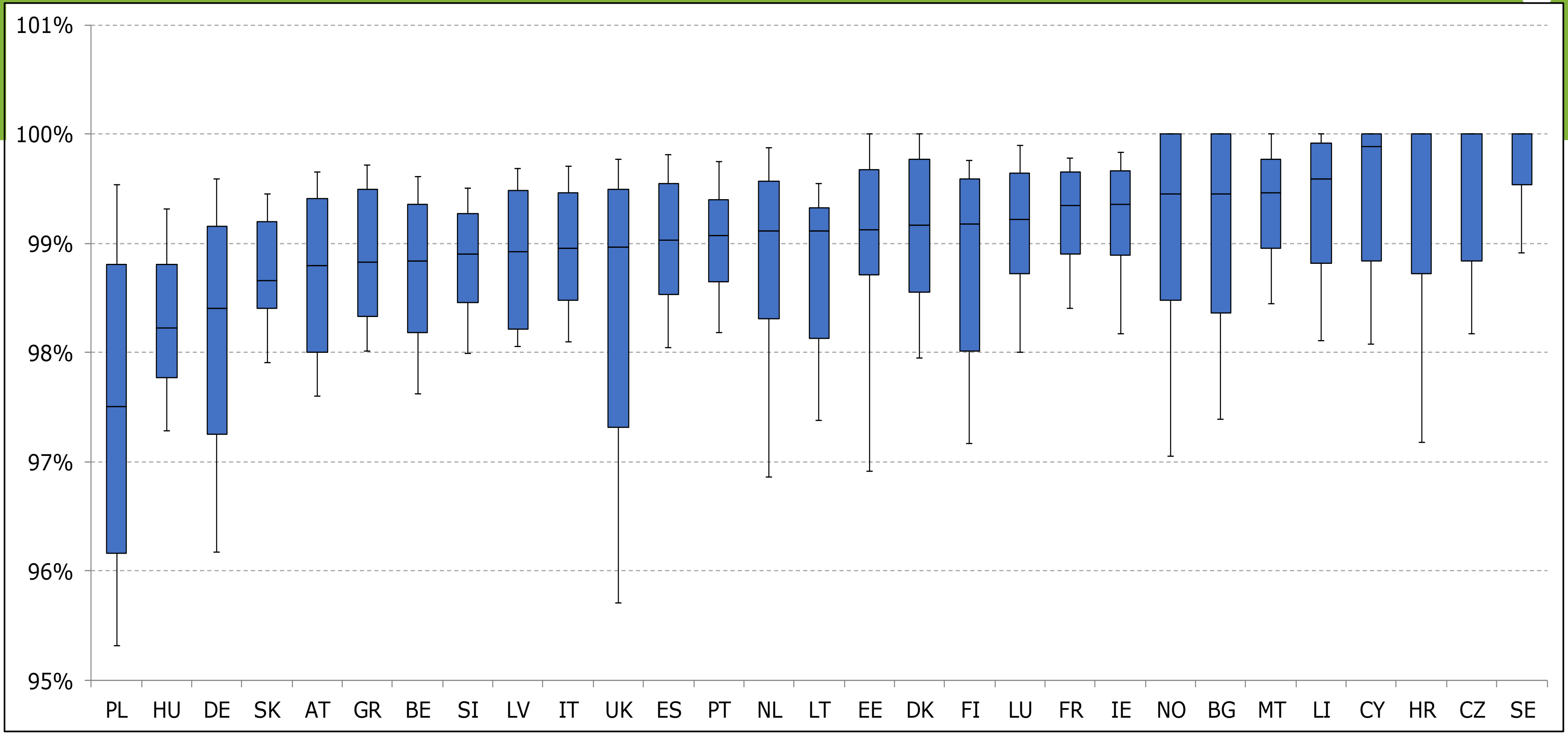
- For each mild/tight scenario (LGD and *χj)* and IAM, we compute the shock on the value of each bond

- We compute the *portfolio impact* of climate policy shock on the value of EU insurance portfolio as ratio of the value of the portfolio after the shock over the initial value before the shock.

- **3 drivers of magnitude of the portfolio impact:**

  - For each sov. bond, negative shocks (e.g. on primary energy fossil) can be compensated by positive shocks (e.g. electricity based on renewable sources)
  - Negative aggregate shocks from a less climate-aligned sovereign can be compensated by positive shocks from more climate-aligned sovereign
  - This application does not consider macroeconomic reverberations of a shock

Results



- *Distribution of impact on sovereign holdings of European insurers conditioned across climate policy shock scenarios and **adverse** scenario on market conditions (100% expresses 0% impact, 97% corresponds to drop of 3%)*
- *Potential impacts on insurers' portfolios is moderate but non-negligible*

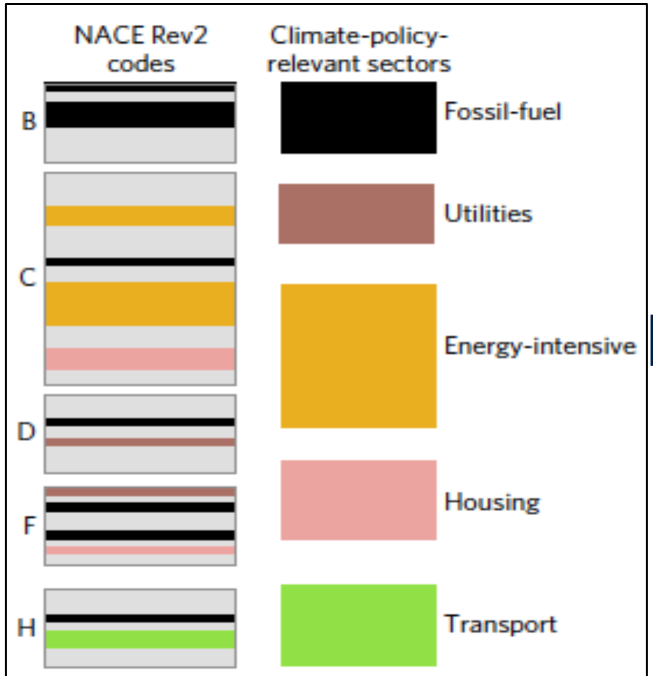
You think shocks are small?

- Consider that:
  - For leveraged institutions (leverage = 30), shock of 1% = 1/3 losses
  - Countries are not aligning to pledges thus tighter policy scenarios may be considered
  - IAMs' policy scenarios before the Paris Agreement (now SSPs)
  - Even few decimal points of GDP growth change could impact yields due to expectations (IT)
- ***Thus, our shocks results are conservative***

Assess exposure of investors the Climate Policy Relevant Sectors

Classify investors' exposure to Climate Policy Relevant Sectors (CPRS)

- NACE no proxy of risk: no technology risk, car companies classified as **financial** (FIAT)
- We developed **5 Climate Policy Relevant Sectors (CPRS)** classification:
  - Direct/indirect/induced contribution to emissions (scope)
  - Relevance for climate policy (carbon leakage)
  - Firm business model and technology mix (CAPEX), role in the energy value chain

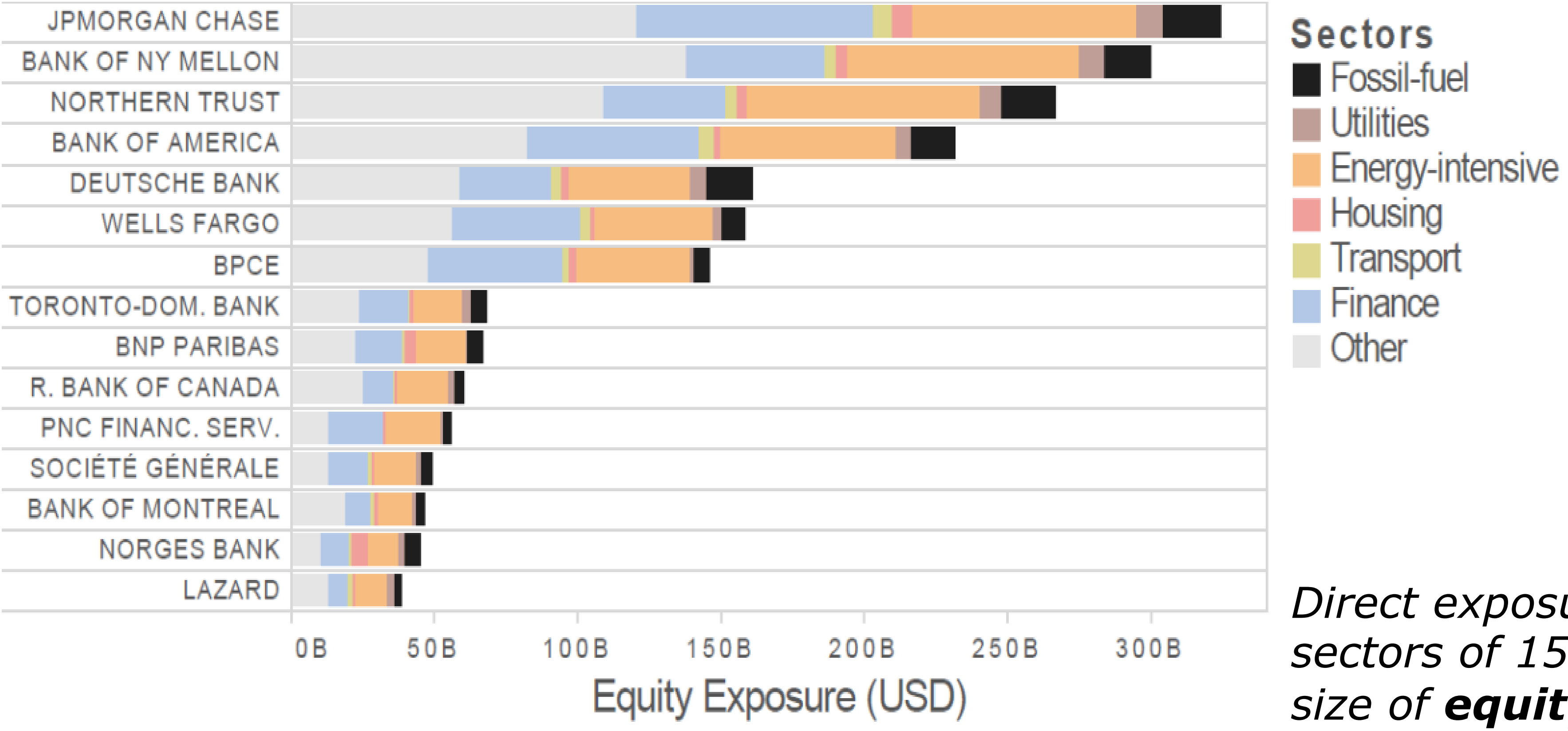


CPRS 1	CPRS Rev 2
1-fossil	1-fossil|coal
	1-fossil|oil
	1-fossil|gas
2-utility	2-utility|electricity|coal
	2-utility|electricity|gas
	2-utility|electricity|solar
	2-utility|electricity|wind
	2-utility|electricity|biomass
	2-utility|electricity|marine
	2-utility|electricity|nuclear
	2-utility|other
	2-utility|water&sewerage
	2-utility|waste

Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin (2017). A Climate stress-test of the EU financial system. *Nature Climate Change*, 7, 283–288.

Banks' direct exposure to Climate Policy Relevant Sectors (CPRS)

- CPRS represent important value of world top banks' equity portfolios



*Direct exposures to climate-relevant sectors of 15 top banks worldwide by size of **equity** portfolio*

Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin (2017). A Climate stress-test of the EU financial system. *Nature Climate Change*, 7, 283–288.

CPRS used by ECB in its climate risk and financial stability considerations

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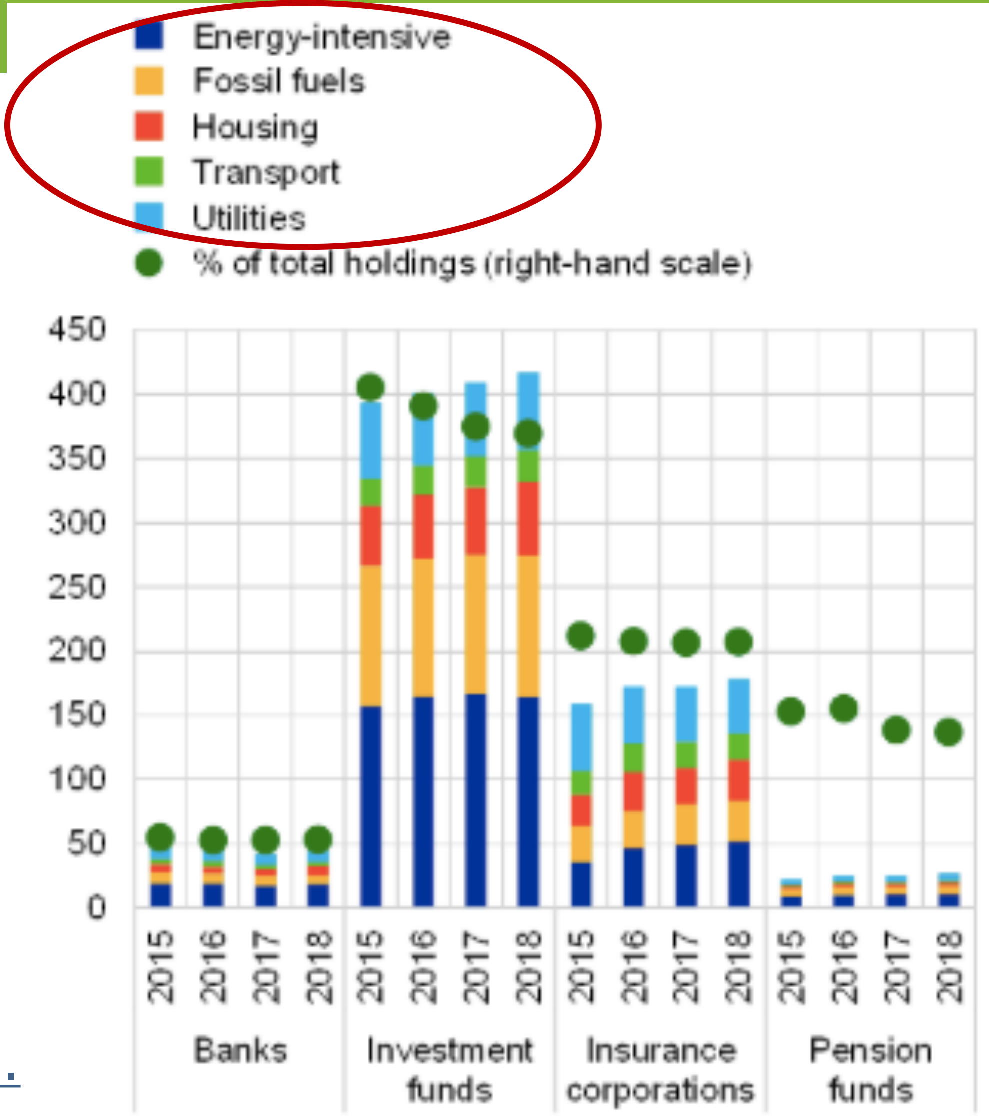
- **European Central Bank** (2019)'s **"Climate change and financial stability"** (in Financial Stability Review (May 2019):
  - Euro area financial institutions' exposures to transition risk based on CPRS classification by Battiston et al. 2017



https://www.ecb.europa.eu/pub/financial-stability/fsr/special/html/ecb.fsrart201905_1~47cf778cc1.en.html

Climate Stress-test

Assess direct and indirect investors' exposures to CPRS

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Direct exposures: through assets of the market player

$$A_i = \left(\sum_{S \in S} \sum_{j \in S} \alpha_{ij}^{Equity} + \alpha_{ij}^{Bonds} + \alpha_{ij}^{Loans} \right) + R_i$$

S - Set of climate-relevant sectors

A_i - Total assets of the financial actor *i*

α_{ij} - Monetary value of exposure of *i* to *j*

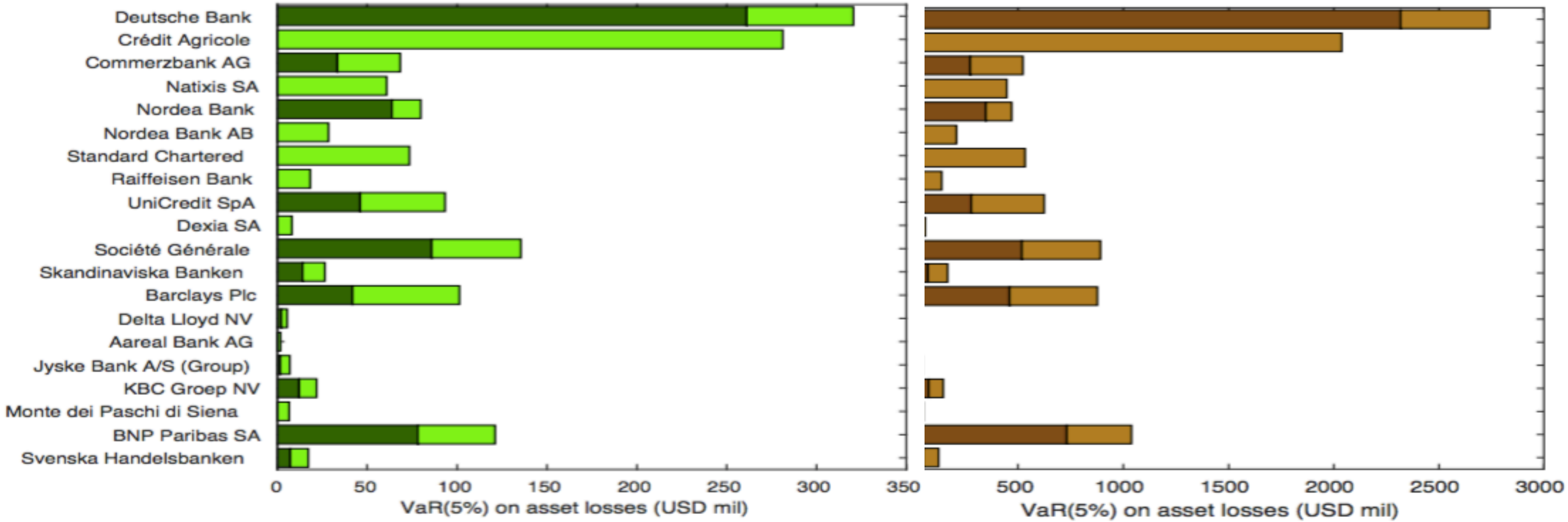
$A_{FS} = \sum_{i \in F} \alpha_{iS}$ - Exposure of institution *F* to a given climate sector

Indirect exposures: through interlinckages of the market player with its couterparties

$$A_i = \left(\sum_{j \in F} \alpha_{ij}^{Equity}(A_j) + \alpha_{ij}^{Bonds}(A_j) + \alpha_{ij}^{Loans}(A_j) \right) + \left(\sum_{k \in A/F} \alpha_{ik}^{Equity} + \alpha_{ik}^{Bonds} + \alpha_{ik}^{Loans} \right) + R_i$$

Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin (2017). A Climate stress-test of the EU financial system. *Nature Climate Change*, 7, 283–288.

Climate VaR conditioned to climate transition scenarios (equity)



***Value at Risk** (5% significance) on equity holdings of 20 most affected EU banks under scenario of green (brown) investment strategy. Dark/light colors: first/second round losses.*

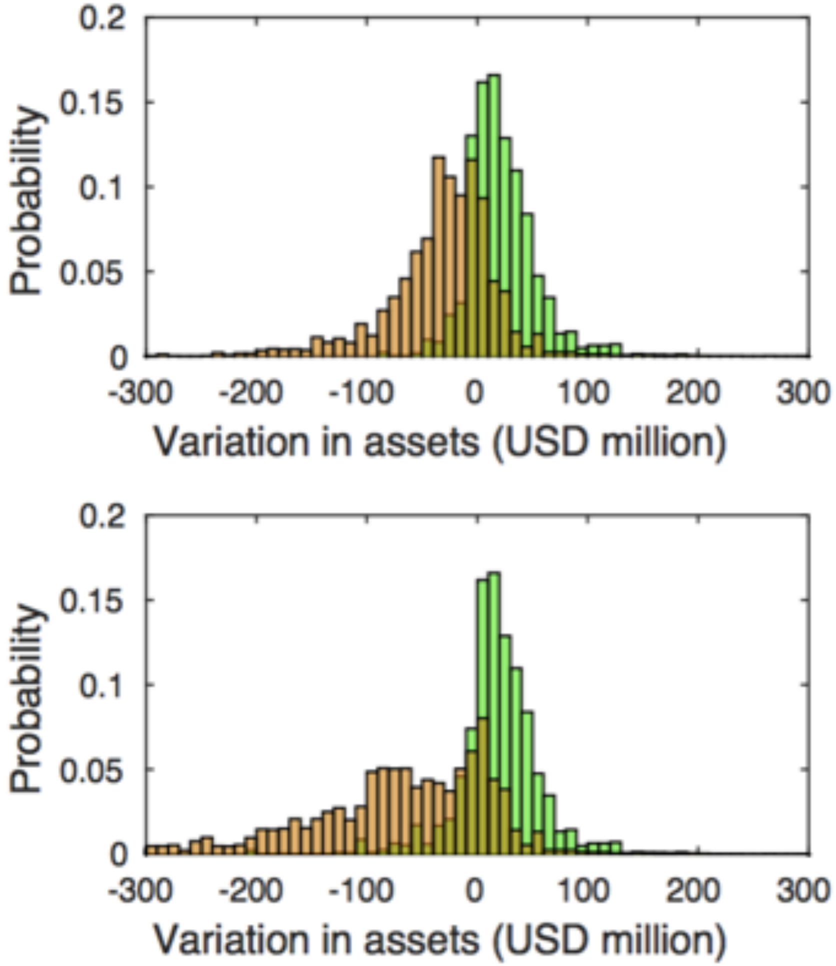
Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin (2017). A Climate stress-test of the EU financial system. *Nature Climate Change*, 7, 283–288.

Climate Stress-test of top 20 Euro Area banks under green/brown investment strategy

- **1st round (top figure):** a bank with brown investment strategy incurs more losses than a bank with green strategy

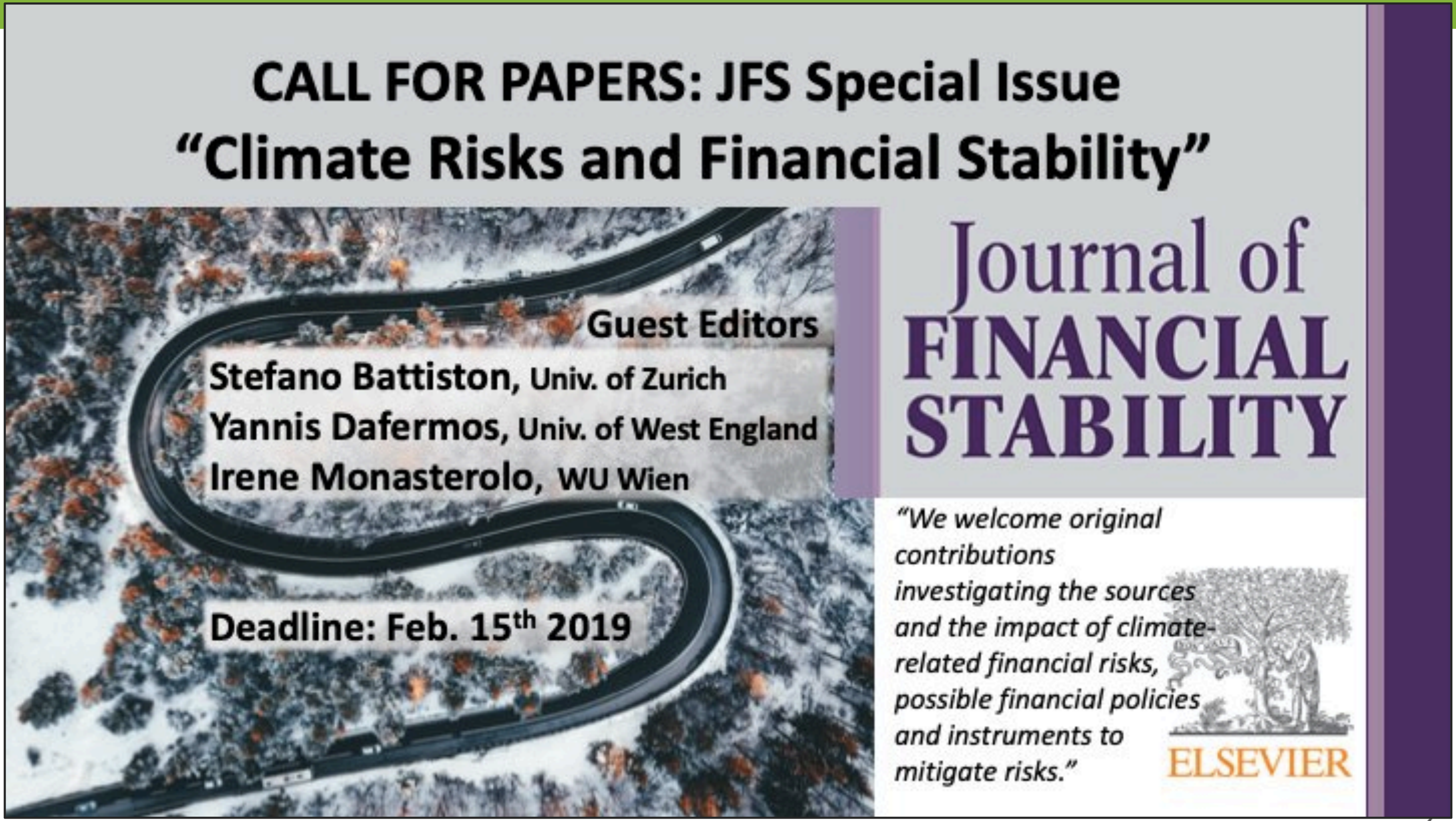
- Losses are small in comparison to bank's total assets ($ 604 bn), *but equity holdings represent only 3.8% of EU banks total assets*
- *-> our results are conservative*

- **Adding 2nd round** effects (bottom figure) further polarizes distribution of losses for the brown bank



Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin (2017). A Climate stress-test of the EU financial system. *Nature Climate Change*, 7, 283–288.

Climate Risks and Financial Stability: special issue on JFS forthcoming



Our stream of research and collaborations with financial institutions

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1. Battiston S., Mandel A, Monasterolo I., Schuetze F. & G. Visentin **(2017). A Climate stress-test of the EU financial system**. *Nature Climate Change*, 7, 283–288.
2. Monasterolo, I., ea. (2018). A carbon risk assessment of China's overseas energy portfolios. *China & World Economy 26*(6), 116–142. **G20 Task Force "An International Financial Architecture for Stability and Development".**
3. Battiston S., Mandel A., Monasterolo I. (2019). **CLIMAFIN handbook**: pricing forward-looking climate risks under uncertainty. Available at SSRN.
4. Roncoroni A. ea. (2019). Climate risk and financial stability in the network of banks and investment funds. **Banco de Mexico.**
5. Battiston, S. and Monasterolo, I. (2019). A climate risk assessment of sovereign bonds' portfolio. Working paper forth. as **OeNB** financial stability report.
6. Battiston, S., ea. 2019. Climate risk assessment of the sovereign bond portfolio of European insurers. **EIOPA Financial Stability Report**, pp. 69-89
7. Monasterolo, I., de Angelis, L. (2020). **Blind to carbon risk?** An analysis of stock market's reaction to the Paris Agreement. *Ecological Economics*, 170, 1-10