Climate risk from the lenses of complexity economics and finance

Prof. Irene Monasterolo

Utrecht University School of Economics, CEPR and SUERF

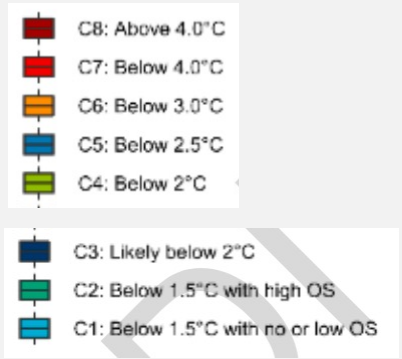
Outline

- The climate-economy-finance nexus
  - Climate-related financial risks (physical, transition)
  - Climate risk and financial stability
- Why we need a complexity approach to climate economics and climate finance
- Assessing climate risk: examples of applications
  - The EIRIN Stock-Flow Consistent – Agent Based model
  - Climate stress-test of the financial system

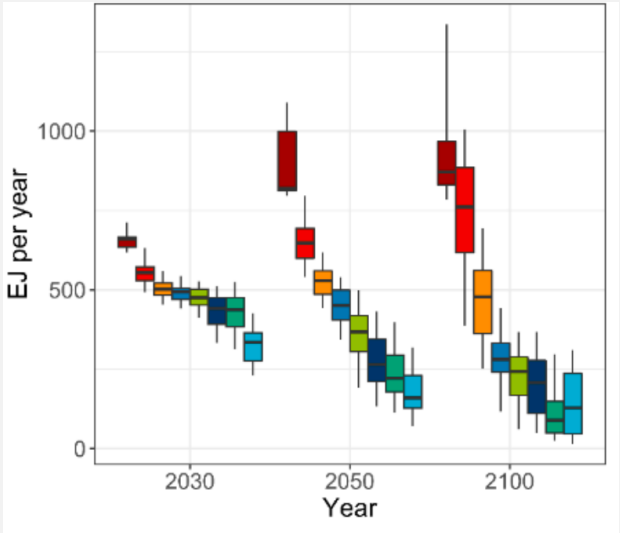
Mitigating climate change: the low carbon-transition

- **Mitigation** requires to halt growth of cumulative (net) anthropogenic Greenhouse gases (GHG) emissions
- CO2: mostly energy value chain; methane: agriculture and natural gas value chain
- Decarbonization requires large adjustments across sectors: primary energy, electricity, transport, buildings and agriculture. How much?
- **IPCC AR6 WGIII Ch3**: Current Policies scenarios vs e.g. NetZero scenarios.

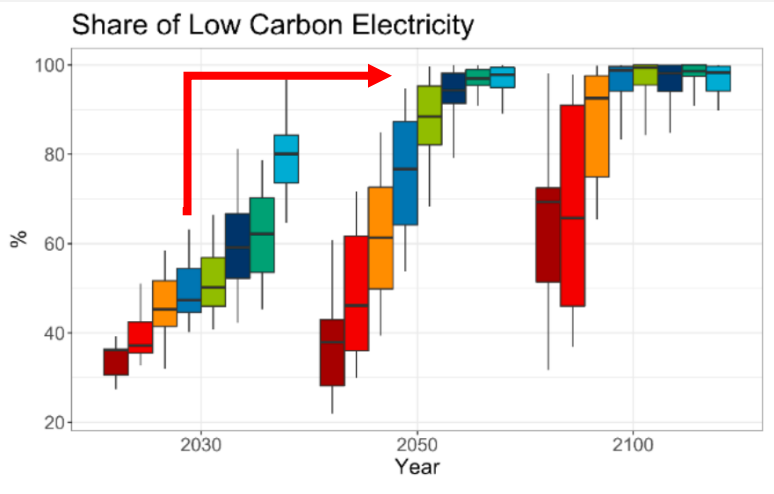
Legend: categories of scenarios



Fossil: example C5 → C1 implies decrease in output by ~ 60% by 2050



Electricity: growth + change in composition. Example C5 → C1 implies change in % low-carbon electricity ~30% → 95%.



The Paris Agreement

- On 12 December 2015, UN Parties reached a landmark agreement to combat climate change and to accelerate actions and investments for a sustainable low-carbon future
- First time all nations agreed to undertake efforts to mitigate climate change and adapt to its effect.
- Max global temperature increase to 2ºC above pre-industrial levels (desirable 1.5ºC)

Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

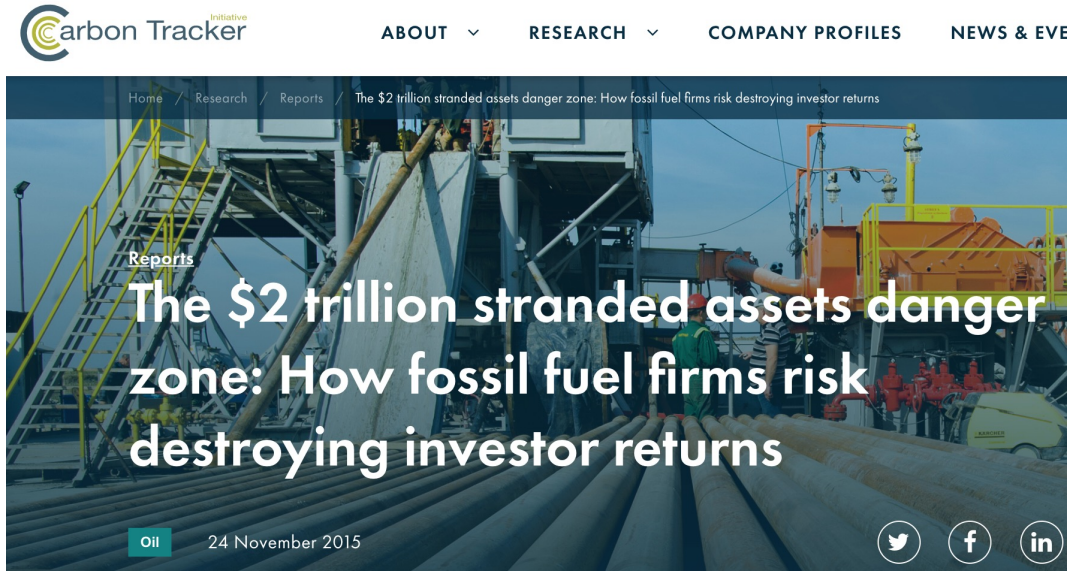
(a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

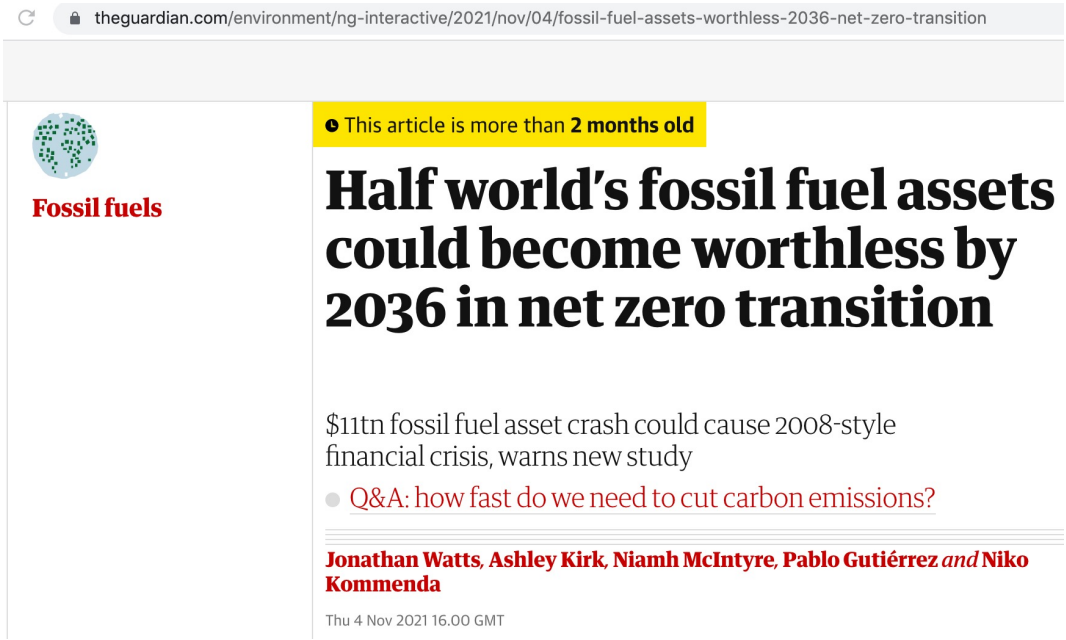
(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

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

Carbon stranded assets



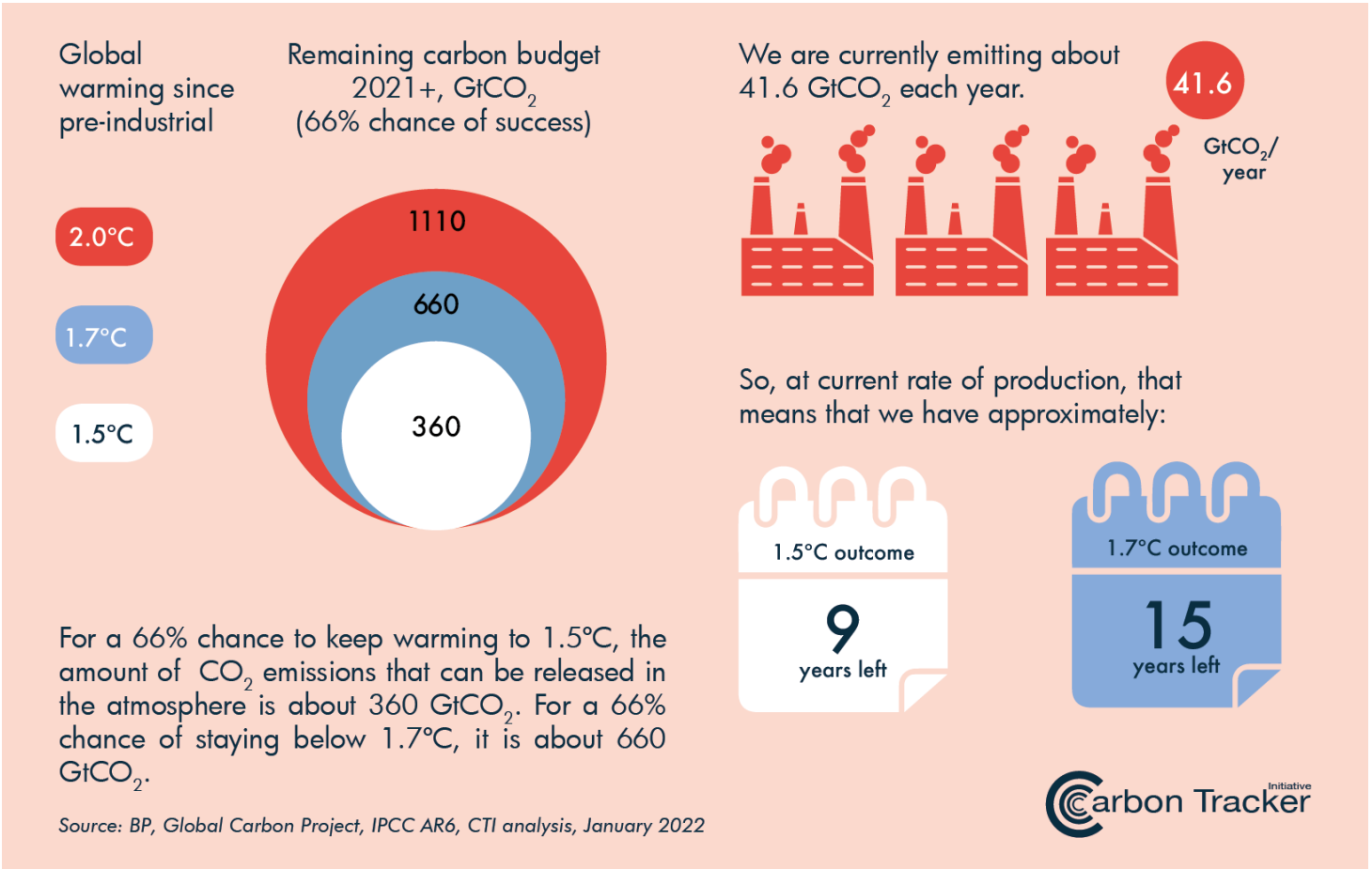


- Carbon stranded assets: assets whose value could decrease as a result of a (disorderly) transition to a low-carbon economy, i.e. a sudden phase out of fossil fuels (MacGlade and Ekins 2015).
- Rationale: to achieve the Paris Agreement fossil fuels must stay in the ground (to limit new emissions)
- **This structural adjustment could drive fossil fuels firms out of business. The same could occur for several high-carbon and energy intensive firms** that will face higher costs of production.

Carbon stranded assets and the carbon budget

Limiting global temperature increase to below 2C or 1.5C corresponds to a maximum amount of CO2 emissions that we can still add to the atmosphere: **carbon budget**

The later we start the low-carbon transition, the lower the carbon budget that we have, and the larger the structural change needed to meet the temperature targets.
This means **larger adjustment costs** for firms (including bankruptcies) with implications for their investors.

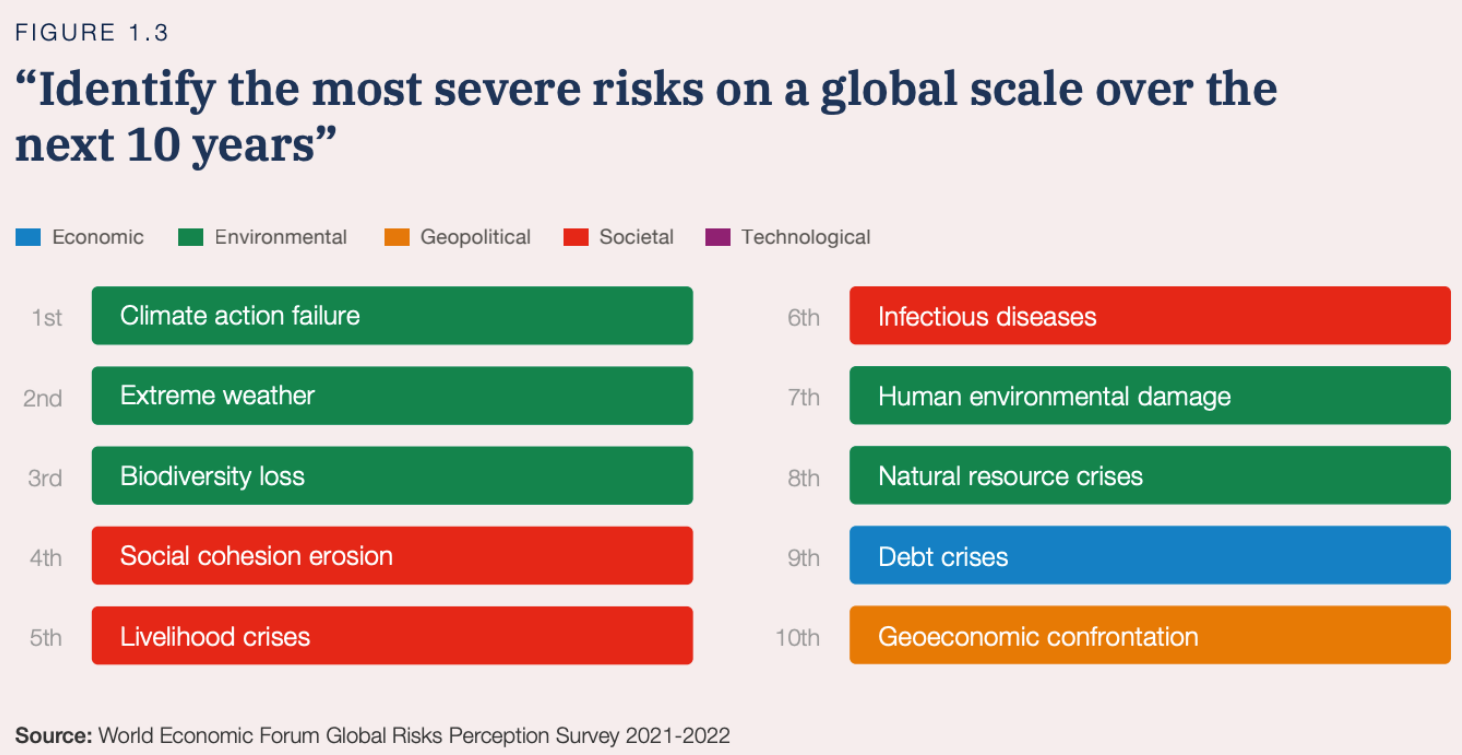


The macro-financial criticality of climate risks

Climate change as a new global risk

The World Economic Forum Global Risks Report climate change as main global risk:

- **“Climate action failure is the number one long-term threat to the world** and the risk with potentially the most severe impacts over the next decade."
- “Governments, businesses and societies are facing increasing pressure to thwart the worst consequences. Yet a **disorderly climate transition characterized by divergent trajectories worldwide and across sectors will further drive apart countries** and bifurcate societies, creating barriers to cooperation.”



Climate change as a new type of financial risk

- 2015: M. Carney, warns investors of large climate-related losses due to the “Tragedy of the Horizons”:
  - Short term investment horizon in finance (6 months for AM, 3y for monetary policy) vs
  - Mid-long term dimension of climate change

- **Investors are largely exposed to climate risks**: losses for their portfolios (equity, bonds, loans) (over 40% of equity portfolio of pension funds and insurance, Battiston et al. 2017)

- **Financial stability risk:** mispricing and repricing of assets leading to large asset price volatility
  - Example: house mortgages in the financial crisis

- 2017: Network for Greening the Financial System (NGFS)

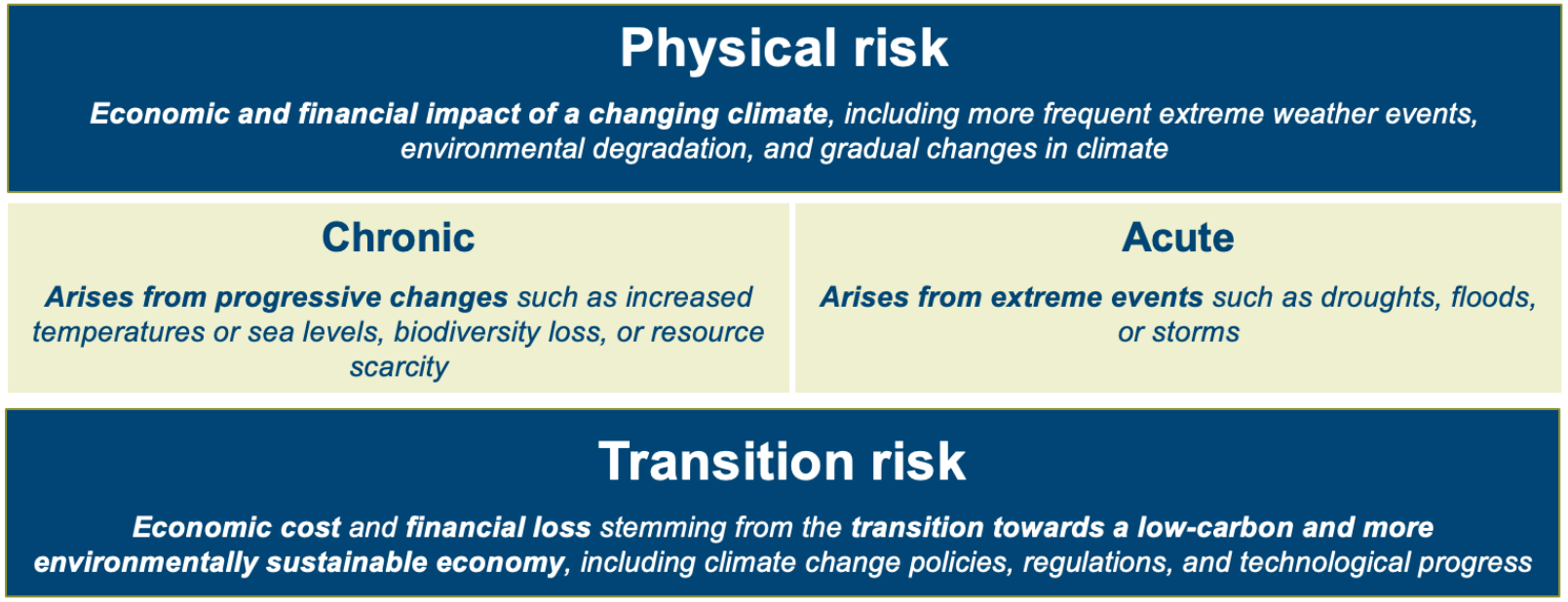
Carney warns of risks from climate change 'tragedy of the horizon'

Bank of England governor tells Lloyd's insurers that 'challenges currently posed by climate change pale in significance compared with what might come'

Mark Carney said: 'Once climate change becomes a defining issue for financial stability, it may already be too late.' He proposes that firms 'would disclose not only what they are emitting today, but how they plan their transition to the net-zero world of the future'. Photograph: Jonathan Brady/PA

Why? Climate-related financial risks

- Unmitigated climate change (e.g. failing to decarbonize the economy to achieve the Paris Agreement targets) and poor adaptation (fail to build resilience to climate change short and long-term impacts) will bring new risks for the economy and finance
- Climate physical and transition risks



Source: ECB Guide on climate-related and environmental risks (2020)

Climate physical risk transmission channels

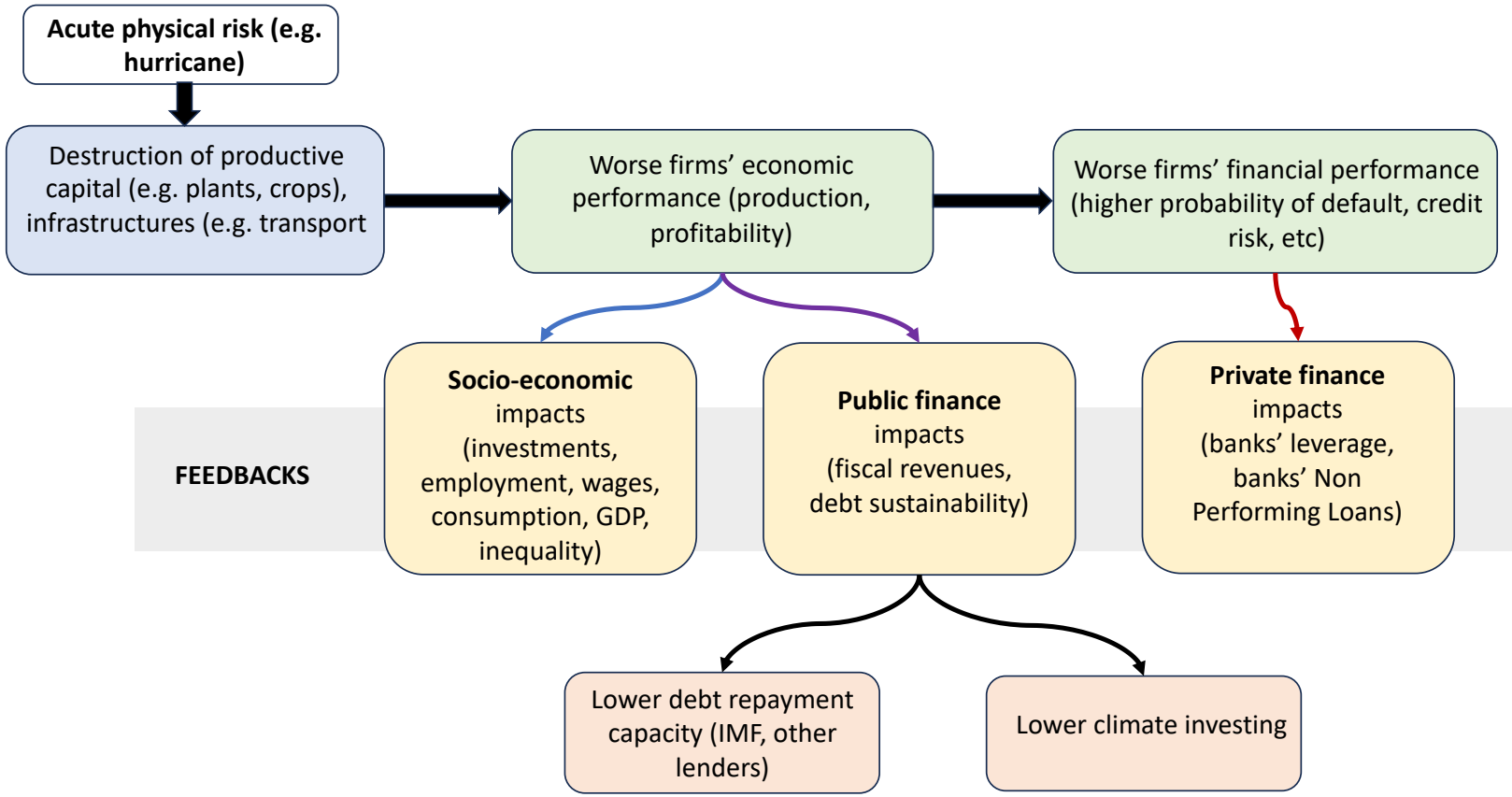


Fig. Risk transmission channels from physical risk (example of hurricanes) to the economy, public and private finance, country's debt repayment and climate investing capacity. Blue boxes: shock entry point in the economy. Green boxes: direct impacts. Yellow boxes: indirect impacts. Orange boxes: cascading impacts on creditors.

Climate transition risk transmission channels

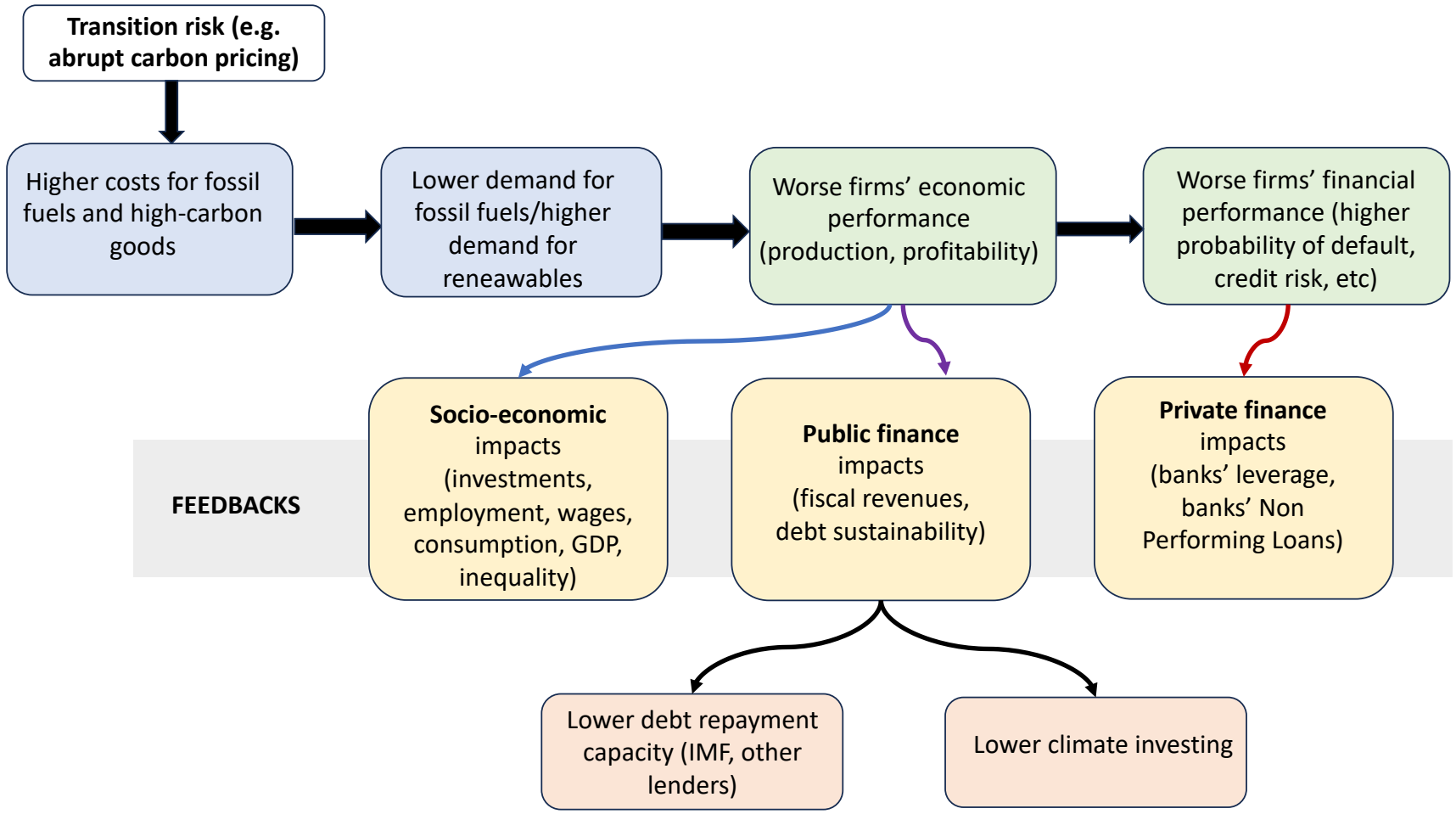
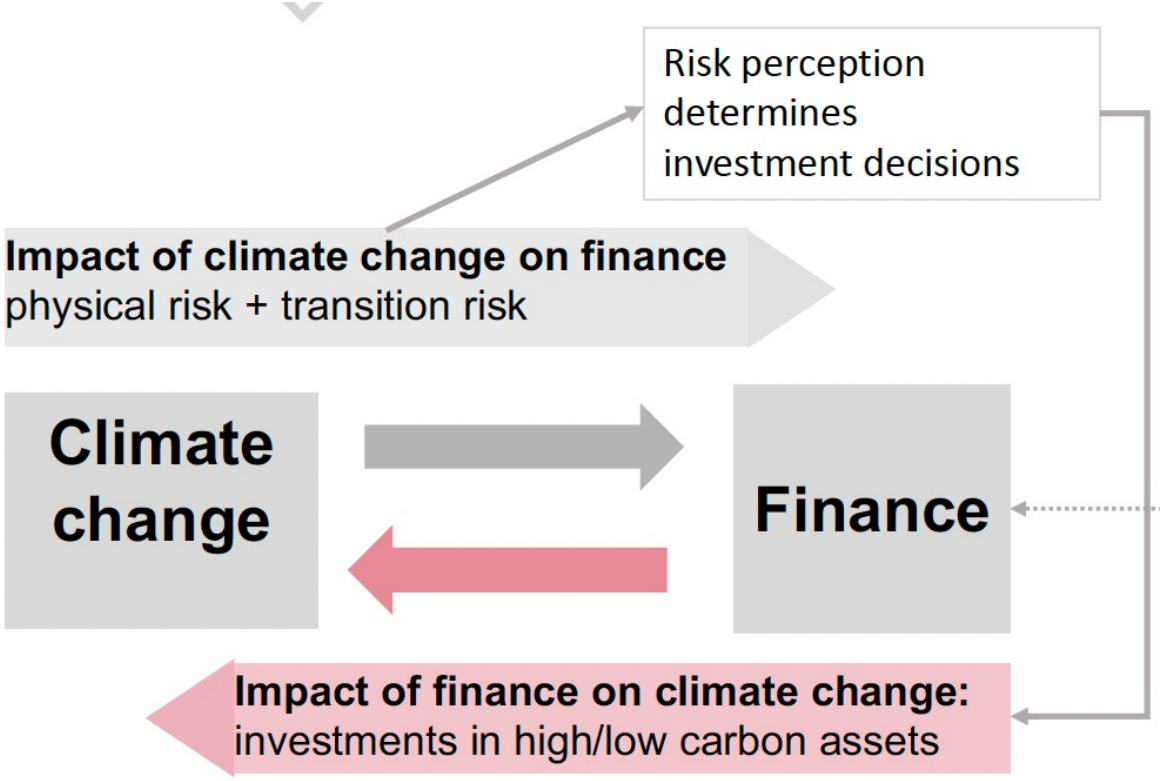


Fig. Risk transmission channels from transition risk (example of late carbon tax) to the economy, public and private finance, country's debt repayment and climate investing capacity. Blue boxes: shock entry point in the economy. Green boxes: direct impacts. Yellow boxes: indirect impacts. Orange boxes: cascading impacts on creditors.

The importance to assess climate financial risks

- Some central banks carried out climate stress tests (e.g. ECB 2021, 2023; OeNB 2022, Banque de France 2020, Bank of England 2022, etc).
- **Climate stress-test:** quantifies the losses that a financial actor could face on the balance sheet, conditional to the realisation of a set of **climate scenarios** (Battiston et al. 2017, Battiston and Monasterolo 2024 for a technical description)
- Losses depend on:
  - Financial actor's direct exposure to climate risks and
  - Leverage; indirect exposures through financial network; potential mispricing of collaterals associated to financial contracts
  - Uncertainty captured by the *breadth* of climate scenarios. **Policy credibility is a key driver of uncertainty.**
- Goal: help financial institutions to (i) **assess and manage risks,** (ii) **reallocate capital.**

Poor climate financial risk assessment prevents capital reallocation in the market



Source: courtesy of S. Battiston, IPCC lead author

- Firms make investment decisions (CAPEX) in high/low carbon equipment (e.g. wind vs coal power plants)
  - These decisions give rise to sectors' output trajectories of process based Integrated Assessment Models (IAM) in the NGFS scenarios
- **Financial actors influence these decisions** by making capital more/less expensive for firms (e.g. interest rate)
- **The feedback btw climate financial risk assessment – investment decisions is not considered by NGFS scenarios**

Climate scenarios for climate risk assessment

- How does climate change imply new sources of financial risk?
- In the **absence of a sufficient and early mitigation**, climate change implies increasing potential for adverse socio-economic impacts because of acute (extreme weather events and other types of hazards) and chronic **physical risks**, across several economic activities and geographical areas.
- However, **mitigation action** that would succeed in avoiding catastrophic climate change will require a very **fast and large transformation** of how we consume, produce and invest in both industrialised and developing economies.
- This **structural change in the economy** could generate significant **disruption**, having adverse impacts on several economic activities and sectors, creating at the same time **new opportunities** for others

➢ Orderly vs disorderly transition: differences in economic and financial implications.

Climate risks: orderly vs disorderly transition

- + 130 central banks and supervisors joined the Network for Greening the Financial System (NGFS) recommending investors **climate risk assessment and climate stress test** using climate scenarios.
- NGFS scenarios co-designed with scientists, build on process-based Integrated Assessment Models (IAM, see D. Van Vuuren's talk)
- **Scenarios are not predictions**: trajectories of how sectors should adjust given a carbon budget (coherent with a temperature target) and the law of physics.

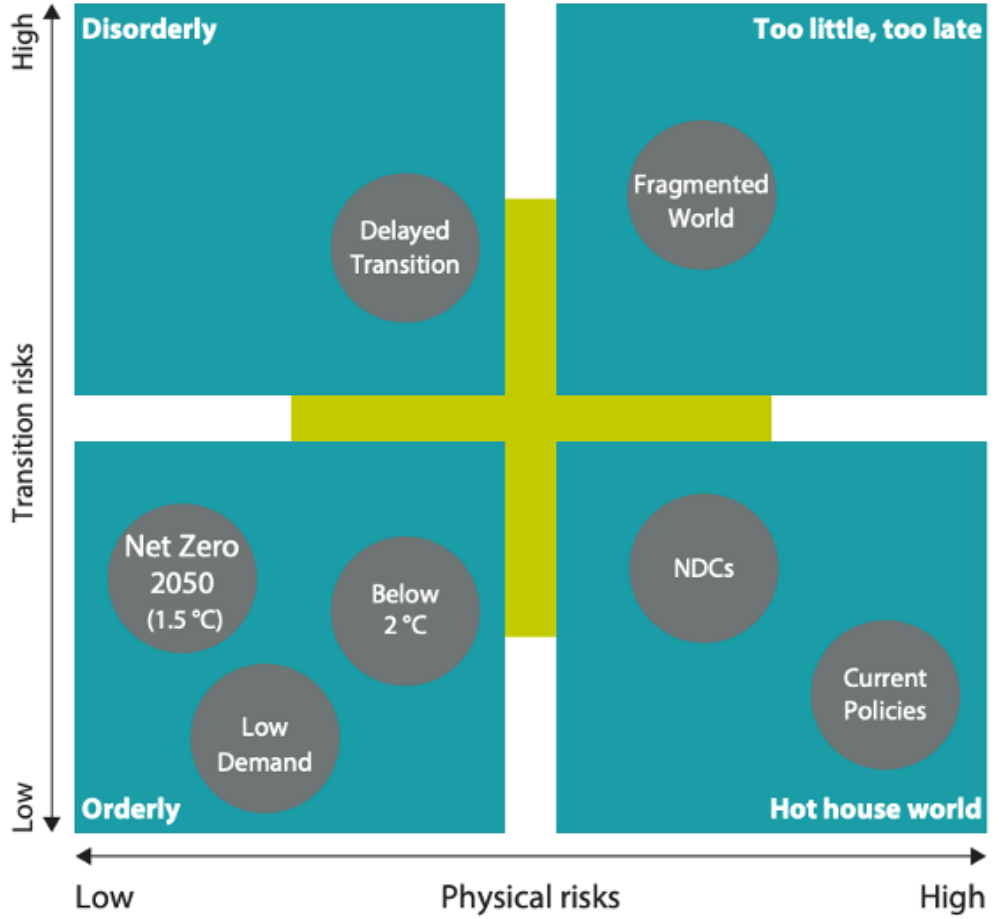
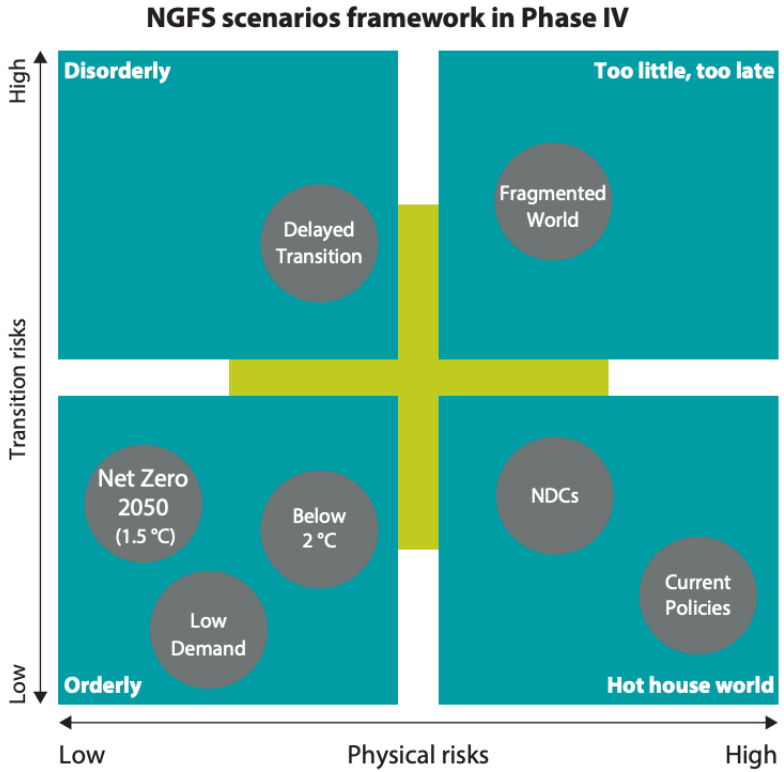


Fig: NGFS climate scenarios framework. Source: NGFS 2023.

NGFS climate scenarios



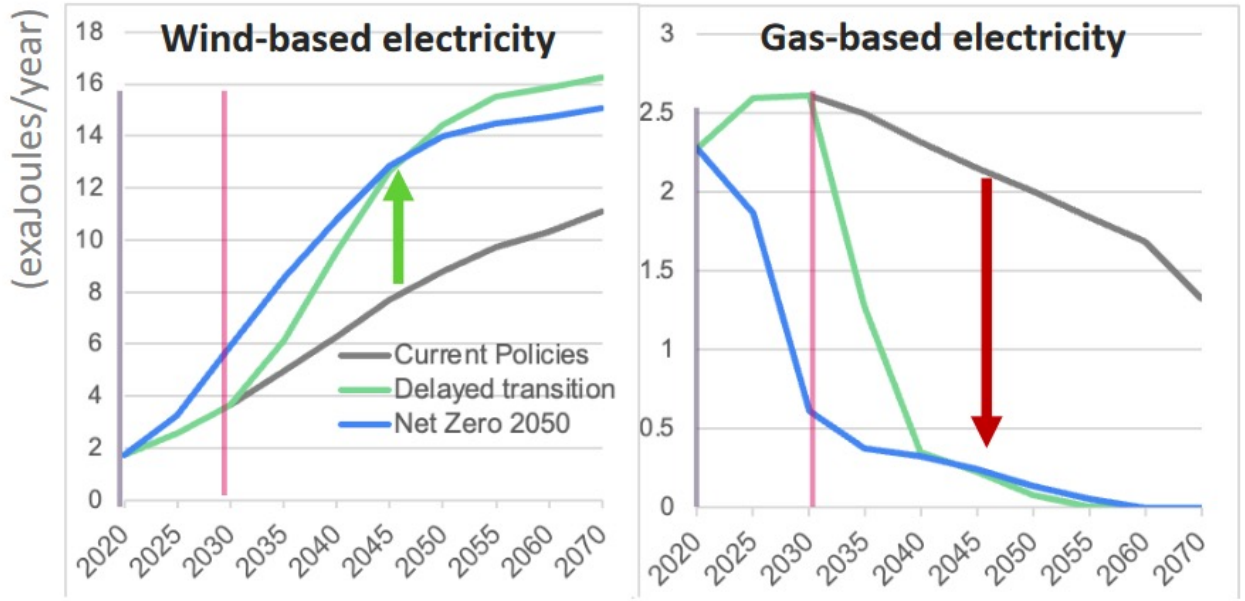


Fig. *NGFS scenario data,* region EU, 2020-2070, model "REMIND-Mag-Pie, 3 NGFS scenarios/ *Source: Authors' own elaboration*

- Given a GHG emission target (eg. 2C-aligned), IAM compute sectors' output (high/low carbon sectors)
- 3 Process based IAM: REMIND MagPie (PIK), MESSAGE Globiom (IIASA), GCAM (PNNL)
  - Timing of climate policies (carbon price): e.g. 2030
  - Emissions and temperature target (1.5C, 2C)
  - Reliance on Carbon Dioxide Removal (CDR): low, medium reliance
  - Technology development

(Some) limitations of NGFS scenarios

- Limited consideration of **acute physical risks** within economic projections (impacts only for tropical cyclones and pluvial floods. No droughts, etc.)
- **Poor granularity of exposures** fails to capture the overall magnitude of losses (Bressan et al. 2022)
- **The compounding of shocks is neglected** – yet can lead to persistent shocks (see e.g. countries' analyses in Dunz et al. 2021, Ranger et al. 2022)
- **Lack of money and finance:** no financial actors that decide how to allocate capital based on risk assessment that affects the cost of capital (Battiston et al. 2021)
- **Finance is missing** but a key driver of the transition (via risk assessment)!
- **Many of these limitations addressed in the new NGFS short term climate scenarios forthcoming Dec. 2024!**

Source: Monasterolo et al. (2023).

A delayed transition brings economic losses

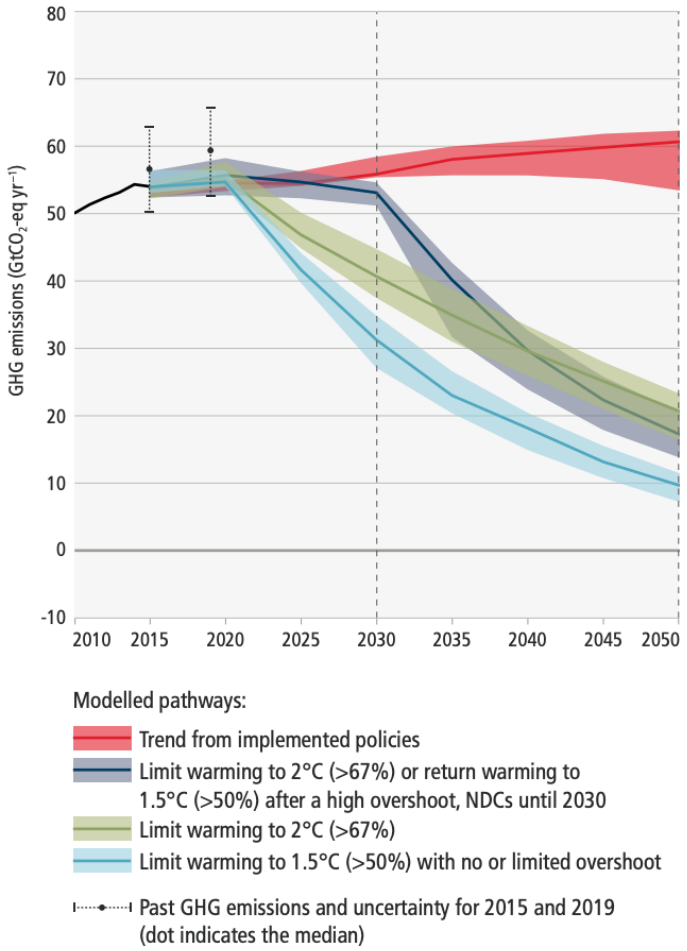


Fig: global GHG emissions projections by policy action until 2100. Source: IPCC (2022)

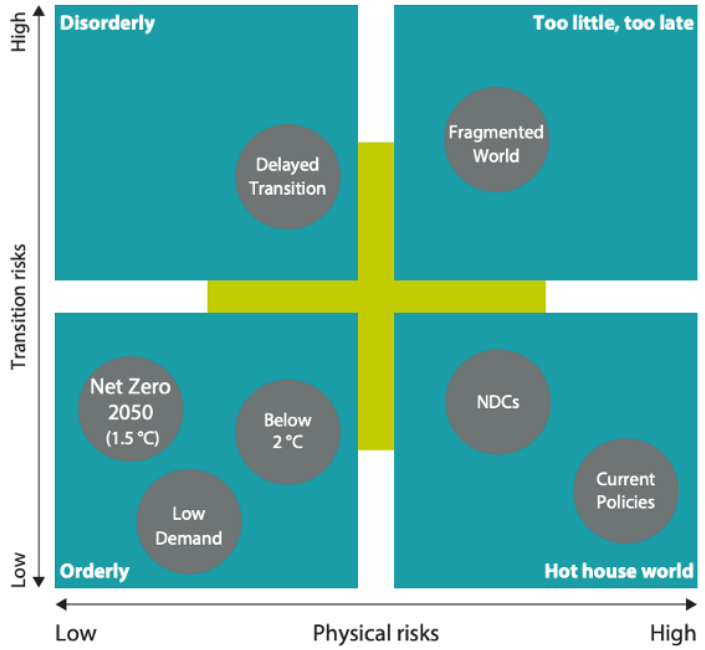


Fig: NGFS climate scenarios framework. Source: NGFS 2023.

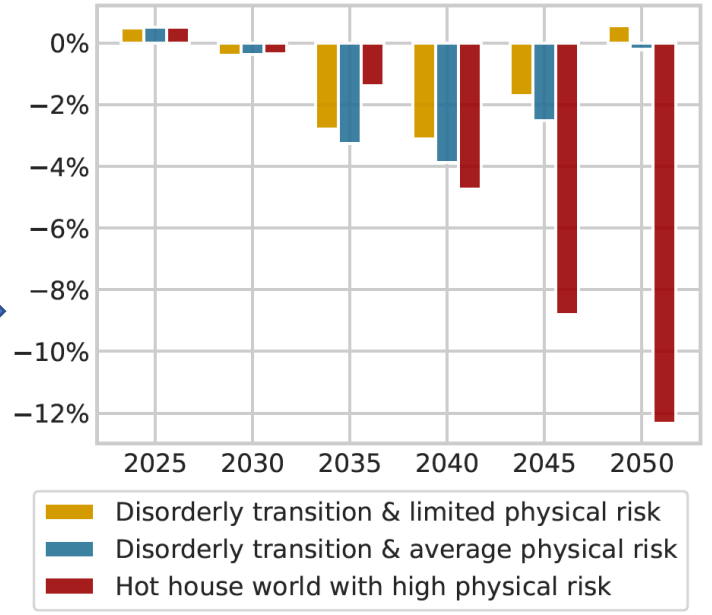


Fig: Real GDP euro area, comparison with orderly transition scenario. Source: Gourdel et al. 2022.

Why we need a complexity approach to climate finance?

Climate-economy-finance nexus as a complex system

Intrinsic characteristics of climate risk (Monasterolo 2020):

- **Forward-looking**: future impacts and losses will look very different from the past.
  - Thus, using historical data (e.g. disasters losses) to calculate expected risks, as current practice in finance, leads to an imprecise assessment of financial risk (Battiston et al. 2017)
- **Non-linearity and tipping points**: emissions concentration leading to irreversible changes in system earth dynamics (Steffen et al. 2018, Lenton et al. 2019, Armstrong McKay et al. 2022)
- **Compound**: climate risks do not happen in isolation but can compound (e.g. COVID-19 pandemic + hazards; nature loss + climate) leading to amplification of magnitude and duration of losses (Dunz et al. 2021, Ranger et al. 2022)
- **Endogeneity**: perceptions of climate risk impact on policy and investment decisions that make difference between succeeding and failing mitigation (Battiston et al. 2021):
  - **Political economy** of the transition can make difference btw achieving or missing the climate targets.

Additional source of complexity: (lack of) policy credibility

- **Markets may efficiently assimilate new information, but recent events challenge it:**
  - Transition risk: shifts in U.S. climate policy, EU political elections (and current campaign), COP28 mitigation failure: markets often misjudge the economic implications of new risks, indicating a substantial materiality of transition risks
  - Physical risk: GHG emissions concentration increases and unpredictability of intensity and occurrence of extreme events; intrinsic uncertainty on ecosystems' response; lower

FROM POLITICOPRO

Dec 2023

EU's green funds are under the guillotine

A massive investment plan designed to help fight climate change is at risk of being beheaded.

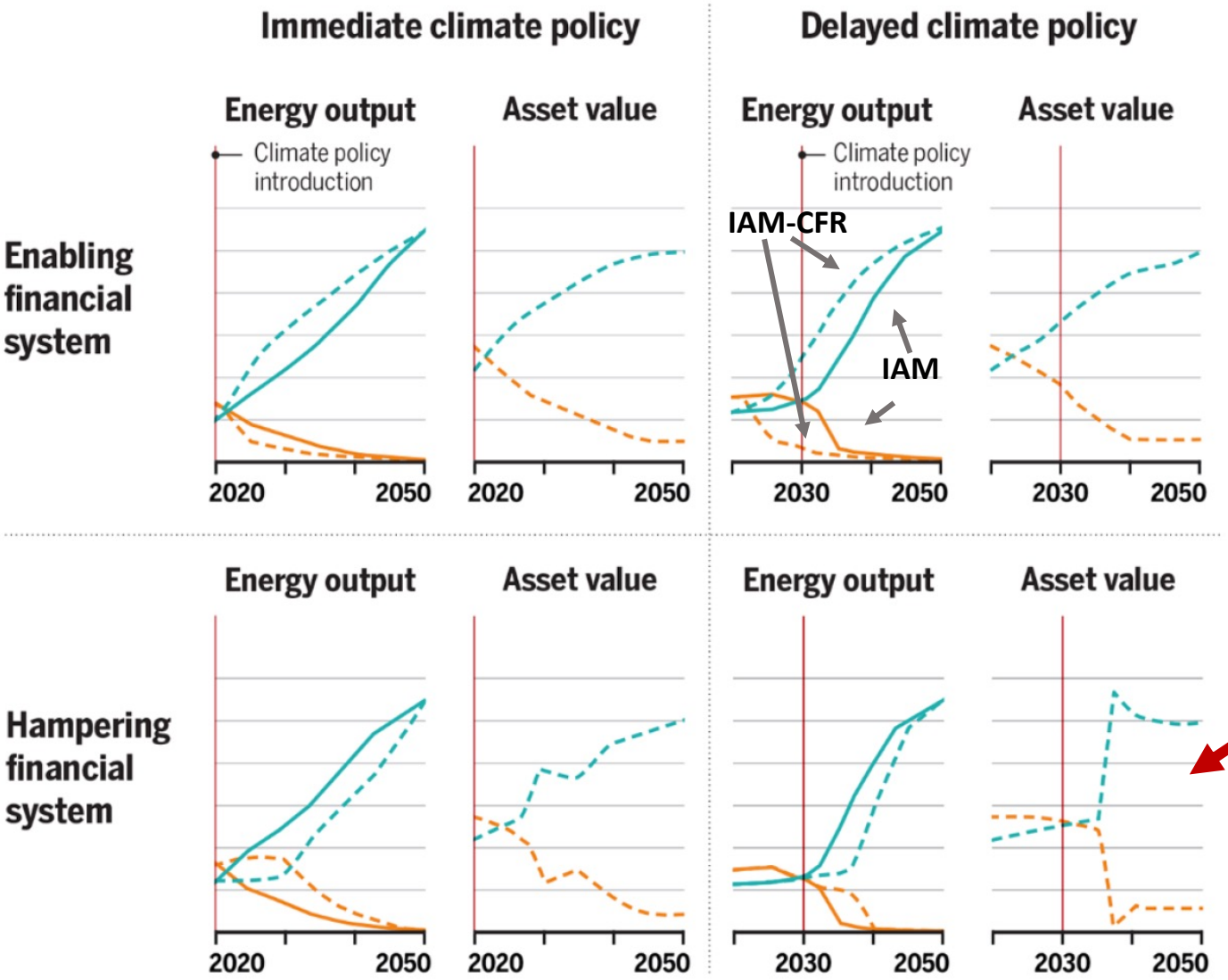
FROM POLITICOPRO

Jan 2024

Ursula's empty green Davos promise

Last year, EU chief Ursula von der Leyen promised a deluge of green tech cash. But politics, fiscal austerity and military anxieties have since intervened.

Endogeneity affects transition trajectories and risk



Endogenizing the transition features:

- An immediate transition to 2C classified in NGFS scenarios as orderly. But in the hampering case: delayed transition, large and sudden financial value adjustments as in a disorderly scenario.
- **Delayed** transition to 2C : **disorderly**. But in enabling case gradual price adjustments more consistent with orderly
- **Hampering** role: disorderly transition could also lead to higher risk than in NGFS disorderly

Legend:

Source: Battiston ea (2021), Science

The economy as a complex system

Where modern macroeconomics went wrong

Joseph E Stiglitz

Oxford Review of Economic Policy, Volume 34, Issue 1-2, Spring-Summer 2018, Pages 70–106, https://doi.org/10.1093/oxrep/grx057

Published: 05 January 2018

"At the heart of the failure **were the wrong micro-foundations**, which failed to incorporate key aspects of economic behaviour, e.g. insights from information economics and behavioural economics.

Inadequate modelling of the financial sector meant they were ill-suited for predicting or responding to a financial crisis;

and a **reliance on representative agent models** meant they were ill-suited for analysing either the role of distribution in fluctuations and crises or the consequences of fluctuations on **inequality**".

- **Role for complementary approaches in economics** (e.g. Stock-Flow Consistent, Agent Based, network models) to capture the characteristics of climate risk avoiding strong, unrealistic assumptions that bound results (e.g. smoothing climate shocks on GDP: no persistence)

Some reasons why traditional macroeconomic models underestimate climate financial risks

1. **Rationale expectations:** agents anticipate the price impact of transition shocks in their investment/consumption decision, leading to smaller shocks on GDP
2. **Perfect substitutability of production factors:** in the transition skills and technologies not perfectly substitutable (neither raw materials) leading to delays
3. **Representative agents** limit understanding of distributive effects of the transition, which could delay it (see e.g. “gilet jaune” in FR, or in the NL)
4. **Finance:** missing or stylized, banks are conduit savings to investments. But risk assessment and expectations matter for investment decisions (cost of capital)
5. **No finance-macro feedbacks.**

Source: Monasterolo (2020).

Assessing climate risks while getting macro right

- Getting the macro right is challenging due to the nature of climate risks (non-linearity, tail risks, endogeneity) yet crucial (GDP shocks magnitude, persistence) for financial stability and supervision

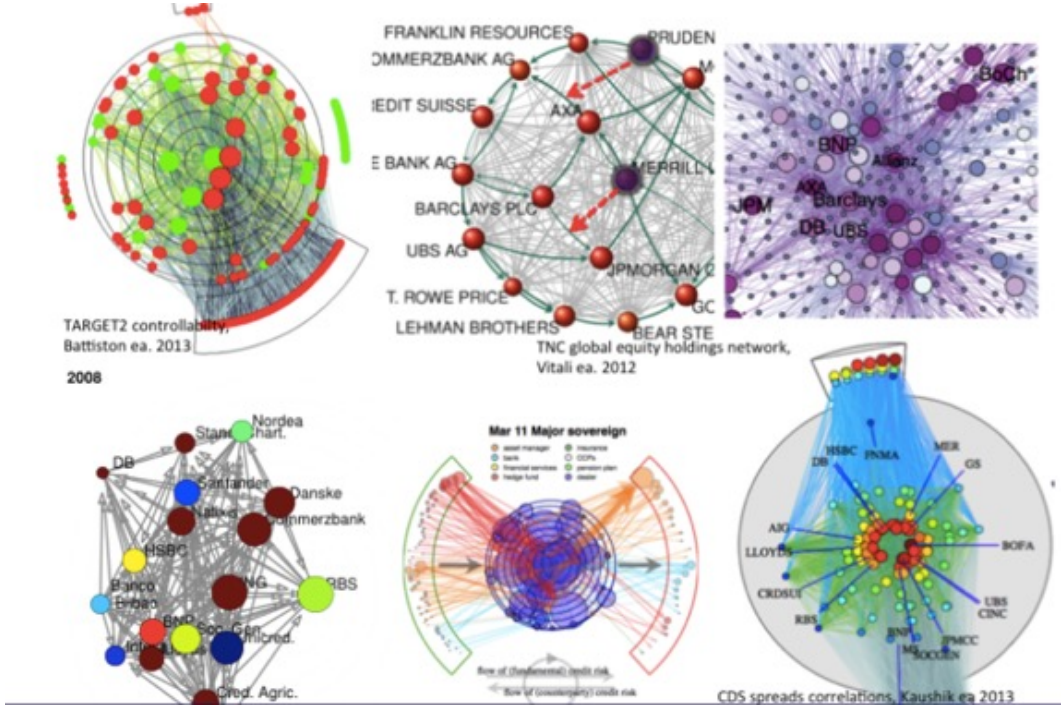
- **DSGE:**
  - Rational expectations
  - Banks are modeled as financial intermediaries
  - Supply-determined output
  - Policy effects: exogenous shocks that drives dynamic evolution of the economy; addresses market failures; no co-benefits
  - Limited or no distributional impacts

- **Stock-Flow Consistent Models:**
  - Bounded rationality, adaptive expectations
  - Comprehensive representation of financial sector and market, and money (nominal var.)
  - Demand-determined output, with supply-side constraints
  - Policy effects: exogenous shocks (scenario) and endogenous shock (fiscal) that drives dynamic evolution of the economy. Policy to address climate and econ. goals. Co-benefits.
  - Distributional impacts across heterogenous agents and/or sectors

Financial networks and complexity

- **Individual financial institutions invest and are invested by other institutions: network**
- **Financial network models** widely used also by central banks to disentangle financial interconnectedness-stability nexus
- We use network models to analyse:
  1. **Largest individual financial losses conditioned to climate scenarios**
  2. **Shocks' propagation** throughout the financial network and amplification effects (system)
  3. Implications on individual and **systemic risk (micro/macroprudential)**

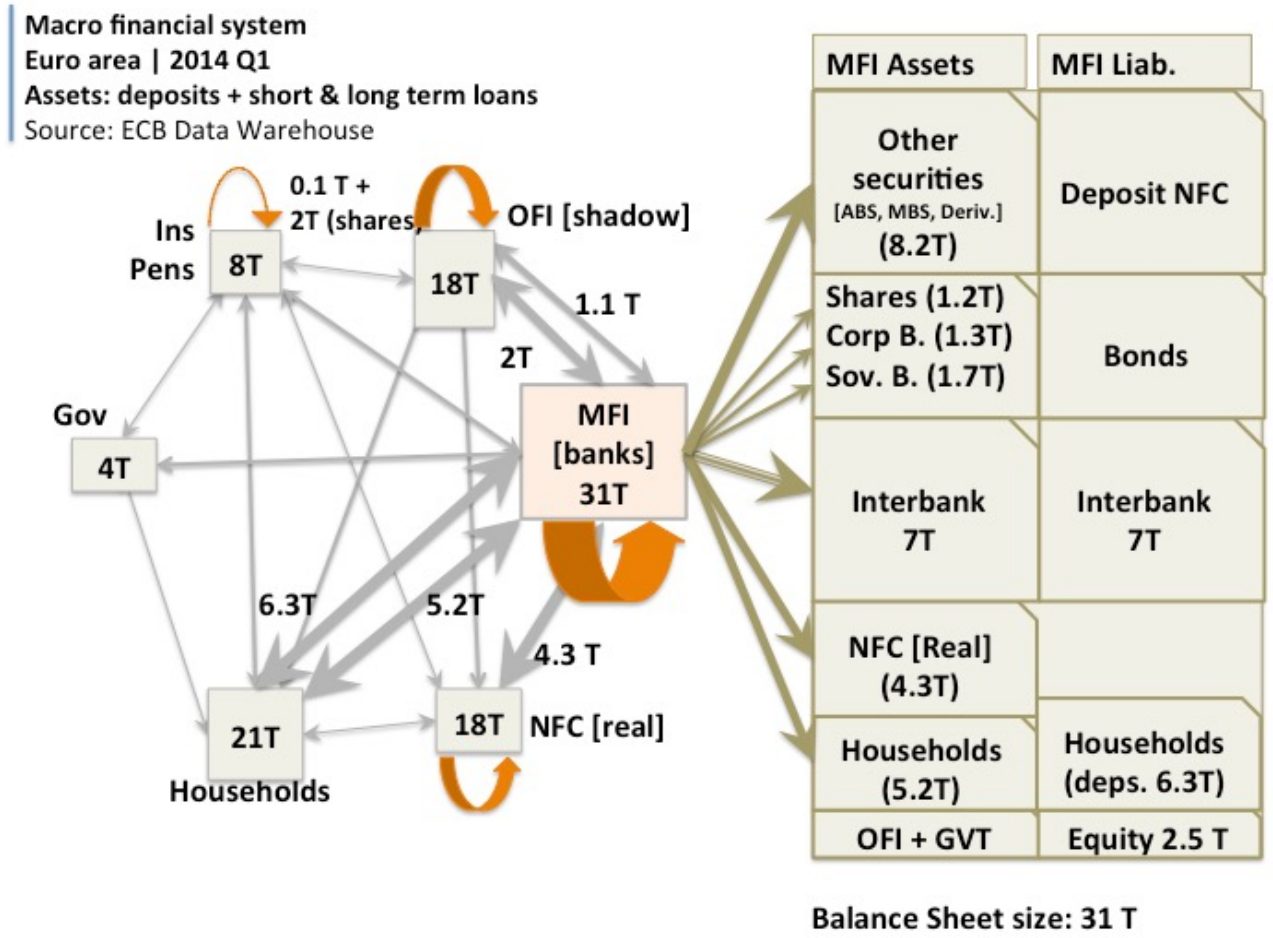
Applied here to disentangle the **climate - financial stability nexus.**



Source: Bardoscia et al. (2021)

Why network effects matter: indirect exposures of individual financial actors

- Large portion of total assets held by financial institutions **are issued by other financial institutions** (40% for banks in Euro Area)
- Thus, systemic risk can materialize through second-round effects



Assessing climate risk in the economy and finance

The EIRIN Stock-Flow Consistent behavioral model

- Agents and sectors: network of interconnected balance sheets economy - finance
- Stock-Flow Consistency provides a rigorous accounting framework that allows us to track shocks transmission and identify amplification points.

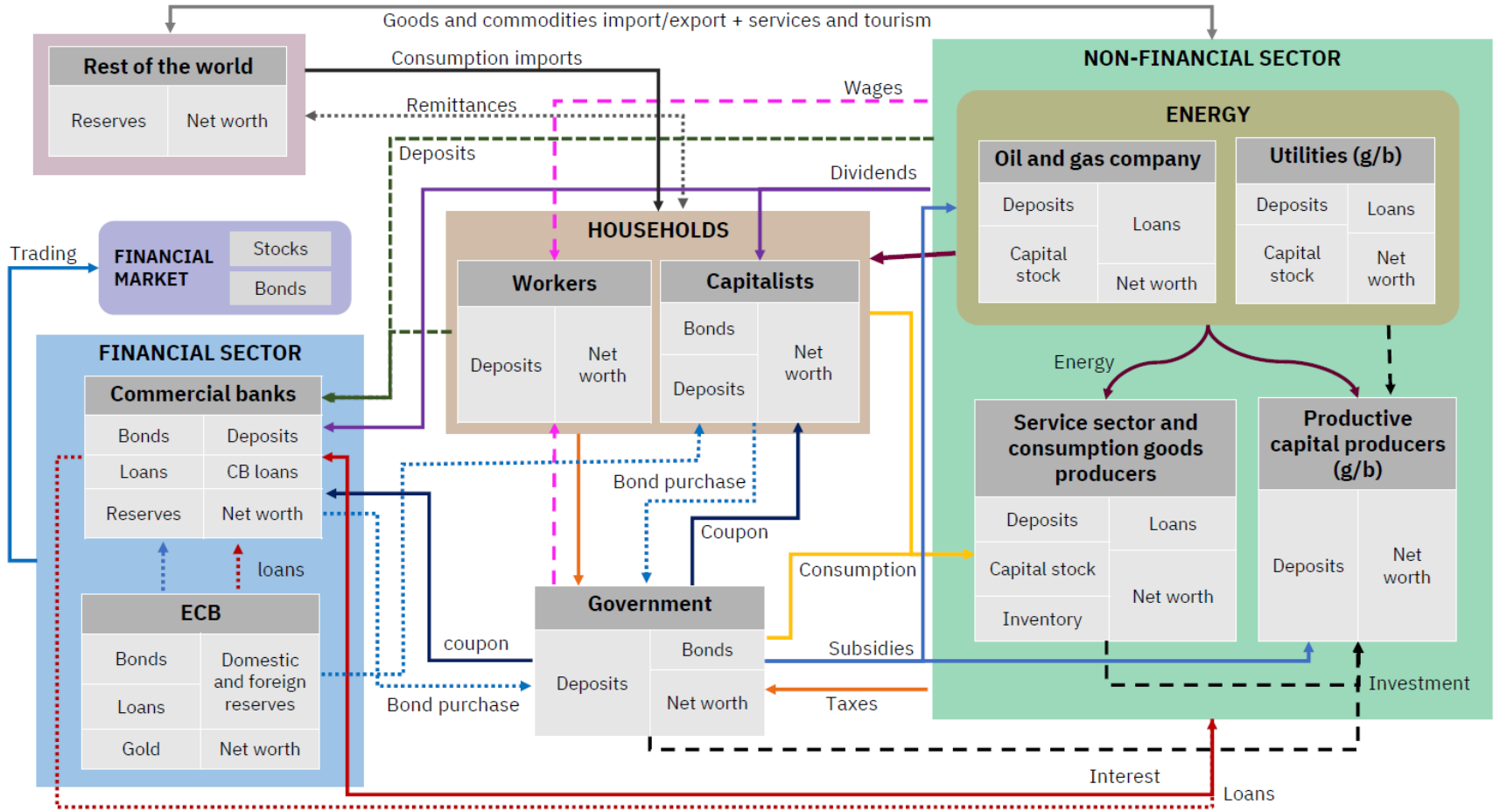
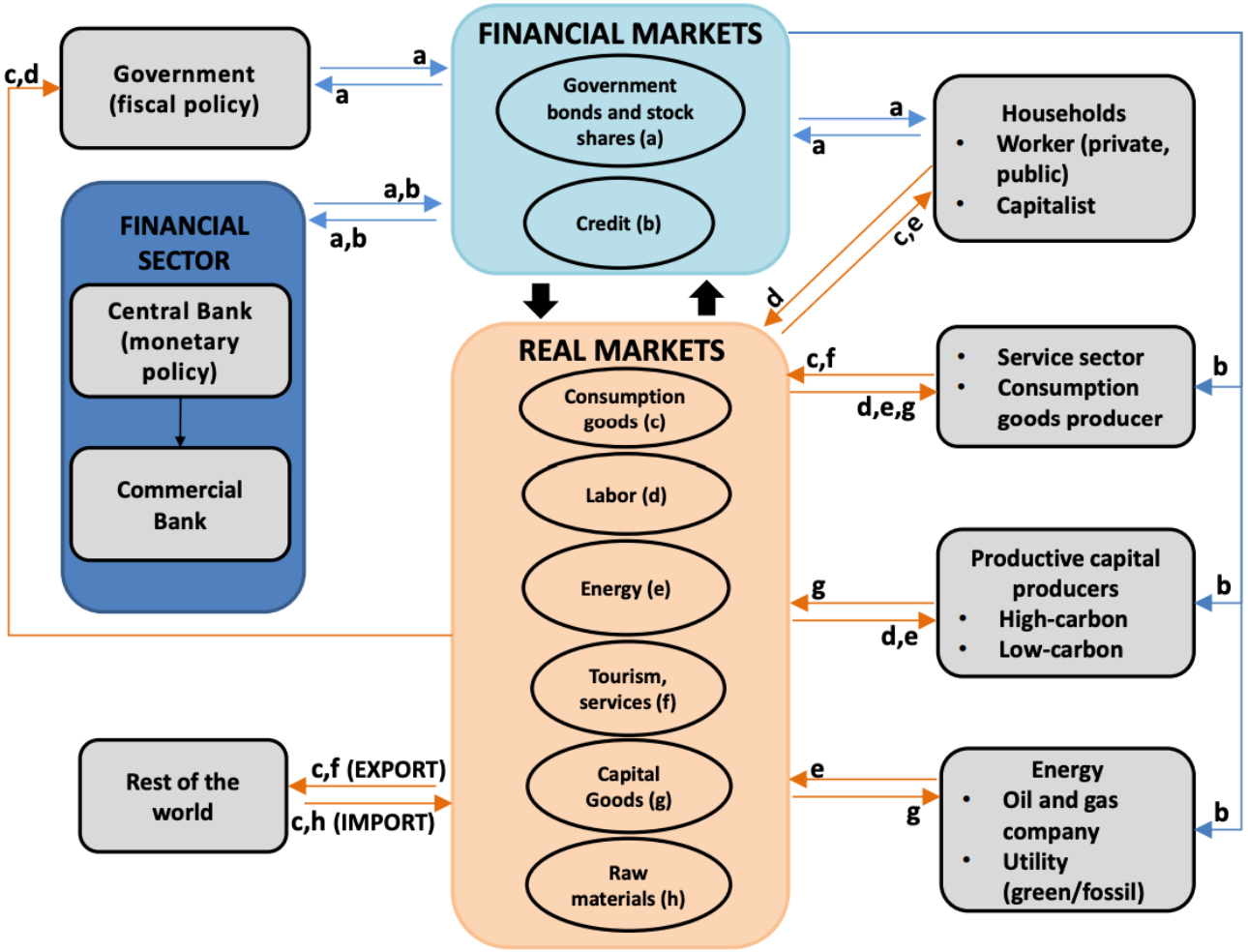


Figure: EIRIN framework: Example of **capital** (dotted) and **current** (solid) account flows. Source: Gourdel et al. 2024.

Heterogenous agents and markets



Legend:

a) Government bonds and stock shares' market

b) Credit market

c) Consumption goods market

d) Labor market

e) Energy market

f) Tourism market

g) Capital goods market

h) Raw materials' market

→ *supply*

← *demand*

***Black boxes**: heterogenous agents and sectors*

***Blue box**: financial markets: i) government bonds and stocks (traded by capitalist HH and bank); ii) credit (bank to firms)*

***Orange box**: real markets*

Agents and sectors interact through real and financial markets.

Outgoing arrows: supply. Incoming arrows: demand

Main structural (left) and behavioral (right) characteristics

- **Agents' heterogeneity**: wealth/income source, dirty/green sectors, access to finance, skills, etc.
- **Real and monetary flows** (endog. money)
  - Central Bank sets the interest rate according to a Taylor-like rule
  - Banks subject to Regulatory Capital Adequacy Ratio (CAR) (Basel IV)
- **Leontief** production function (Capital, Labor, Raw Material, Energy)
- **Firms' portfolio choice** (labour/capital intensive, debt financing):
  - No perfect substitution: different relative prices and technology cost

- Households' saving/consumption (**Deaton's Buffer-Stock Theory):** *maximize their ability to consume in the future*
- Firms' investment decision are endogenous, based on **Net Present Value (NPV):** *optimize their expected return*
- Banks maximize credit allocation based on risk assessment
- Banks and investors form expectations on firms' performance and may revise risk assessment and cost of capital

Source: Monasterolo and Raberto (2018)

EIRIN applications at international financial institutions

- **EIRIN:** applied to the analysis of climate risks and green finance policies (Monasterolo & Raberto 2018 EE, 2019 EP) in collaboration with central banks and financial institutions:
  - **European Central Bank**: impact of carbon tax (NGFS) on macroeconomic and financial variables (GDP, inflation, interest rate, cost of capital) (Gourdel ea 2022a)
  - **The World Bank**: impact of compound climate risks and pandemics on macroeconomic and financial variables (e.g. GDP, inflation, interest rate, cost of capital) (Dunz ea 2023, JBF, Ranger ea 2022)
  - **G24 and V20**: impact of transition spillovers on balance of payment, debt/GDP, yields (Gourdel ea 2022b)
  - **NGFS short term climate scenarios (forthcoming!)**
- **Macroeconomic simulations are integrated in the climate stress-test of the financial system** (Battiston ea 2017, collaborations with SNB, FINMA, MAS, etc).

Climate stress test

Stress-test vs climate stress test

- **Both** stress tests and climate stress test:
  - **quantify the 'largest' losses** that the balance sheet of an individual investor (micro-pru.) or the financial system (macro-pru.) could incur if a scenario materialised
  - translate economic losses, conditioned to scenarios, into adjustments in counterparties' **probability of default, financial performance**, **value of contracts**
  - estimate **distribution of losses** and calculate financial risk measures to capture tails
  - can account for the effects of **financial contagion** (network of pairwise exposures)
- **Differences: scenarios**
  - Stress test: economic scenarios (mild vs adverse). Climate stress test: **climate scenarios**

Source: Battiston and Monasterolo 2024

A climate stress-test of the financial system

Stefano Battiston ✉, Antoine Mandel, Irene Monasterolo, Franziska Schütze & Gabriele Visentin

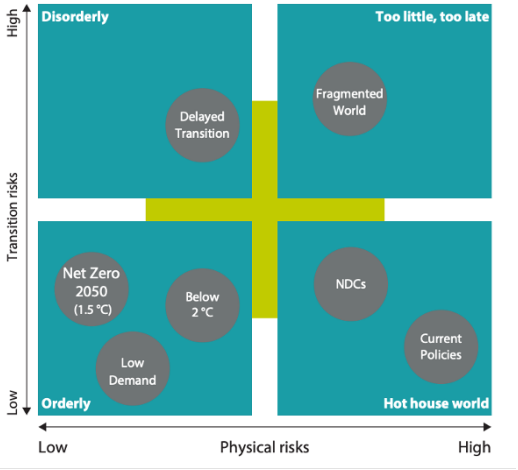
Nature Climate Change **7**, 283–288 (2017) | Cite this article

- **2017: the Climate Stress-test first framework** to embed process-based IAMs' climate scenarios (reviewed by IPCC) in a stress test of individual portfolios and the financial system

- **Key messages:**
  - a disorderly transition could lead to large losses for individual financial institution, with potential implications on financial instability
  - An early green investment strategy could smooth the risk of carbon stranded assets for investors and support the transition.

Climate stress-test framework

Climate scenarios

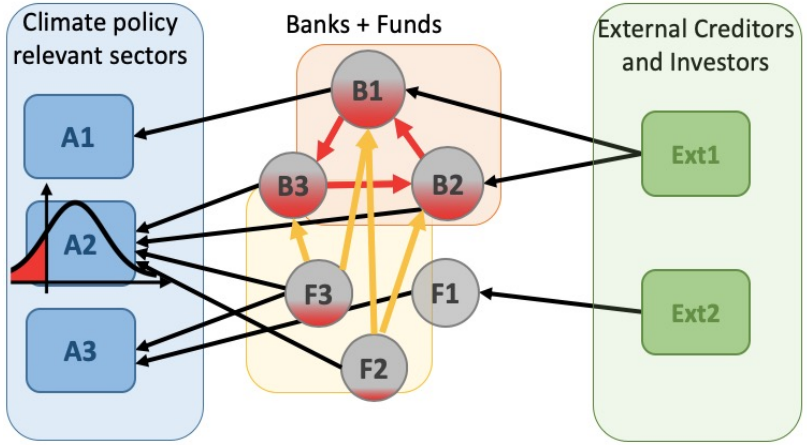


NGFS 2023

- Climate scenarios (physical, transition risk)
- Estimates of sectors' production by energy technology, cash-flow streams of securities
- Valuation adjustment of issuers' default probability, bond spread, credit risk etc.

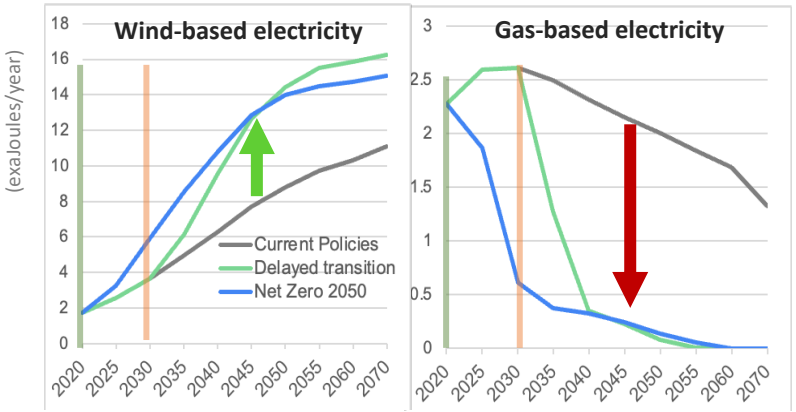
→ Reallocation of capital to less risky assets

Amplifications via financial networks



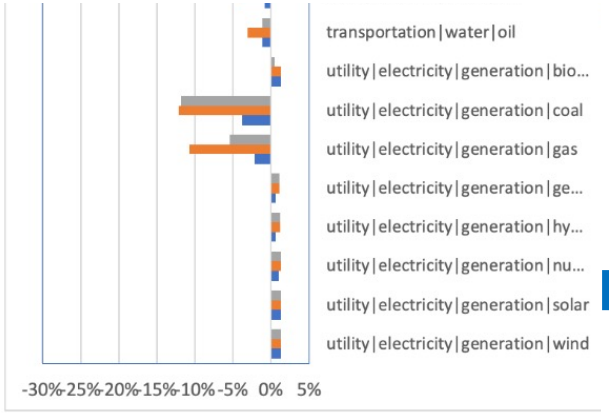
Roncoroni et al. 2021

Output trajectories

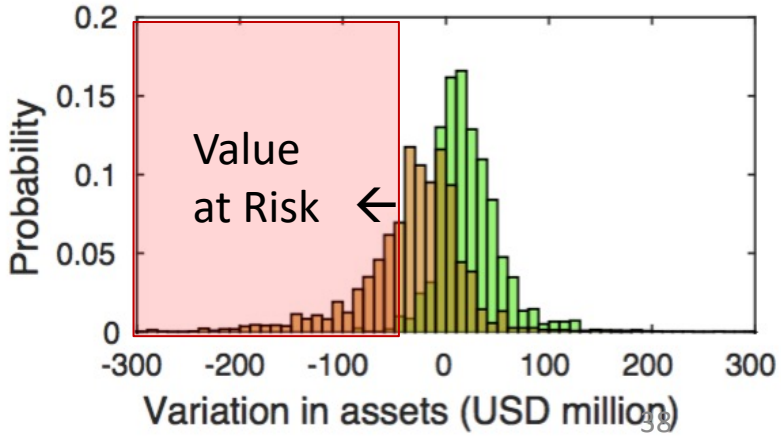


Own elaborations on NGFS database explorer

Financial valuation adjustment



Adjustment of gain/losses distribution



Investors have large exposures to climate risks

Investors have large, heterogeneous exposure to transition risk via Climate Policy Relevant Sectors

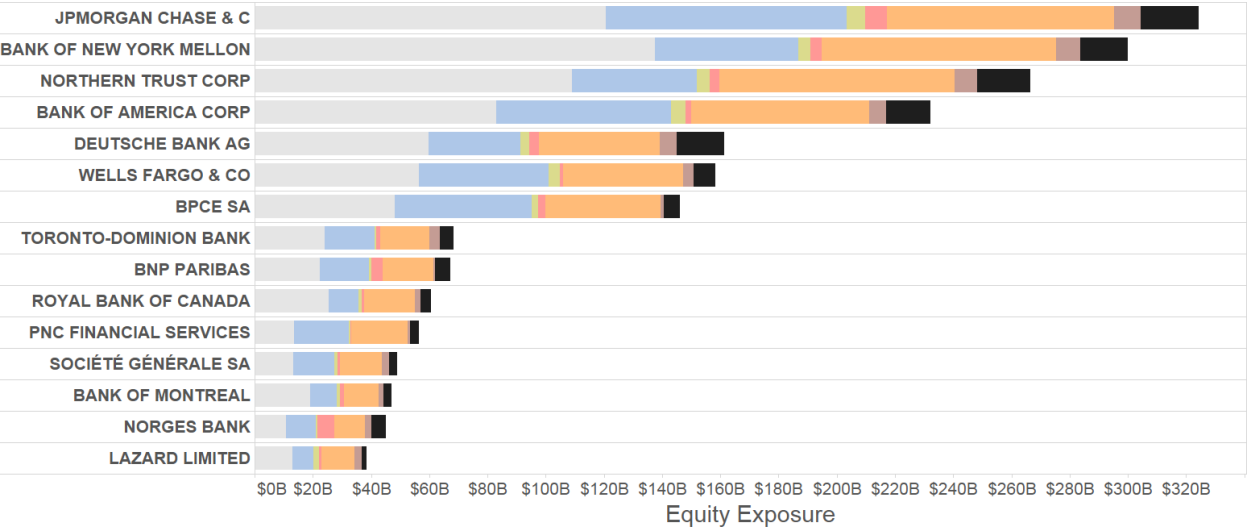


Fig. Exposure (USD billion) of equity portfolio of largest banks to Climate Policy Relevant Sectors (CPRS) including fossil (black), utilities (grey), energy-intensive (orange), housing (pink), transport (green). Battiston et al. 2017.

Losses from a high-carbon investment strategy

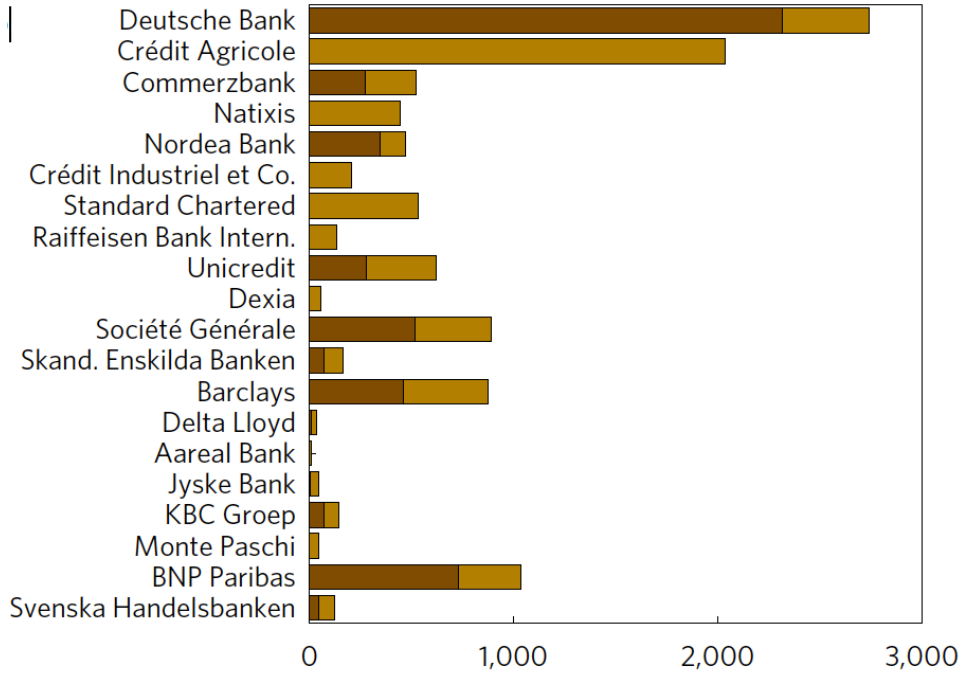
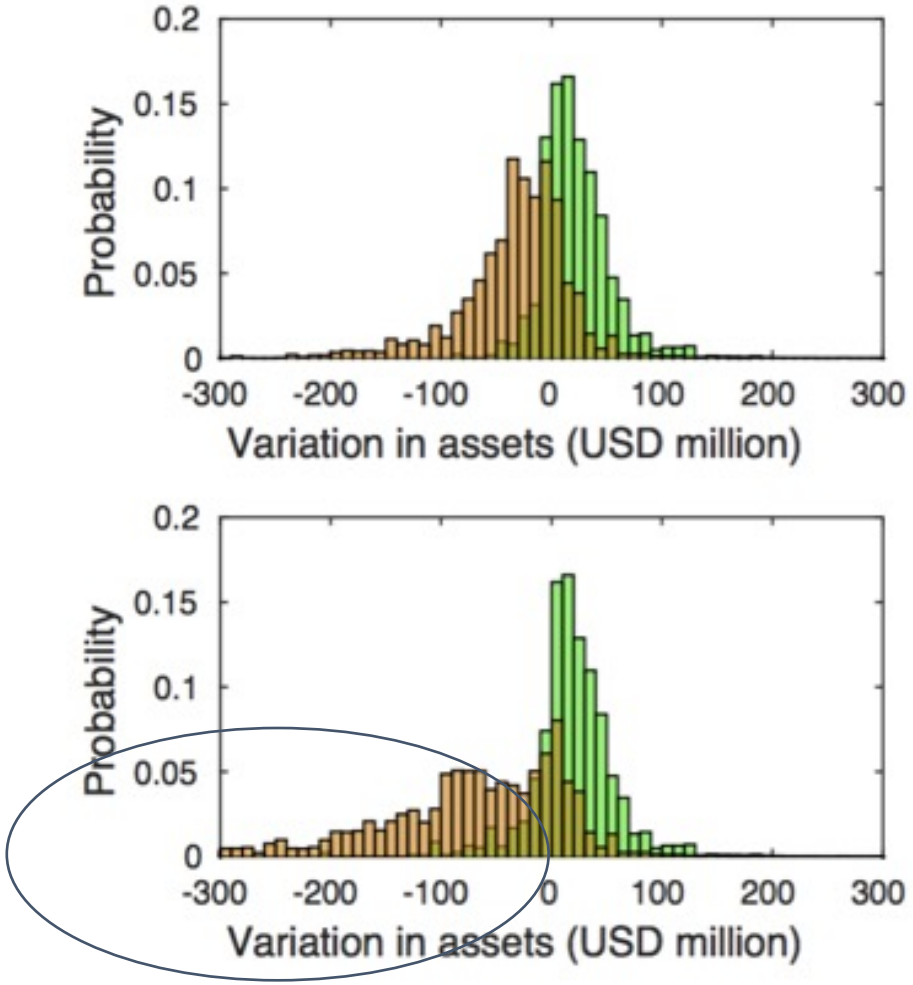


Fig. Climate Value at Risk on holdings of 20 most affected EU banks under current investment strategy. Dark/light : first/first+second round losses. Battiston et al. 2017.

Financial interconnectedness can lead to amplification of losses

- **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



Conclusion

- **Investors' ability to withstand climate risks** depends on i) exposures, ii) climate scenarios, iii) financial risk characteristics
- **Lesson 1 - disclosure of exposures**:
  - Standardized, compulsory disclosure at fin./non fin. level
  - Science-based taxonomies (also for stranded assets, e.g. CPRS)
  - Consider forward-looking risk (beyond emissions)
- **Lesson 2 - risk assessment**:
  - Understand characteristics and limits of climate scenarios
  - Introduce finance and its expectations in climate scenarios
- **Lesson 3 - financial risk matters**:
  - Financial interconnectedness and network effects matters to avoid to underestimate risk.

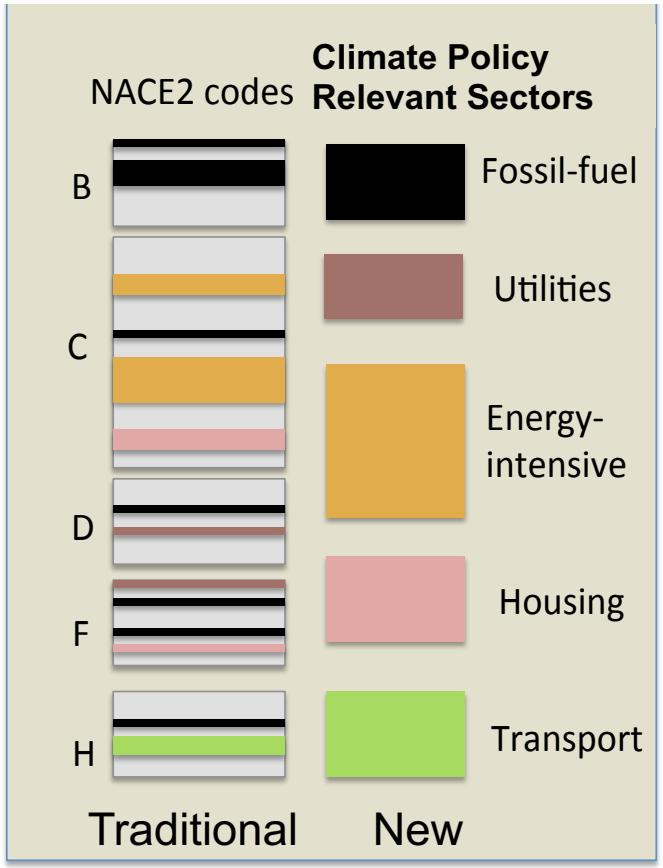
Appendix

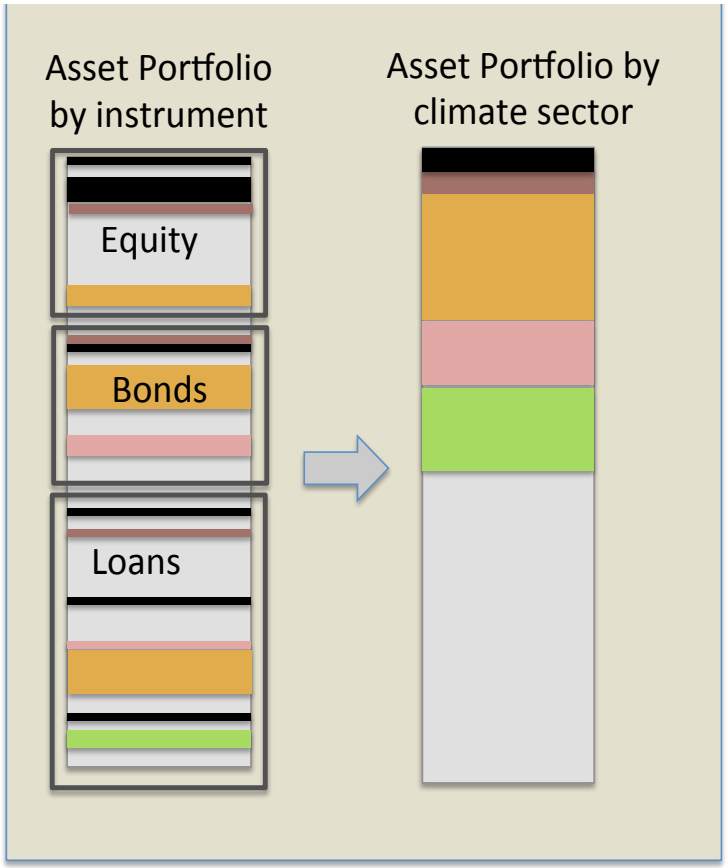
Investors’ exposure to climate transition risk

Climate Policy Relevant Sectors

Map NACE 4digit codes into classes of transition risk:

- Energy tech composition of revenues
- Business model and substitutability of fossil fuel
- Contribution to GHG emissions (Scope 1,2,3)
- Relevance for climate policy implementation (costs sensitivity, e.g. to EU carbon leakage directive 2003/87/EC)





Classification free download here
https://www.df.uzh.ch/en/people/professor/battiston/projects/CPRS.html

Why the need for tailored classifications of activities

Sector B should contain fossi fuel related activities. In fact, they are spread across sectors.

Division	Group	Class	
			SECTION B – MINING AND QUARRYING
05			Mining of coal and lignite
	05.1		Mining of hard coal
		05.10	Mining of hard coal
	05.2		Mining of lignite
		05.20	Mining of lignite
06			Extraction of crude petroleum and natural gas
	06.1		Extraction of crude petroleum
		06.10	Extraction of crude petroleum
	06.2		Extraction of natural gas
		06.20	Extraction of natural gas
07			Mining of metal ores
	07.1		Mining of iron ores
		07.10	Mining of iron ores
	07.2		Mining of non-ferrous metal ores
		07.21	Mining of uranium and thorium ores
		07.29	Mining of other non-ferrous metal ores

CPRS 01-Fossil: activities of (or supporting) extraction, production, transportation, sale of primary energy derived from fossil:

- low direct emission, high indirect emissions
- specific policy processes: yes
- substitutability of input: no

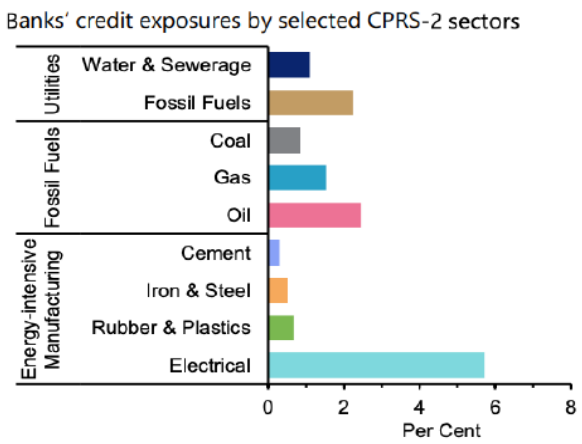
			SECTION H- TRANSPORT
	49.4		Freight transport by road and removal services
		49.41	Freight transport by road
		49.42	Removal services
	49.5		Transport via pipeline
		49.50	Transport via pipeline
			SECTION C- MANUFACTURING
19			Manufacture of coke and refined petroleum products
	19.1		Manufacture of coke oven products
		19.10	Manufacture of coke oven products
	19.2		Manufacture of refined petroleum products
		19.20	Manufacture of refined petroleum products
20			Manufacture of chemicals and chemical products
	20.1		Manufacture of basic chemicals, fertilisers and nitrogen co synthetic rubber in primary forms
		20.11	Manufacture of industrial gases
			SECTION D — ELECTRICIT Y, GAS, STEAM AND AIR CONDITIONING SUPPLY
35			Electricity, gas, steam and air conditioning supply
	35.1		Electric power generation, transmission and distribution
		35.11	Production of electricity
		35.12	Transmission of electricity
		35.13	Distribution of electricity
		35.14	Trade of electricity
	35.2		Manufacture of gas; distribution of gaseous fuels through mains
		35.21	Manufacture of gas
		35.22	Distribution of gaseous fuels through mains
		35.23	Trade of gas through mains
	35.3		Steam and air conditioning supply
		35.30	Steam and air conditioning supply

Climate Policy Relevant Sectors

CPRS main	Category of economic activities	Role in GHG emissions value chain	Specific policy processes	Nature of transition risk in relation to business model	NACE 4 digits Main groups of codes (selected, see full table)
Fossil fuel	Carry out / support production / delivery of primary energy based on fossil fuel.	Mostly indirect CO2 emissions	Oil politics, taxes/subsidies	No fuel substitutability	B-Mining and quarrying: coal, oil and gas; C-Manufacturing: coal, oil and gas; D-Electricity and gas (e.g. 35.21); G-Wholesale: fuel sales (e.g. 47.30); H-Transportation: pipelines (e.g. 49.50).
Utility electricity	Carry out or support production of secondary energy.	Mostly direct CO2 emissions (fuel mix).	Electricity authorities (e.g. feed-in tariffs)	Medium fuel substitutability (e.g. wind farms).	D-Electricity production, transmission and distribution (e.g. 35.11, 35.12, 35.13)
Energy intensive	Manufacturing activities with intensive use of energy according to EU classification Carbon Leakage	Mostly direct CO2 emissions (fuel mix).	No specific policy processes as a group.	Low substitutability (e.g. steel or rockets)	See Carbon Leakage list. B-Mining and quarrying (e.g. 07.10, 07.29, 08.91 etc.); C-Manufacturing (about 200+ sectors, e.g. 11.01, 13.10, 15.11 etc.). NOTE: Nace codes falling in other CPRS are not included.
Transport	Provision of or support to transport services (e.g. vehicles manufacturing, roads and railways)	Mostly direct CO2 emissions (fuel mix).	Transport authorities and policies.	Low substitutability (e.g. motor vehicles fleet)	C-Manufacturing: motor vehicles, ships and trains (e.g. 29.10, 29.20, 30.11, 30.20 etc.); F-construction: roadways and railways (e.g. 42.11, 42.12); G-Wholesale: vehicles (e.g. 45.32); H-Transportation: land, air, and sea transport (49.10, 49.20, 49.41, 50.10, 51.10, etc.)
Buildings	Provision of or support to buildings services (e.g. residential and commercial)	Mostly direct CO2 emissions (fuel mix).	Housing policies.	Low substitutability (e.g. heating/cooking)	F-Construction: residential and commercial building (e.g. 41.10, 41.20, 43.22, 43.91 etc.); I-Accommodation (e.g. 55.10, 55.20); L-Real-estate (e.g. 68.10,68.20, 68.30); M-Professional: architectureal activities (e.g. 71.11)
Agriculture	Provision of and support of agriculture and forestry	Direct CO2 emissions from fossil fuel; other direct GHG emissions. Negative emissions (afforestation).	Agricultural policies.	Low Substitutability (as for transport). But emission reductions via low carbon farming.	A - Agriculture forestry and fishery (from 01.10 to 02.40)

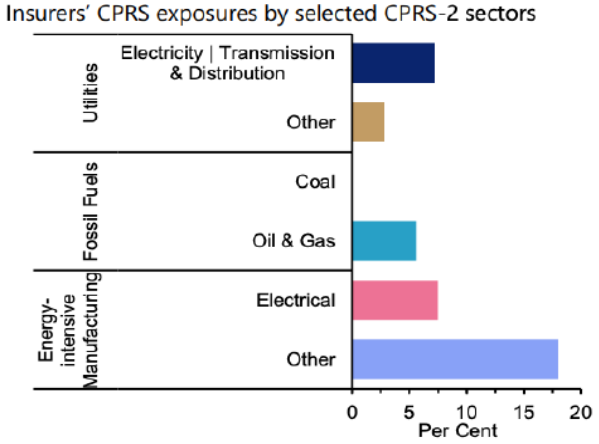
Example of applications

Chart S1.2 CPRS-2 allows for more granular sectoral analysis of transition risk for banks...



Source: Banks' submissions, MAS estimates

Chart S1.3 ... and insurers



Source: Insurers' submissions, MAS estimates

Figure: Source: Monetary Authority of Singapore, 2023

Other examples: EIOPA Financial Stability Report Dec. 2018; Dec. 2019

ECB Financial Stability Report, May 2019, 2020, etc

EC JRC study of EU Taxonomy financial impact 2021

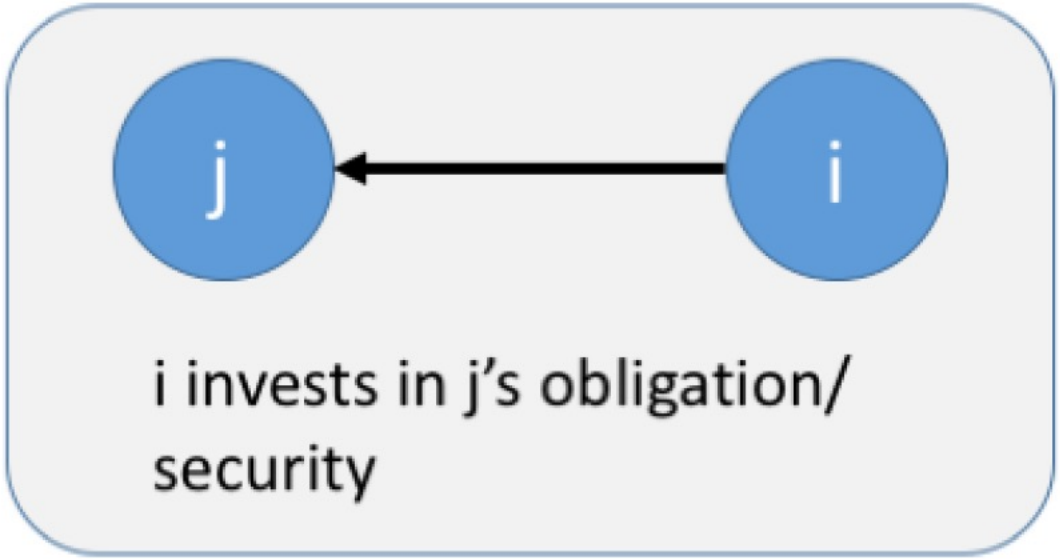
EBA Risk assessment of the EU banking system, Dec. 2020

National Bank of Austria Financial Stability Report 2020

MAS Financial Stability Review 2023

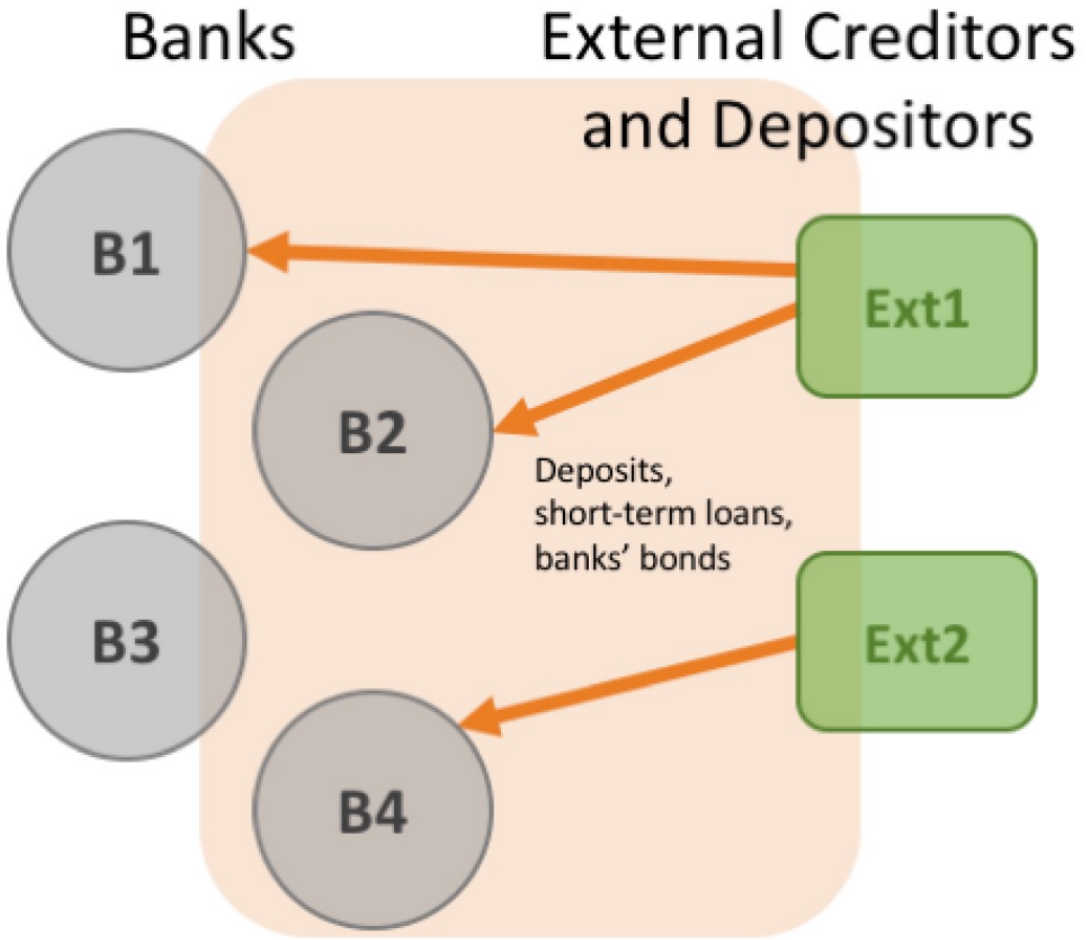
Financial network effect

How do network effects work?



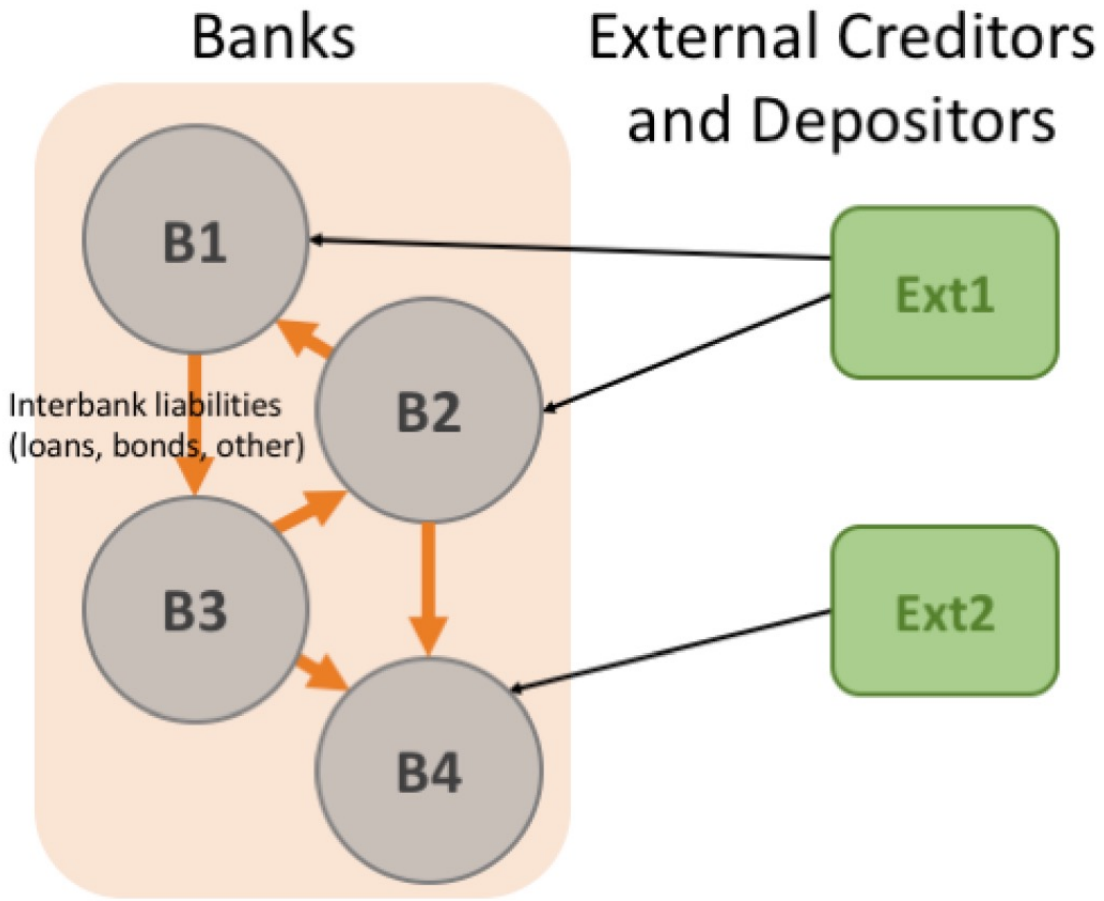
Source: Roncoroni, A., Battiston, S., Escobar-Farfán, L. O., & Martinez-Jaramillo, S. (2021). Climate risk and financial stability in the network of banks and investment funds. *Journal of Financial Stability*, *54*, 100870.

How do network effects work?



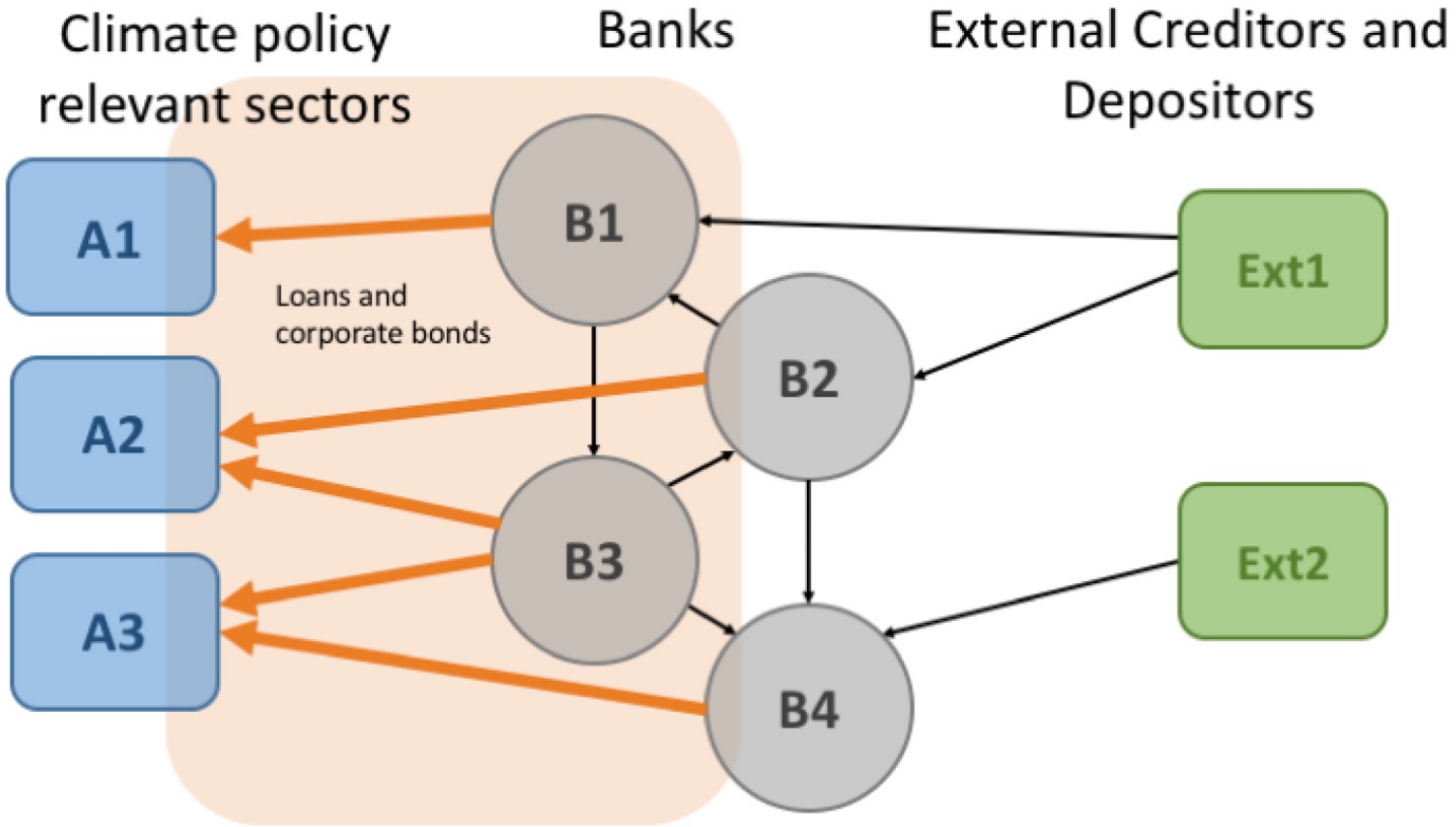
Source: Roncoroni et al. (2021)

How do network effects work?



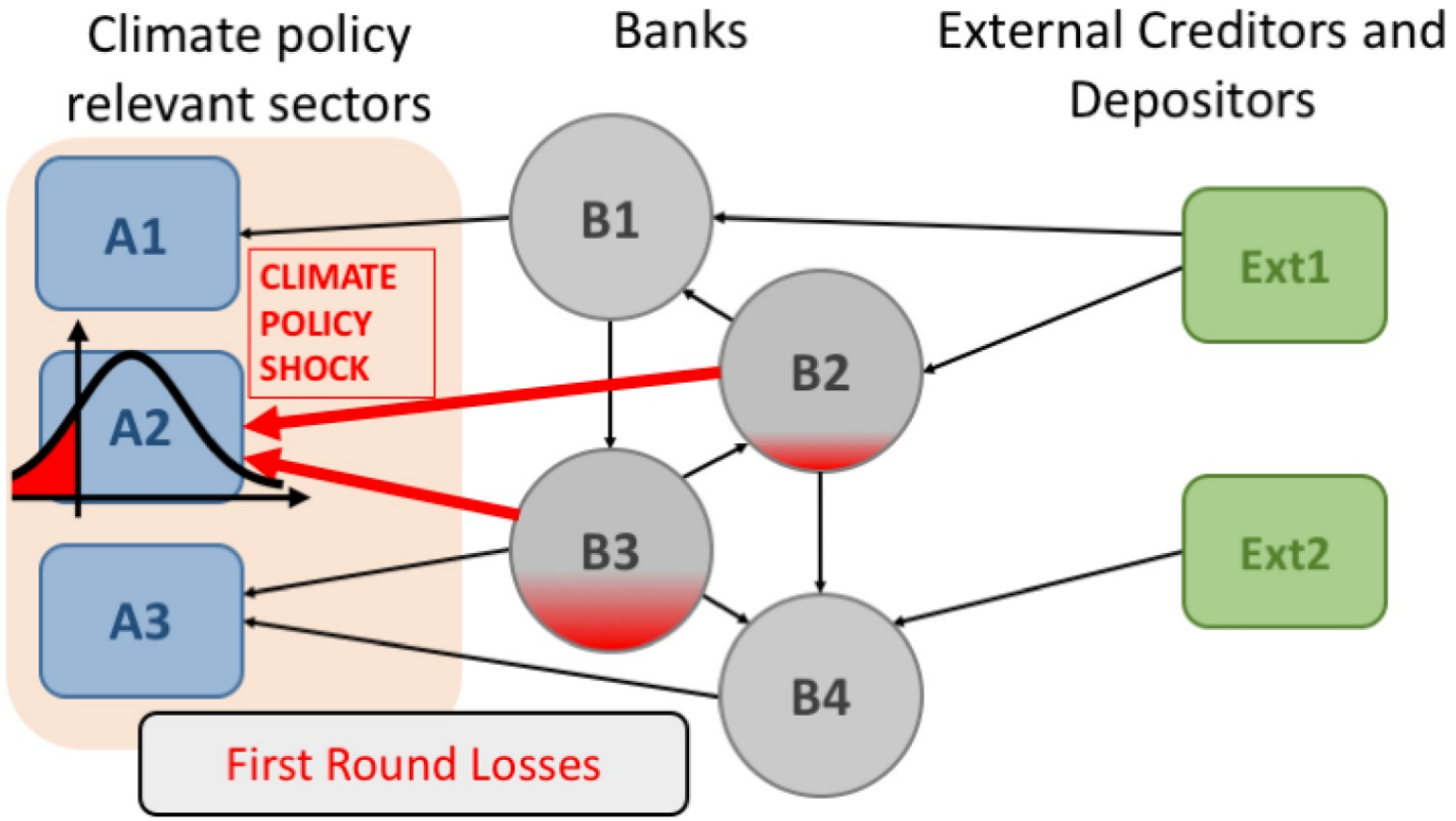
Source: Roncoroni et al. (2021)

How do network effects work?



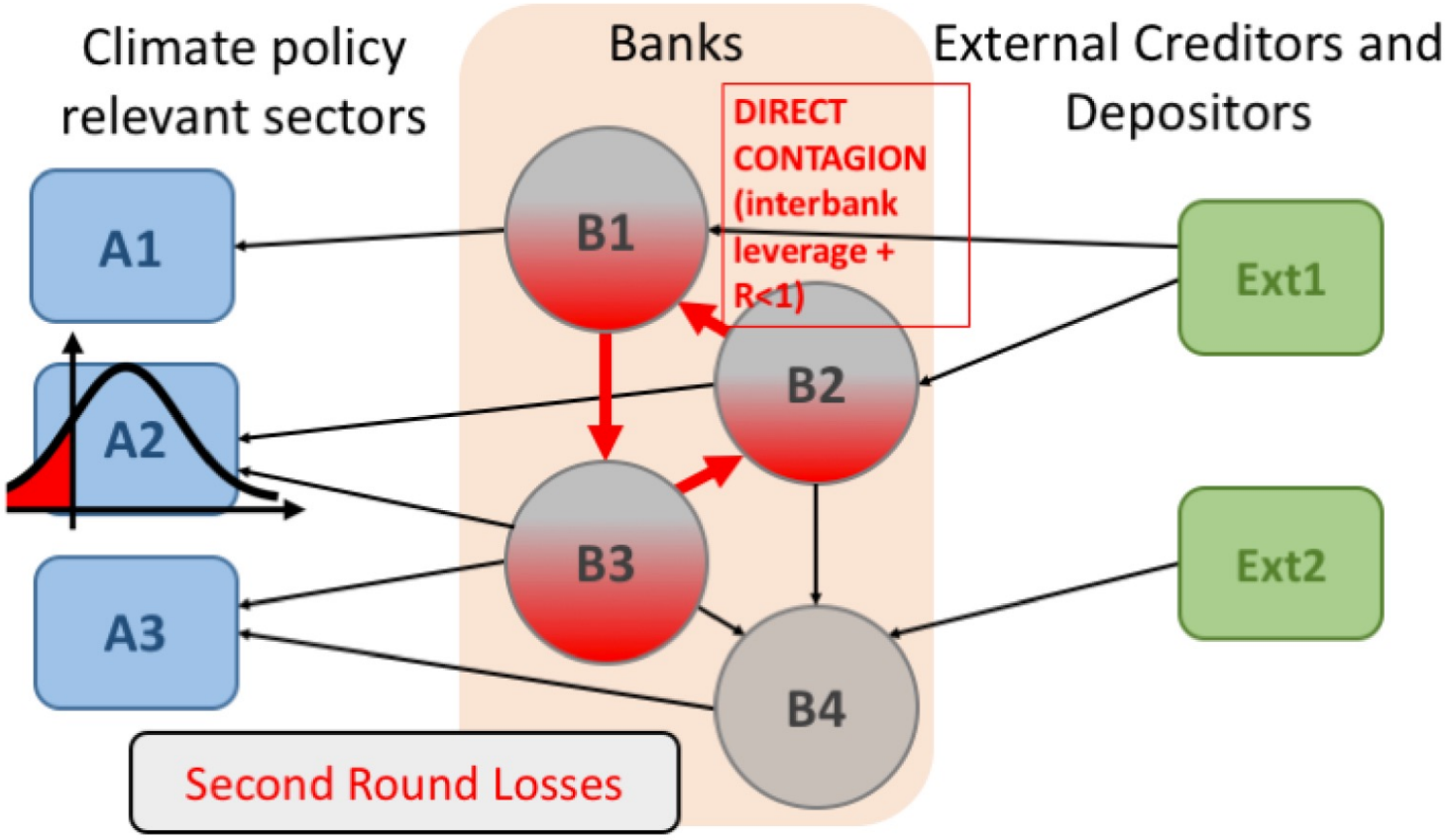
Source: Roncoroni et al. (2021)

How do network effects work?



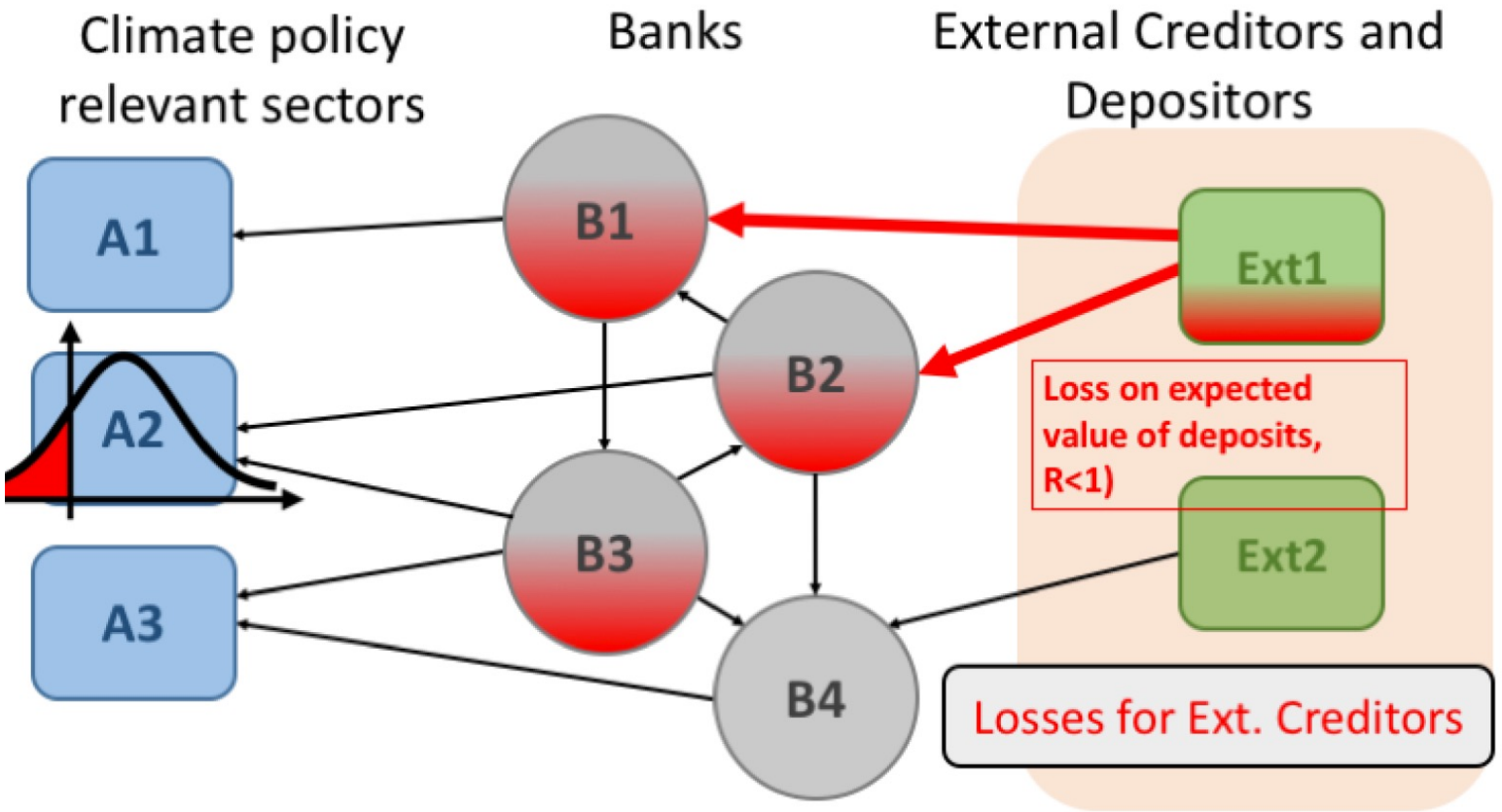
Source: Roncoroni et al. (2021)

How do network effects work?



Source: Roncoroni et al. (2021)

How do network effects work?



Source: Roncoroni et al. (2021)

References

Alogoskoufis S, Dunz N, Emambakhsh T, Hennig T, Kaijser M et al. (2021). *ECB economy-wide climate stress-test Methodology and results*. Occasional Paper Series 281. Frankfurt: European Central Bank

Armstrong McKay, D. I., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., ... & Lenton, T. M. (2022). Exceeding 1.5 C global warming could trigger multiple climate tipping points. *Science*, *377*(6611), eabn7950.

Bardoscia, M., Barucca, P., Battiston, S., Caccioli, F., Cimini, G., Garlaschelli, D., ... & Caldarelli, G. (2021). The physics of financial networks. *Nature Reviews Physics*, *3*(7), 490-507.

Battiston, S, Monasterolo, I (2024). Enhanced scenarios for climate stress-test. INSPIRE Sustainable Central Banking Toolbox – Policy Briefing No.16.

Battiston S. Monasterolo, I., Riahi, K., and van Rujiven, B. (2021). Accounting for finance is key for climate mitigation pathways. *Science*, *372*(6545), 918-920.

Battiston S, Mandel A, Monasterolo I, Schütze F, Visentin G. (2017). A climate stress-test of the financial system. *Nature Climate Change,* 7(4): 283–288.

Cahen-Fourot, L., Campiglio, E., Godin, A., Kemp-Benedict, E., & Trsek, S. (2021). Capital stranding cascades: The impact of decarbonisation on productive asset utilisation. *Energy Economics*, *103*, 105581.

Dunz, N., Mazzocchetti, A., Monasterolo, I., Essenfelder, A., Raberto, M. (2021). Compounding COVID-19 and climate risks: the interplay of banks' lending and government's policy in the shock recovery. *Journal of Banking and Finance, 106303.*

References

Gourdel, R., Monasterolo, I, Dunz, N., Mazzocchetti, A. and Parisi, L. (2024). The double materiality of climate physical and transition risks in the euro-area. *ECB working paper series,* n. 2665, May 2022. *Journal of Financial Stability*.

Gourdel, R., Monasterolo, I., Gallagher, K. (2022). Climate transition spillovers and sovereign risk: evidence from Indonesia. Working paper, G24-V20 Task Force on Climate Policy for Development at the International Monetary Fund (https://bit.ly/3JYpzfM).

Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., & Schellnhuber, H. J. (2019). Climate tipping points—too risky to bet against. *Nature*, *575*(7784), 592-595.

McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 C. *Nature*, *517*(7533), 187-190.

Monasterolo, I., Nieto, M., Schets, E. (2023). The good, the bad and the hot-house world. Conceptual underpinnings of the NGFS Scenarios and suggestions for improvement. *Banco de España working paper series.*

Monasterolo, I. (2020). Embedding finance in the macroeconomics of climate change: research challenges and opportunities ahead. *CESIfo Forum*, 4/2020, p.25-33.

Monasterolo, I., Raberto, M (2018). The EIRIN flow-of-funds behavioral model of green fiscal policies and green sovereign bonds. *Ecological Economics*, 144, 228-243.

Network for Greening the Financial System (NGFS) (2023). NGFS Climate Scenarios for central banks and supervisors - Phase IV. Available at: https://www.ngfs.net/en/ngfs-climate-scenarios-phase-iv-november-2023

References

Network for Greening the Financial System (NGFS) (2023). NGFS Climate Scenarios for central banks and supervisors - Phase IV. Available at: https://www.ngfs.net/en/ngfs-climate-scenarios-phase-iv-november-2023

Ranger, N., Mahul, O., Monasterolo, I. (2022). Assessing Financial Risks from Physical Climate Shock: A Framework for Scenario Generation. *The World Bank*, Equitable Growth, Finance & Institutions Insight. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/37041

Roncoroni, A., Battiston, S., Escobar-Farfán, L. O., & Martinez-Jaramillo, S. (2021). Climate risk and financial stability in the network of banks and investment funds. *Journal of Financial Stability*, *54*, 100870.

Semieniuk, G., Holden, P. B., Mercure, J. F., Salas, P., Pollitt, H., Jobson, K., ... & Viñuales, J. E. (2022). Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nature Climate Change*, *12*(6), 532-538.

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., ... & Schellnhuber, H. J. (2018). Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences*, *115*(33), 8252-8259.

Van der Ploeg, F., & Rezai, A. (2020). Stranded assets in the transition to a carbon-free economy. *Annual review of resource economics*, *12*, 281-298.