Climate economics and asset valuation changes

Régis Gourdel

Vienna University of Economics and Business

Full Immersion Experience

June 21, 2022

GrEnFIn

Greening Energy Market and Finance

Project website: http://grenfin.eu

With the support of the Erasmus+ Programme of the European Union

Outline

Introduction

Climate change and policies

Economic and financial risk from climate change

Climate risk disclosure and data

Climate risk assessment frameworks and scenarios

Asset-level calculations

Introduction

Overview

What you will learn:

- Why climate risks differ from traditional risks analysed in finance
- What are the climate change scenarios, how they are obtained and implications for use in climate economics and finance
- Main climate policies (fiscal, monetary, macro-prudential) and why they differ in terms of implementation
- Metrics and methods for disclosure and risk assessment
- Models to anticipate and estimate climate risk impact

Contact: regis.gourdel@wu.ac.at

Motivation: real economy

Climate change would impact the real economy through many channels

- Lower productivity in some sectors
- House prices and insurance contracts
- Disruption in key sectors due to transition
- Inflationary risks
- Losses for individuals through financial ownership of stranded assets [35]
- Impact on the evolving expectations of households and firms about the future trajectory of the economy [21]

Motivation: financial side

Why worry about climate change in finance?

- Possibility of “green swan” events [7]: costs to insurance and devaluation of assets
- A disorderly transition to a low-carbon economy could trigger losses for financial institutions [2]
- Losses can be amplified by the interconnectedness of financial networks
- Sovereign debt issuance to become more risky [4, 19, 38]

Regulators started taking action on climate

- Several central banks and financial regulators joined the *Network for Greening the Financial System* (NGFS) [28]
- *Countries* assess their exposure to climate risk [30]
- *Multi-national institutions* make effort to integrate it in their toolbox

Financial corporations

- Institutions commit to greening their portfolio
- Groups of financial corporations are created to act jointly on the matter
- But the industry is still massively financing “carbon bombs” and very exposed to high-carbon industries

Methodological framework

Assessing the relation between climate change and the financial system:

1. Climate financial risk *disclosure*: assess investors' exposure to climate relevant activities (beyond emissions and energy technology)
   - Through standardized, granular classification of economic activities, e.g. EU Taxonomy
   - Through ad hoc taxonomy, e.g. Climate Policy Relevant Sectors (CPRS)
2. Climate financial risk *assessment*:
   - Climate *scenarios*: consider the role of finance and its complexity because it can alter orderly/disorderly trajectories [3]
   - Climate *stress test*: consider network effects because financial actors' interconnectedness can amplify risks (eg second, third rounds)

Climate change and policies

Past carbon emissions

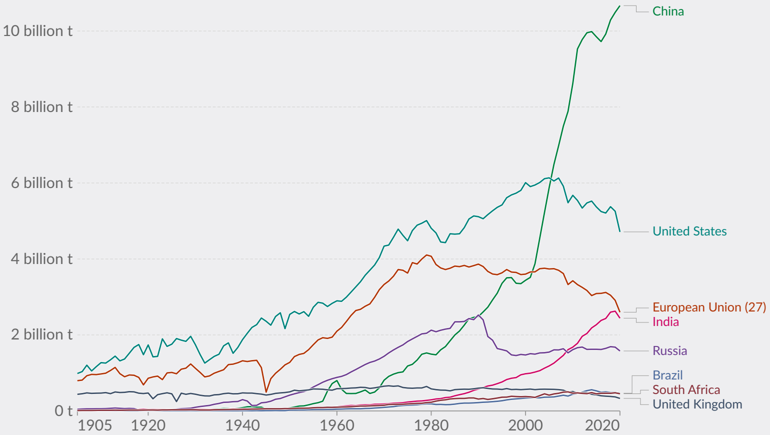

Figure 1: Annual CO_2 emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Source: Global Carbon Project, OurWorldInData.

The climate science report

- The *Intergovernmental Panel on Climate Change* (IPCC) founded in 1988, is a UN body in charge of assessing (mostly) peer-reviewed research on climate and impacts, every 7 years
- It review climate mitigation scenarios (not predictions!) of emissions concentration evolution based on assumptions (population, GDP growth, technological change, etc)
- IPCC [18]: world is on track for 3°C of warming by 2100.
- Limiting 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

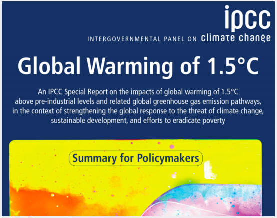

Figure 2: `http://www.ipcc.ch/report/sr15/`

Gree House Gas (GHG) trajectories

Future emissions cause future additonal warming, with total warming dominated by past and future CO_2 emissions.

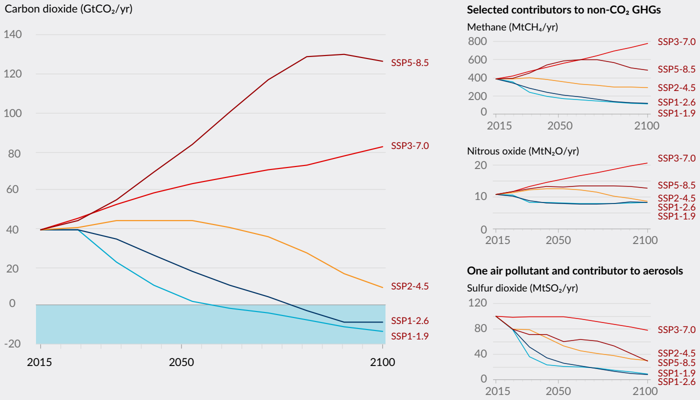

Figure 3: Future annual emissions of CO_2 and of a subset of key non-CO_2 drivers (right), across five illustrative scenarios. Source: IPCC [17].

▸ IPCC pathways

Limiting the impact of climate change to 2°C: the Paris Agreement

- At COP21 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 brings all nations into a common cause to undertake efforts to *mitigate climate change and adapt* to its effects
- Max global temperature increase to *2°C* above pre-industrial levels (desirable 1.5°C)
- Achieving this goal requires *decarbonizing our production and consumption* system by 2050, i.e. cut anthropogenic CO_2 emissions

Are we on track?

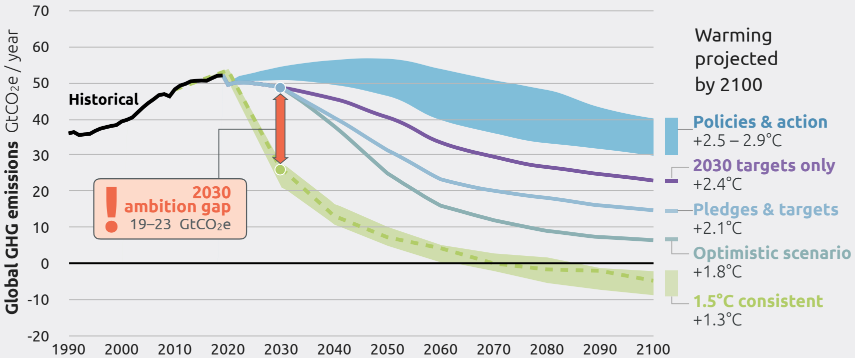

Figure 4: Global GHG emission pathways for estimates of policies and action: 2030 targets only, 2030 and binding long-term targets and an optimistic pathway based on net zero targets of over 140 countries in comparison to a 1.5°C consistent pathway.
Source: Stockwell et al. [36]

See also the ▸ UNEP Net-Zero trajectories

An economic addiction to fossil fuels

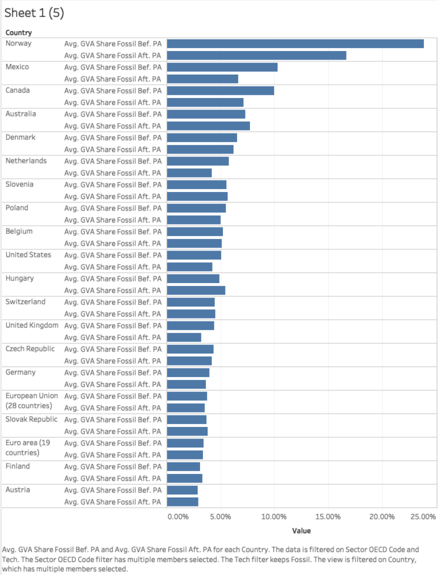

Figure 5: Share of fossil fuels' gross value added in GDP.

Economic and financial risk from climate change

Types of risk

The risks to the financial system can be categorized in two categories [26]:

Physical risk

Impact of extreme weather events on economic activities:

- 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 risk

- Shocks from policy shifts or technology changes
- Losses on carbon-intensive assets → investors' portfolios → cascading effect on their investors in the financial network

Climate physical risk

- Climate change physical risk refers to 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, in the current Greenhouse Gases (GHG) emission trajectory: severe socio-economic consequences are likely to occur (IPCC reports)

Distinction between two types:

- *Chronic risk*: sea level rise, hotter climate with diminished crop yields
- *Acute risk*: increased frequency of extreme weather events such as drought, floods and heatwaves

Consequences of physical risks for financial institutions

Adverse consequences of physical risk include:

- 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
- 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

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
- Even European countries are exposed in the short-term

Example of materiality of climate risk

THE WALL STREET JOURNAL.

Subscribe | Sign In

English Edition ▾ | October 23, 2019 | Print Edition | Video

ome World U.S. Politics Economy **Business** Tech Markets Opinion Life & Arts Real Estate WSJ. Magazine

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 risk is new for financial actors

- *Deep uncertainty*: climate forecasts and its impact contain irreducible uncertainties e.g. presence of tail events (Weitzman 2009) and tipping points (Solomon et al. 2009) that may trigger domino effects (Lenton et al. 2019)
- *Non-linearity*: distribution of extreme climate-related events (heat/cold waves) is highly non-linear (Ackerman 2017) and makes historical data poor proxy of future events
- *Forward-looking nature* of risk: climate impacts are expected in mid to long term while time horizon of finance is shorter (months for investors, 3y for central banks)
- *Endogeneity*: successful transition depends on governments and firms' investment decisions (policy, investments). But both decisions depend on perception of climate risk → occurrence of climate risk scenarios (above 2°C) to realize depends on risk perception of decision makers.

Transition risk

Unanticipated changes in asset values resulting from not transitioning smoothly:

- We tend to think market players are good at anticipating price changes, so policy makers are unlikely to pass climate policies that could entail risks.
- However, past events show that market players may collectively make wrong predictions and policies that entail new risks are sometimes adopted, and unexpectedly so.

Case of unanticipated carbon tax (CT) increase:

- CT can be transferred to households via mark-up pricing, affecting demand
- May induce a relative price effect in favor of green capital goods
- Both channels contribute to decreasing the profitability of brown firms, lowering their ability to service loans
- NPL risk can be transferred to bank, revising capital ratio and worsening lending conditions

Transition risk, winners and losers

- "The (premature) obsolescence of capital stock is a recurring feature [...] as new products and industries replace old 'sunset' ones, and is not typically associated with systemic financial risks because the financial sector is buoyed by the new 'sunrise' sectors. Yet, in the case of the low-carbon transition, the rate of industrial change required for achieving a 2°C, let alone 1.5°C, goal is so large 11 that *the rapid collapse of fossil-fuel 'sunset' industries presents major transition risks*." [35]
- The cheapest fossil fuel producers are likely to survive longer, while those with more costly extraction are exposed in the short-term [25]
- Western countries with little fossil fuel productions are also exposed through financial ownership [35]
- Engaging in decarbonization is optimal for fossil fuel importers [12, 25]

Climate risk disclosure and data

A push for disclosure

- *General lack of reliable data* is a key issue for climate assessments
- Climate-related information has an intersection with ESG data
- Mandatory ESG disclosure is found to have beneficial informational effects (pricing on financial markets) and real effects (incidents become less likely) [20]
- Transparency can address behavioral biases, and improve pricing and market efficiency, but is *not enough alone* for transformation [1]

Key examples of data used:

- carbon emissions (and other GHG)
- commitments/investments to abatement and decarbonization
- biodiversity-related metrics
- exposures to extreme weather events
- investments in adaptation to physical risk
- use of voting rights (for financial institutions)

Disclosure of climate-related financial risks

Governance
The organization’s governance around climate-related risks and opportunities

Strategy
The actual and potential impacts of climate-related risks and opportunities on the organization’s businesses, strategy, and financial planning

Risk Management
The processes used by the organization to identify, assess, and manage climate-related risks

Metrics and Targets
The metrics and targets used to assess and manage relevant climate-related risks and opportunities

Figure 6: Core elements of recommended climate-related financial disclosures, from the G20-FSB Task Force Climate-Related Financial Disclosure (TCFD) [33]

Known issues with climate-related data

For carbon emission, abatement and mitigation policies:

- ESG ratings vary a lot between providers [5]
- Transition risk metrics also vary as they rely on different scenarios [6]
- Carbon emissions often inferred and not reported
- Makes preferences and pricing less meaningful

For physical risk exposure:

- Hain et al. [15] find substantial divergence between six physical risk scores scores, even among those based on similar methodologies
- Lack of clear values also impedes pricing

Exposures can lead to carbon stranded assets

The term stranded assets refers to assets the value of which could decrease (i.e. be "stranded") as a result of either:

- The introduction of climate policies or regulations that discourage the utilization of the fossil fuel in the context of climate change mitigation
- If the introduction of such policies is uncertain and investors cannot anticipate them → disorderly transition
- More frequent/extreme natural hazards (floods, hurricanes, etc) that destroy firms' capital stock affecting productivity and value of the activities

When it comes to a precise definition, there seem to be different uses of the term in the literature [22]:

1. oil and gas reserves and infrastructures for drilling
2. 1 + financial assets of firms that own the rights to use reserves
3. 2 + plus other activities related to fossil industry

Limits with the definition of carbon stranded assets

- No standardized definition of carbon stranded assets
- No classification of sectors at risk (no detailed list of NACE codes)
- Only negative connotation (shadows green opportunities → low market signaling/high moral hazard)
- Difficult to compare estimates of stranded assets across models, countries or investors
- The Climate Policy Relevant Sectors (CPRS) [2] are developed to overcome this limitation: identified based on general criteria, cover activities affected both in terms of risk and opportunities, based on 4-digit NACE codes

How material is the risk of stranded asset?
Depends on how we transition

Orderly

Introduction of credible and stable policies → investors can anticipate the policy and price it (e.g. increase (decrease) exposure to sustainable (dirty) assets → smooth price adjustment

Disorderly

Delayed policy introduction (late and sudden wrt targets, eg EU2030) → investors do not fully anticipate the policy impact on the economy and finance → no portfolio alignment to sustainability

Stranded assets can lead to asset price volatility:

- If large asset classes and systemic investors involved → financial instability
- In reality, most fossil firms are buying renewable plants and buy insurance to hedge against risk (Exxon)

Do we have the right data?

Currently available data are sufficient to carry out a rough estimate of climate risk of financial institutions. However, there are knowledge gaps:

a) Non financial information
   - Firm revenues from energy tech (fossil/renewable) across business lines
   - Science-based classification of stranded assets to complement EU taxonomy

b) Financial information: data on holdings classified by their climate risk (physical, transition) and counterparty

Are we looking at the right variables?

- Transition risk: see above
- Physical risk: beyond emissions and geo-referenced location of activities, downscaled (local) assessment of disasters' losses by sector needed

Climate risk assessment frameworks and scenarios

What are climate mitigation scenarios?

- Climate mitigation scenarios are not predictions.
- They describe what the economy and land use might look like in the next decades.
- Climate mitigation scenarios are paths forward to achieve mitigation goals in time, constrained by:
  - laws of physics (e.g., cumulative CO_2 emissions, i.e. terms of carbon budget until 2100 leading to global warming levels with associated probabilities)
  - technological constraints (e.g. technological efficiency, limits to speed of technology deployment) and finite nature of the planet.
- Process-based, large-scale Integrated Assessment Models (IAM): used to develop long-term scenarios of emissions and socio-economic variables assessed by IPCC [23].

Network for Greening the Financial System's scenarios

The NGFS [27, 29] is the main source of climate scenarios for finance.

- Set of archetypical IAM scenarios assessed by the IPCC with distinct features of the transition
  - timing of carbon price increase (2020, 2030);
  - temperature target (1.5C, 2C)
  - extent of reliance on Carbon Dioxide Removal (CDR)
- NGFS has followed these dimensions to identify 4 high-level scenarios
- Climate transition risk happening sooner and more financially relevant than physical risk

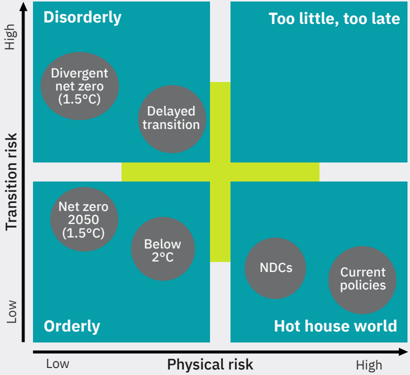

Figure 7: NGFS scenarios framework.

Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100. Source: NGFS [27]

Short-term alternative to scenarios: input-output models

To simulate the impact of policies in the near term, frameworks can rely on so called *IO models*:

- Supply chain view: what are the flows from a sector to others
- Capture production dependencies
- Can be used to model the transmission of carbon prices [10, 14] or the impact of stranded assets [8]
- Key refinements that can be missing: reallocation of flows to different sectors (replacement) and emergence of "sunrise" industries

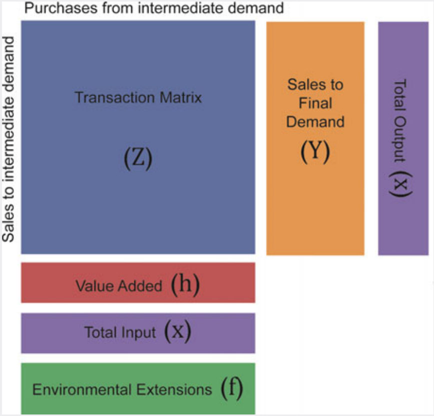

Figure 8: A symmetric input–output table. Source: Owen [32].

The role of contagion

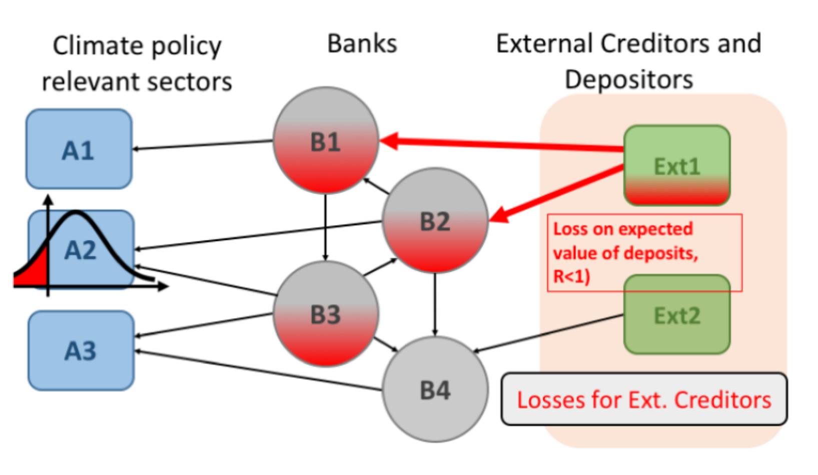

Figure 9: Propagation of a shock affecting firms in the real economy

Examples of climate stress test outcomes

- Battiston et al. [2] find that 43-45% of the equity holdings portfolios of pension funds and investment funds are exposed to disorderly transition. In the US, two thirds of banks' syndicated loans are exposed to transition risk (via fossil fuel and utility firms in particular).
- Guth et al. [14] find that a short-term introduction of a carbon pricing mechanism in Austria would cause a 2.7% decrease for the CET1 ratio of the Austrian banking system in a disorderly scenario

Asset-level calculations

Why does this matter?

For financial instability: missing feedback loop expectations – scenarios can lead to underinvestments wrt to climate targets and disorderly transition (transition risk) or missing the transition (physical and/or transition risk).

Example: consider a utility firm that seeks financing to shift its power plants from high to low-carbon technologies.

- If the bank perceives the strategy as less risky than status quo (high carbon), because climate policy (e.g. carbon price) is perceived as credible, it will charge a lower interest rate on the loan, thus facilitating the firm's technological conversion.
- If the bank perceives the strategy as more risky than status quo (high carbon), because climate policy is perceived as non credible, it will charge a higher interest rate on the loan, thus delaying the firm's technological conversion.

Enabling or hampering

Possible hampering role:

- If investors interpret NGFS orderly transition as scenario where high-carbon firms only slightly more risky than low-carbon (firms adjust tech mix and spread stranded assets over time)
- Limited reallocation of capital could be insufficient to fund investments assumed in scenario
- Transition more costly for society, because it can lead to abrupt reallocations of capital and price adjustments.

The enabling or hampering roles of the financial system can explain how the orderly and disorderly transition in NGFS scenarios emerge endogenously from the interplay of policy timing and investors’ reactions.

For real assets of companies: the NPV approach

- Investments in assets for a company are often informed by their **Net Present Value** (NPV), i.e. the time-discounted expected gain to realize from the asset.
- This value relies on the purchase as well as *projecting future cash flows* related to the asset → can be impacted by climate risk [12]

Typically, the key revenues and input purchases related to an asset are assumed not to change directly from climate variables/policies[1] So, we can isolate an adjustment due to climate specifically, such as

$$\Delta \mathrm{NPV} = \sum_{t=0}^{\infty} \frac{q_t \nu_t \Delta p_E(t, \tau_t) + \gamma_t \tau_t}{(1+r)^t}$$

with r a discount factor, q the production level, τ the carbon tax rate, γ the carbon intensity, Δp_E the difference in energy prices induced by τ, and ν the energy intensity.

[1] Although climate physical risk could cause decreases in production for instance, regardless of commercial inputs.

Real-options valuation (from Flora and Tankov [11])

- Applies option valuation techniques to capital budgeting decisions.
- *Real option* = right to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting a capital investment project.
- To evaluate energy assets and potential investment projects *under transition scenario uncertainty*
- Realization of scenarios is uncertain, and economic agents attach different prior probabilities to it
- Information about the scenario path is acquired progressively by observing a signal $y_t \rightarrow$ Bayesian update
- Formulation as an American option pricing problem: calculates a vector $\mathbf{P}_t$ of risk factors
- Associates a profit an loss function: $h(\mathbf{P}_t)$
- Can be used to determine the optimal exit from a carbon-intensive power plant

Risk metrics: Value at Risk (VaR)

Value-at-risk

Given some confidence level $\alpha \in]0, 1[$, the VaR of a portfolio with loss L at the confidence level α is given by the smallest number l such that the probability that the loss L exceeds l is no larger than $1 - \alpha$. Formally,

$$\mathrm{VaR}_\alpha(L) = \inf\{l \in \mathbb{R} \mid \mathbb{P}(L > l) \leq 1 - \alpha\}$$

In probabilistic terms, VaR is therefore simply a *quantile of the loss distribution*. Typical values for α are $\alpha = 0.95$ or $\alpha = 0.99$; in market-risk management, the time horizon Δt is usually one or ten days, while in credit risk management and operational risk management, Δt is usually one year.

→ VaR has been adapted to the losses from climate risk, especially disorderly transition scenarios [31].

Risk metrics: illustration

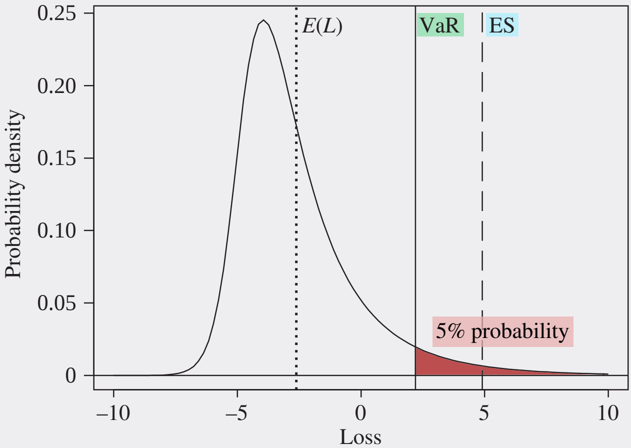

Figure 10: Example of a loss distribution with the 95% VaR marked as a vertical line; the mean loss is shown with a dotted line and the 95% ES is marked with a dashed line. Source: McNeil et al. [24].

Risk metrics: Expected Shortfall (ER)

Expected shortfall (ES)

ES at level α is the expected return on the portfolio in the worst part α of the cases (hence also called “conditional value at risk” because conditioned to returns lower than worst α). Formally,

$$\mathrm{ES}_{\alpha}(L) = \frac{1}{1-\alpha}\int_{\alpha}^{1} q_L(u)\mathrm{d}u,$$

where q_L is the quantile function of the distribution of L.

ES is closely related to VaR and there is an ongoing debate on the strengths and weaknesses of both measures.

With sufficient regularity conditions, we have

$$\mathrm{ES}_{\alpha}(L) = \mathbb{E}[L \mid L \geq \mathrm{VaR}_{\alpha}(L)] \,.$$

Input shocks: how to use the risk metrics?

General challenge: infer the distribution of future returns

- In the short-term: could be determined by current measurable exposures and past market movements [13]
  - Currently available data relevant for shocks happening now, and informing contemporaneous investors' reaction
  - The recent volatility and performance of an asset could delimit the scope of near-term market reaction
- In the long-term:
  - More assumptions needed and highly non-linear effects
  - Tipping point in climate could change the shock distribution brutally
  - Scenarios are a first approximation that reduce the scope of possibilities to a discrete set, but could be generalized sometimes
  - Can use the metrics on the outcome linked to a scenario when it is stochastic (so the values measured are conditional on the scenario's assumptions)

Climate-adjusted probabilities of default (PD)

- PDs are at the core of credit risk and asset pricing more generally
- Climate risk would imply an adjustment of individual financial contracts/securities
  → **climate spread**: difference between the original PD and the one induced by a scenario and reflective of climate risks (both transition and physical)
- Key variable to understand markets' reaction
  - Paris agreement has an effect on the credit rating of high polluting firms [9]

The Merton approach

In Merton's structural credit risk model [24], the market value of assets are

- For equity: $\text{MV}_E(t) = V_t\Phi(d_1) - Le^{-r(T-t)}\Phi(d_2)$
- For debt: $\text{MV}_D(t) = Le^{-r(T-t)}\Phi(d_2) + V_t\Phi(-d_1)$

where we have

$$d_1 = \frac{\ln(V_t/L) + (r + \sigma_V^2/2)(T-t)}{\sigma_V\sqrt{T-t}}, \qquad d_2 = d_1 - \sigma_V\sqrt{T-t}$$

- V the value of the company's assets
- L the value of the company's debt
- σ_V the standard deviation of stock returns
- T the debt's time to maturity
- r the risk-free interest rate
- Φ the c.d.f. of the normal distribution

▸ Merton model assumptions

A Merton approach to climate-adjusted PDs

A shock ξ is applied to the company's assets [34], such that V becomes $V^* = (1-\xi)V$. Then

- d_1^* and d_2^* are calculated using V^*,
- MV_E^* and MV_D^* are computed similarly to the initial case.

The initial shock ξ is obtained such that $\xi / V_t = \Delta\mathrm{NPV}_{\mathrm{tax}}$, where

$$\Delta\mathrm{NPV}_{\mathrm{tax}} = \sum_{t=0}^{T} (1-r)^t \gamma_t (1-\phi_t)(-\tau_t)$$

is the carbon tax adjustment in NPV, with r a discount rate, γ the carbon emissions, ϕ a pass-through rate, and τ the carbon tax rate.

Appendix

References

References

[1] Nadia Ameli, Paul Drummond, Alexander Bisaro, Michael Grubb, and Hugues Chenet. "Climate finance and disclosure for institutional investors: why transparency is not enough". In: *Climatic Change* 160.4 (2020), pp. 565–589. DOI: 10.1007/s10584-019-02542-2.

[2] Stefano Battiston, Antoine Mandel, Irene Monasterolo, Franziska Schütze, and Gabriele Visentin. "A climate stress-test of the financial system". In: *Nature Climate Change* 7.4 (2017), pp. 283–288. DOI: 10.1038/NCLIMATE3255.

[3] Stefano Battiston, Irene Monasterolo, Keywan Riahi, and Bas J van Ruijven. "Accounting for finance is key for climate mitigation pathways". In: *Science* 372.6545 (2021), pp. 918–920. DOI: 10.1126/science.abf3877.

[4] John Beirne, Nuobu Renzhi, and Ulrich Volz. "Feeling the heat: Climate risks and the cost of sovereign borrowing". In: *International Review of Economics & Finance* 76 (2021), pp. 920–936. DOI: 10.1016/j.iref.2021.06.019.

[5] Monica Billio, Michele Costola, Iva Hristova, Carmelo Latino, and Loriana Pelizzon. "Inside the ESG Ratings:(Dis) agreement and performance". In: *Corporate Social Responsibility and Environmental Management* 28.5 (2021), pp. 1426–1445. DOI: 10.1002/csr.2177.

References

[6] Julia Anna Bingler, Chiara Colesanti Senni, and Pierre Monnin. *Climate Transition Risk Metrics: Understanding Convergence and Divergence across Firms and Providers*. Working Paper 21/363. Center of Economic Research at ETH Zurich, 2022. DOI: 10.3929/ethz-b-000505345.

[7] Patrick Bolton, Morgan Després, Luiz Awazu Pereira Da Silva, Frédéric Samama, and Romain Svartzman. ““Green Swans”: central banks in the age of climate-related risks”. In: *Bulletin de la Banque de France*. Vol. 229. 8. 2020.

[8] Louison Cahen-Fourot, Emanuele Campiglio, Antoine Godin, Eric Kemp-Benedict, and Stefan Trsek. “Capital stranding cascades: The impact of decarbonisation on productive asset utilisation”. In: *Energy Economics* 103 (2021), p. 105581. ISSN: 0140-9883. DOI: 10.1016/j.eneco.2021.105581.

[9] Sante Carbone et al. *The low-carbon transition, climate commitments and firm credit risk*. Working Paper 2631. European Central Bank, 2021. DOI: 10.2866/56399.

[10] John Creedy and Catherine Sleeman. “Carbon taxation, prices and welfare in New Zealand”. In: *Ecological Economics* 57.3 (2006), pp. 333–345. DOI: 10.1016/j.ecolecon.2005.04.015.

[11] Maria Flora and Peter Tankov. “Green investment and asset stranding under transition scenario uncertainty”. 2022.

References

[12] Régis Gourdel, Irene Monasterolo, Nepomuk Dunz, Andrea Mazzocchetti, and Laura Parisi. *The double materiality of climate physical and transition risks in the euro area*. Working Paper 2665. European Central Bank, 2022. DOI: 10.2866/870362.

[13] Régis Gourdel and Matthias Sydow. *Risk on both sides: dualities in shock transmission and climate stress for investment funds*. Working Paper Series. Forthcoming. European Central Bank, 2022.

[14] Martin Guth et al. "OeNB climate risk stress test–modeling a carbon price shock for the Austrian banking sector". In: *Financial Stability Report*. 42. 2021, pp. 27–45.

[15] Linda I. Hain, Julian F. Kölbel, and Markus Leippold. "Let's get physical: Comparing metrics of physical climate risk". In: *Finance Research Letters* (2022), p. 102406. ISSN: 1544-6123. DOI: 10.1016/j.frl.2021.102406.

[16] IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Tech. rep. Intergovernmental Panel on Climate Change, 2014.

References

[17] IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Tech. rep. Intergovernmental Panel on Climate Change, 2021.

[18] IPCC. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Tech. rep. Intergovernmental Panel on Climate Change, 2018.

[19] Gerhard Kling, Yuen C Lo, Victor Murinde, and Ulrich Volz. “Climate vulnerability and the cost of debt”. In: *Available at SSRN 3198093* (2018). DOI: 10.2139/ssrn.3198093.

[20] Philipp Krueger, Zacharias Sautner, Dragon Yongjun Tang, and Rui Zhong. *The Effects of Mandatory ESG Disclosure around the World*. Finance Working Paper 21-44. European corporate governance institute, 2021.

[21] Philip R. Lane. *Climate Change and the Irish Financial System*. Economic Letter 1. 2019.

[22] James Leaton. *Unburnable Carbon—Are the World’s Financial Markets Carrying a Carbon Bubble?* Tech. rep. Carbon Tracker Initiative, 2011.

References

[23] David L. McCollum et al. “Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals”. In: *Nature Energy* 3.7 (2018), pp. 589–599. DOI: 10.1038/s41560-018-0179-z.

[24] Alexander J McNeil, Rüdiger Frey, and Paul Embrechts. *Quantitative risk management: concepts, techniques and tools-revised edition*. Princeton university press, 2015.

[25] J-F Mercure et al. “Reframing incentives for climate policy action”. In: *Nature Energy* 6.12 (2021), pp. 1133–1143. DOI: 10.1038/s41560-021-00934-2.

[26] Irene Monasterolo. “Climate change and the financial system”. In: *Annual Review of Resource Economics* 12 (2020), pp. 299–320. DOI: 10.1146/annurev-resource-110119-031134.

[27] Network for Greening the Financial System. *NGFS Climate Scenarios for central banks and supervisors*. Tech. rep. Network for Greening the Financial System, 2021.

[28] NGFS. *A call for action. Climate change as a source of financial risk*. First comprehensive report. Network for Greening the Financial System, 2019.

[29] NGFS. *NGFS Climate Scenarios for central banks and supervisors*. Tech. rep. Network for Greening the Financial System, 2020.

References

[30] OBR. *Fiscal risks report*. Tech. rep. CP 453. Office for Budget Responsibility, 2021.

[31] Javier Ojea-Ferreiro, Juan C Reboredo, Andrea Ugolini, et al. *The impact of climate transition risks on financial stability. A systemic risk approach.* JRC Working Papers in Economics and Finance 2022/1. Joint Research Centre, 2022.

[32] Anne Owen. *Techniques for Evaluating the Differences in Multiregional Input-Output Databases. A Comparative Evaluation of CO_2 Consumption-Based Accounts Calculated Using Eora, GTAP and WIOD*. Developments in Input-Output Analysis. Springer, 2017. DOI: 10.1007/978-3-319-51556-4.

[33] *Recommendations of the Task Force on Climate-related Financial Disclosures*. Tech. rep. Task Force on Climate-related Financial Disclosures, 2017.

[34] Henk Jan Reinders, Dirk Schoenmaker, and Mathijs A Van Dijk. *A finance approach to climate stress testing*. Discussion Paper DP14609. CEPR, 2020.

[35] Gregor Semieniuk et al. “Stranded fossil-fuel assets translate to major losses for investors in advanced economies”. In: *Nature Climate Change* (2022). DOI: 10.1038/s41558-022-01356-y.

References

[36] Claire Stockwell et al. *Glasgow's 2030 credibility gap: net zero's lip service to climate action. Wave of net zero emission goals not matched by action on the ground*. Warming Projections Global Update. Climate Action Tracker, 2022.

[37] UNEP. *The Heat Is On. A world of climate promises not yet delivered*. Emissions Gap Report 2021. United Nations Environment Programme, 2021.

[38] Ulrich Volz et al. *Climate change and sovereign risk*. Tech. rep. SOAS Centre for Sustainable Finance, Asian Development Bank Institute, World Wide Fund for Nature Singapore, Four Twenty Seven, 2020.

Additional policy information

The types of carbon trajectories

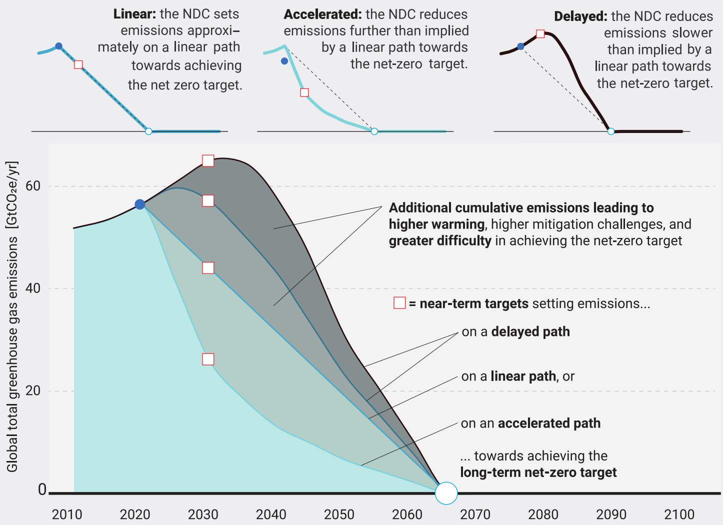

Figure 11: Trajectories for carbon emissions. Source: UNEP [37]

The Nationally Determined Contributions

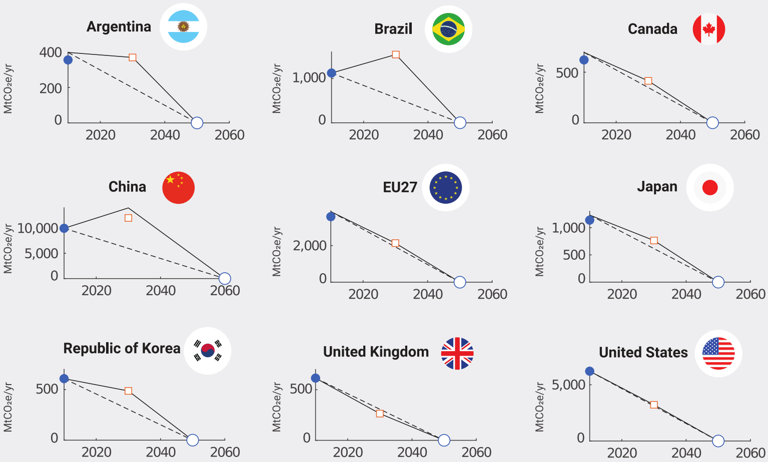

Figure 12: Emission trajectories based on Nationally Determined Contributions (NDCs) for a selection of G20 countries. Source: UNEP [37]

The IPCC pathways

- IPCC scenarios are used to make projections, especially of GHG emissions.
- They are based population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy.
- *Representative Concentration Pathways* (RCPs): IPCC [16] uses four different 21st century pathways.
- *Shared Socio-economic Pathways* (SSPs): IPCC [17] uses five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature.

Representative Concentration Pathways

- Four 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use:
  1. Stringent mitigation scenario (RCP2.6),
  2. Two intermediate scenarios (RCP4.5 and RCP6.0)
  3. Scenario with very high GHG emissions (RCP8.5).
  4. Baseline scenarios (without additional efforts to constrain emissions) lead to pathways ranging between RCP6.0 and RCP8.5
- RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures.
- Consistent with the wide range of scenarios in the literature as assessed by WGIII

Shared Socio-economic Pathways

- Start in 2015
- Include scenarios with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5), scenarios with intermediate GHG emissions (SSP2-4.5), and scenarios with very low and low GHG emissions, followed by varying levels of net negative CO_2 emissions.
- Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and air pollution controls.

Financial risk appendix

Merton model assumptions

(i) We have frictionless markets with continuous trading.

(ii) The risk-free interest rate is deterministic and equal to $r \geq 0$.

(iii) The firm's asset-value process (V_t) is independent of the way the firm is financed, and in particular it is independent of the debt level B. Moreover, (V_t) is a traded security with dynamics given by the Black–Scholes model

$$\mathrm{d}V_t = \mu_V V_t \mathrm{d}t + \sigma_V V_t \mathrm{d}W_t$$

for constants $\mu_V \in \mathbb{R}$, $\sigma_V > 0$, and a standard Brownian motion (W_t).

GrEnFIn

Greening Energy Market and Finance

Project website: http://grenfin.eu

With the support of the Erasmus+ Programme of the European Union