Course 2021-2022 in ESG and Climate Risks

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[1] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Agenda

- **Lecture 1: Introduction**
  - *Definition, Actors, the Market of ESG Investing* (42 slides)
- **Lecture 2: ESG Investing**
  - *ESG Scoring, ESG Ratings, Performance of ESG Investing, ESG Financing, ESG Premium* (132 slides)
- **Lecture 3: Other ESG Topics**
  - *Sustainable Financing Products, Impact Investing, Voting Policy & Engagement, ESG and Climate Accounting* (82 slides)
- **Lecture 4: Climate Risk**
  - *Definition, Global Warming, Economic Modeling, Risk Measures* (176 slides)
- **Lecture 5: Climate Investing**
  - *Portfolio Decarbonization, Net Zero Carbon Metrics, Portfolio Alignment* (164 slides)
- **Lecture 6: Mathematical Methods, Technical Tools and Exercises**
  - *Scoring System, Trend Modeling, Geolocation Data, Numerical Computations, Optimization* (150+ slides)

General information

1. **Overview**
   The objective of this course is to understand the concepts of sustainable finance from the viewpoint of asset owners and managers
2. **Prerequisites**
   M1 Finance or equivalent
3. **ECTS**
   3
4. **Keywords**
   Finance, Asset Management, ESG, Responsible Investing, Climate Change
5. **Hours**
   Lectures: 18h
6. **Evaluation**
   Project + oral examination
7. **Course website**
   `http://www.thierry-roncalli.com/SustainableFinance.html`

Class schedule

Course sessions

- Date 1 (6 hours, AM+PM)
- Date 2 (6 hours, AM+PM)
- Date 3 (6 hours, AM+PM)

Class times: Friday 9:00am-12:00pm, 1:00pm–4:00pm, Location: University of Evry

Additional materials

http://www.thierry-roncalli.com/SustainableFinance.html

- Slides
- Past examinations
- Exercises + Solutions
- LaTeX source of the slides + figures (in pdf format)
- Links to the references

Main references

Amundi publications on ESG Investing

1. Bennani *et al.* (2018), How ESG Investing Has Impacted the Asset Pricing in the Equity Market, DP-36-2018, 36 pages, November 2018
2. Drei *et al.* (2019), ESG Investing in Recent Years: New Insights from Old Challenges, DP-42-2019, 32 pages, December 2019
3. Ben Slimane *et al.* (2020), ESG Investing and Fixed Income: It's Time to Cross the Rubicon, DP-45-2019, 36 pages, January 2020
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1. Le Guenedal, T. (2019), Economic Modeling of Climate Risk, WP-83-2019, 92 pages, April 2019
2. Bouchet, V., and Le Guenedal, T. (2020), Credit Risk Sensitivity to Carbon Price, WP-95-2020, 48 pages, May 2020
3. Le Guenedal *et al.* (2020), Trajectory Monitoring in Portfolio Management and Issuer Intentionality Scoring, WP-97-2020, 54 pages, May 2020
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5. Ben Slimane, M., Da Fonseca, D., and Mahtani, V. (2020), Facts and Fantasies about the Green Bond Premium, WP-102-2020, 52 pages, December 2020
6. Le Guenedal, Drobinski, P., and Tankov, P. (2021), Measuring and Pricing Cyclone-Related Physical Risk under Changing Climate, WP-111-2021, 42 pages, June 2021
7. Adenot *et al.* (2022), Cascading Effects of Carbon Price through the Value Chain and their Impacts on Firm's Valuation, WP-122-2022, 82 pages, February 2022
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2. Créhalet, E., Foll, J., Haustant, P., and Hessenberger, T. (2021), Carbon Offsetting: How Can It Contribute to the Net Zero Goal?, *Amundi ESG Thema #5*, https://research-center.amundi.com
3. Créhalet, E., and Talwar, S. (2021), Carbon-efficient Technologies in the Race to Net Zero, *Amundi ESG Thema #6*, https://research-center.amundi.com
4. Le Meaux, C., Le Berthe, T., Jaulin, T., Créhalet, E., Jouanneau, M., Pouget-Abadie, T., and Elbaz, J. (2021), How can Investors Contribute to Net Zero Efforts?, *Amundi ESG Thema #3*, https://research-center.amundi.com

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1. Andersson, M., Bolton, P., and Samama, F. (2016), Hedging Climate Risk, *Financial Analysts Journal*, www.ssrn.com/abstract=2499628.
2. Ardia, D., Bluteau, K., Boudt, K., and Inghelbrecht, K. (2021), Climate Change Concerns and the Performance of Green versus Brown Stocks, *National Bank of Belgium, Working Paper*, www.ssrn.com/abstract=3717722.
3. Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., and Visentin, G. (2017), A Climate Stress-test of the Financial System, *Nature Climate Change*, www.ssrn.com/abstract=2726076.
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6. Bolton, P., and Kacperczyk, M. (2021), Do Investors Care about Carbon Risk?, *Journal of Financial Economics*, www.ssrn.com/abstract=3594189
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9. Crifo, P., Diaye, M.A., and Oueghlissi, R. (2015), Measuring the Effect of Government ESG Performance on Sovereign Borrowing Cost, *Quarterly Review of Economics and Finance*, hal.archives-ouvertes.fr/hal-00951304v3
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Part 1. Introduction

Part 2. ESG Investing

Part 3. Other Responsible Investment Topics

Part 4. Climate Risk

Part 5. Climate Investing

Part 6. Mathematical Methods, Technical Tools and Exercises

Course 2021-2022 in ESG and Climate Risks
Lecture 1. Introduction

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Many words, one concept

Figure 1: Many words, one concept

RI, SI, SRI, ESG, etc.

Responsible investment (RI)

Responsible investment is an approach to investment that explicitly acknowledges the relevance to the investor of environmental, social and governance factors, and of the long-term health of the market as a whole

Sustainable investing (SI)

Sustainable investing is an investment approach that considers environmental, social and governance factors in portfolio selection

Socially responsible investing (SRI)

SRI is an investment strategy that is considered socially responsible, because it invests in companies that have ethical practices

Environmental, Social and Governance (ESG)

Environmental, Social, and Corporate Governance (ESG) refers to the factors that measure the sustainability of an investment

Definition

Sustainable Investing

$\approx$

Socially Responsible Investing (SRI)

$\approx$

Environmental, Social, and Governance (ESG)

Remark

Blue Finance $\subset$ **Green Finance**, Climate Finance $\subset$ Sustainable Finance

Historical perspective

- Responsible investment (RI): 2000's
- ESG investing (ESG): 2010's
- Sustainable finance (SF): 2020's

Why?

Historical perspective

- At the beginning, sustainable finance mainly concerns final investors and asset owners (ethics) $\Rightarrow$ **responsible investment**
- Then, it gains momentum in asset management $\Rightarrow$ **ESG investing**
- Finally, it spreads across all financial actors (e.g. issuers, banks, central banks, etc.) $\Rightarrow$ **Sustainable finance**

ESG motivations

Figure 2: The raison d'être of ESG investing

A myriad of acronyms

How many acronyms do you know?

A myriad of acronyms

CAT: Cap-And-Trade, CBI: Climate Bonds Initiative, **CDP: Carbon Disclosure Project**, CDR: Carbon Dioxide Removal, CDSB: Climate Disclosure Standards Board, CI: Carbon Intensity, **COP: Conference of the Parties**, **CTB: Climate Transition Benchmark**, DAC: Direct Air Capture, DICE: Dynamic Integrated Climate-Economy Model, ETS: Emissions Trading Scheme, Eurosif: European Sustainable Investment Forum, ESG: Environmental, Social and Governance, GB: Green Bond, **GBP: Green Bonds Principles**, : Greenhouse gas Emissions per unit of Value Added, **GHG: Greenhouse Gaz**, **GIIN: Global Impact Investing Network**, GLP: Green Loans Principles, GQE: Green Quantitative Easing, GRI: Global Reporting Initiative, **GSIA: Global Sustainable Investment Alliance**, HLEG: High Level Expert Group on Sustainable Finance, IAM: Integrated Assessment Model (economic model of climate risk), IIRC: International Integrated Reporting Council, **IPCC: Intergovernmental Panel on Climate Change**, **NDC: Nationally Determined Contribution**, NFRD: Non-financial Reporting Directive, NGFS: Network for Greening the Financial System, OPS: One Planet Summit, **PAB: Paris Aligned Benchmark**, PBOC: People's Bank of China (China green bonds), **PRI: Principles for Responsible Investment**, **RCP: Representative Concentration Pathway (climate scenario)**, SASB: Sustainability Accounting Standards Board, SB: Social Bond, SBP: Social Bonds Principles, SBT: Science-Based Target, SCC: Social Cost of Carbon (= optimal carbon tax), SDA: Sectoral Decarbonisation Approach **SDG: Sustainable Development Goals**, **SFDR: Sustainable Finance Disclosure Reporting**, SIB: Social Impact Bond, SRI: Socially Responsible Investing, SSB: Sustainabilty Standards Board (IFRS), SSP: Shared Socioeconomic Pathway, **TCFD: Task Force on Climate-Related Financial Disclosures**, TEG: Technical Expert Group on Sustainable Finance, UNPRI: Principles for Responsible Investment (PRI)

Many financial actors

ESG financial ecosystem

- Asset owners (pension funds, sovereign wealth funds (SWF), insurance and institutional investors, retail investors, etc.)
- Asset managers
- ESG rating agencies
- ESG index sponsors
- Banks
- ESG associations (GSIA, UNPRI, etc.)
- Regulators and international bodies (governments, financial and industry regulators, central banks, etc.)
- **Issuers** (equities, bonds, loans, etc.)
- Society and people

ESG Investing $\Leftrightarrow$ ESG Financing (= Sustainable Finance)

ESG regulations

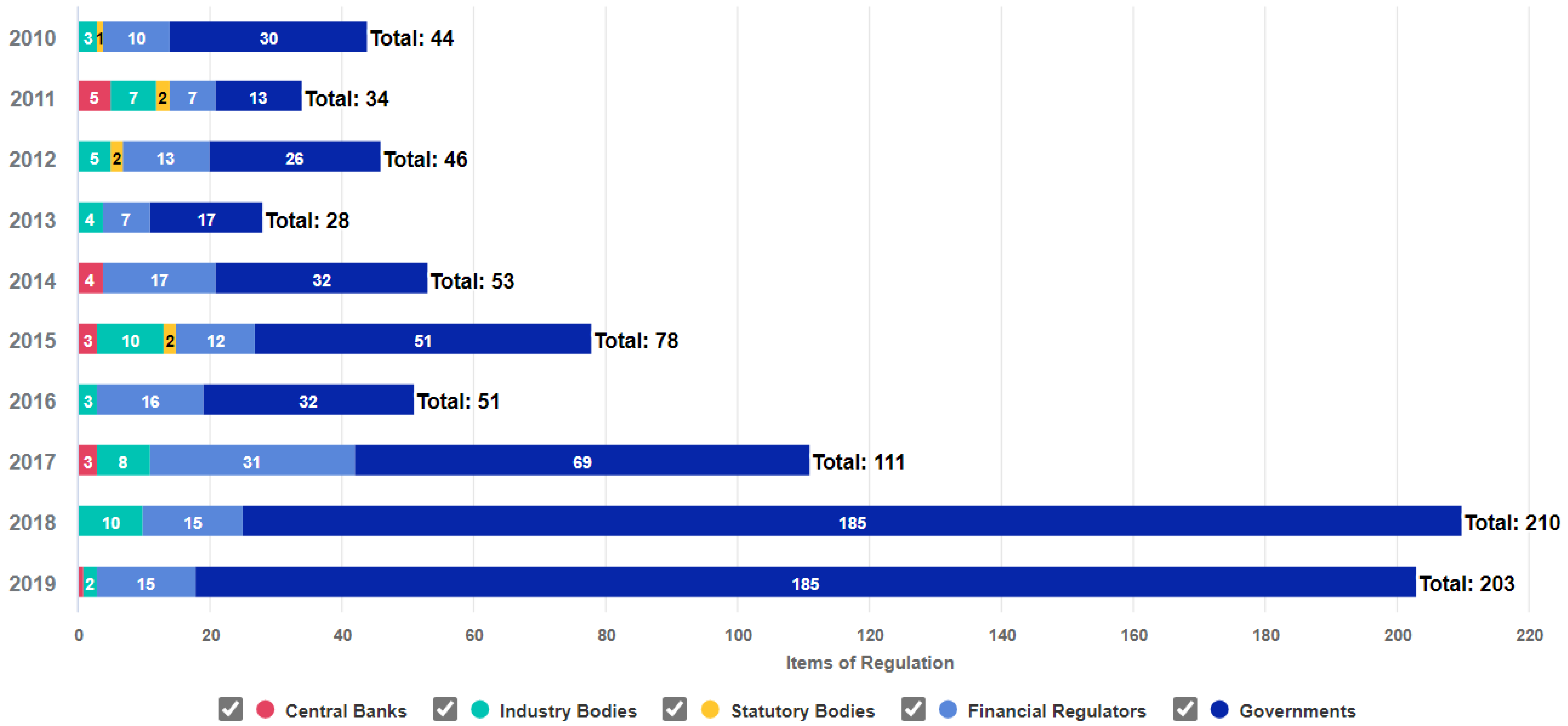

Figure 3: List of ESG regulations (MSCI, Who will regulate ESG?)

ESG regulations

Visit the MSCI website

`https://www.msci.com/who-will-regulate-esg`

and obtain the detailed list of regulations

by year, country, regulator, regulated investors, etc.

ESG regulators

The example of ESMA

ESMA strategy on sustainable finance

1. Completing the regulatory framework on transparency obligations via the Disclosures Regulation (joint technical standards with EBA and EIOPA)
2. TRV (trends, risks and vulnerabilities) reporting of sustainable finance
3. Analyse financial risks from climate change, including potentially climate-related stress testing
4. Convergence of national supervisory practices on ESG factors
5. Participating in the EU taxonomy on sustainable finance
6. Ensuring ESG guidelines are implemented by regulated entities (e.g. asset managers)

ESG regulators

The example of central banks

Figure 4: Network of Central Banks and Supervisors for Greening the Financial System (NGFS)

- Launched at the Paris One Planet Summit (OPS) on December 2017
- 8 founding members: Banco de Mexico, BoE, BdF, Dutch Central Bank, Buba, Swedish FSA, HKMA, MAS and PBOC
- As of March 19th 2021, the NGFS consists of 89 members (CBs, EBA, EIOPA, ESMA) and 13 observers (BCBS, IMF, IAIS, IOSCO)

ESG regulators

The example of central banks

Go the NGFS website (`https://www.ngfs.net`) and download the NGFS climate scenarios

See also `https://data.ene.iiasa.ac.at/ngfs` (NGFS scenario explorer hosted by IIASA[3])

[3] International Institute for Applied Systems Analysis

ESG associations

Figure 5: Global Sustainable Investment Alliance (GSIA)

http://www.gsi-alliance.org

ESG associations

Figure 6: 2018 GSIA report

Figure 7: 2020 GSIA report

ESG associations

GSIA members

- The European Sustainable Investment Forum (Eurosif), `http://www.eurosif.org`
- Responsible Investment Association Australasia (RIAA), `https://responsibleinvestment.org`
- Responsible Investment Association Canada (RIA Canada), `https://www.riacanada.ca`
- UK Sustainable Investment & Finance Association (UKSIF), `https://www.uksif.org`
- The Forum for Sustainable & Responsible Investment (US SIF), `https://www.ussif.org`
- Dutch Association of Investors for Sustainable Development (VBDO), `https://www.vbdo.nl/en/`
- Japan Sustainable Investment Forum (JSIF), `https://japansif.com/english`

ESG associations

Figure 8: 2018 Eurosif report

Figure 9: 2021 Eurosif report

ESG associations

Figure 10: Principles for Responsible Investment (PRI)

`https://www.unpri.org`

ESG associations

PRI (or UNPRI)

- Early 2005: UN Secretary-General Kofi Annan invited a group of the world's largest institutional investors to join a process to develop the Principles for Responsible Investment
- April 2006: The Principles were launched at the New York Stock Exchange
- 6 ESG principles
- The 63 founding signatories are 32 asset owners[a] and 31 asset managers[b] and data providers[c]

[a] AP2, CDC, CDPQ, CalPERS, ERAFP, FRR, IFC, NZSF, NGPF, PGGM, UNJSPF, USS, etc.

[b] Amundi (CAAM), Sumitomo Trust, BNP PAM, Mitsubishi Trust, Threadneedle, Aviva, Candriam, etc.

[c] Trucost, Vigeo, etc.

ESG associations

Signatories' commitment

"As institutional investors, we have a duty to act in the best long-term interests of our beneficiaries. In this fiduciary role, we believe that environmental, social, and corporate governance (ESG) issues can affect the performance of investment portfolios (to varying degrees across companies, sectors, regions, asset classes and through time).
We also recognise that applying these Principles may better align investors with broader objectives of society. Therefore, where consistent with our fiduciary responsibilities, we commit to the following:

- Principle 1: We will incorporate ESG issues into investment analysis and decision-making processes.
- Principle 2: We will be active owners and incorporate ESG issues into our ownership policies and practices.
- Principle 3: We will seek appropriate disclosure on ESG issues by the entities in which we invest.
- Principle 4: We will promote acceptance and implementation of the Principles within the investment industry.
- Principle 5: We will work together to enhance our effectiveness in implementing the Principles.
- Principle 6: We will each report on our activities and progress towards implementing the Principles.

The Principles for Responsible Investment were developed by an international group of institutional investors reflecting the increasing relevance of environmental, social and corporate governance issues to investment practices. The process was convened by the United Nations Secretary-General.
In signing the Principles, we as investors publicly commit to adopt and implement them, where consistent with our fiduciary responsibilities. We also commit to evaluate the effectiveness and improve the content of the Principles over time. We believe this will improve our ability to meet commitments to beneficiaries as well as better align our investment activities with the broader interests of society.
We encourage other investors to adopt the Principles."

Source: `https://www.unpri.org`

ESG associations

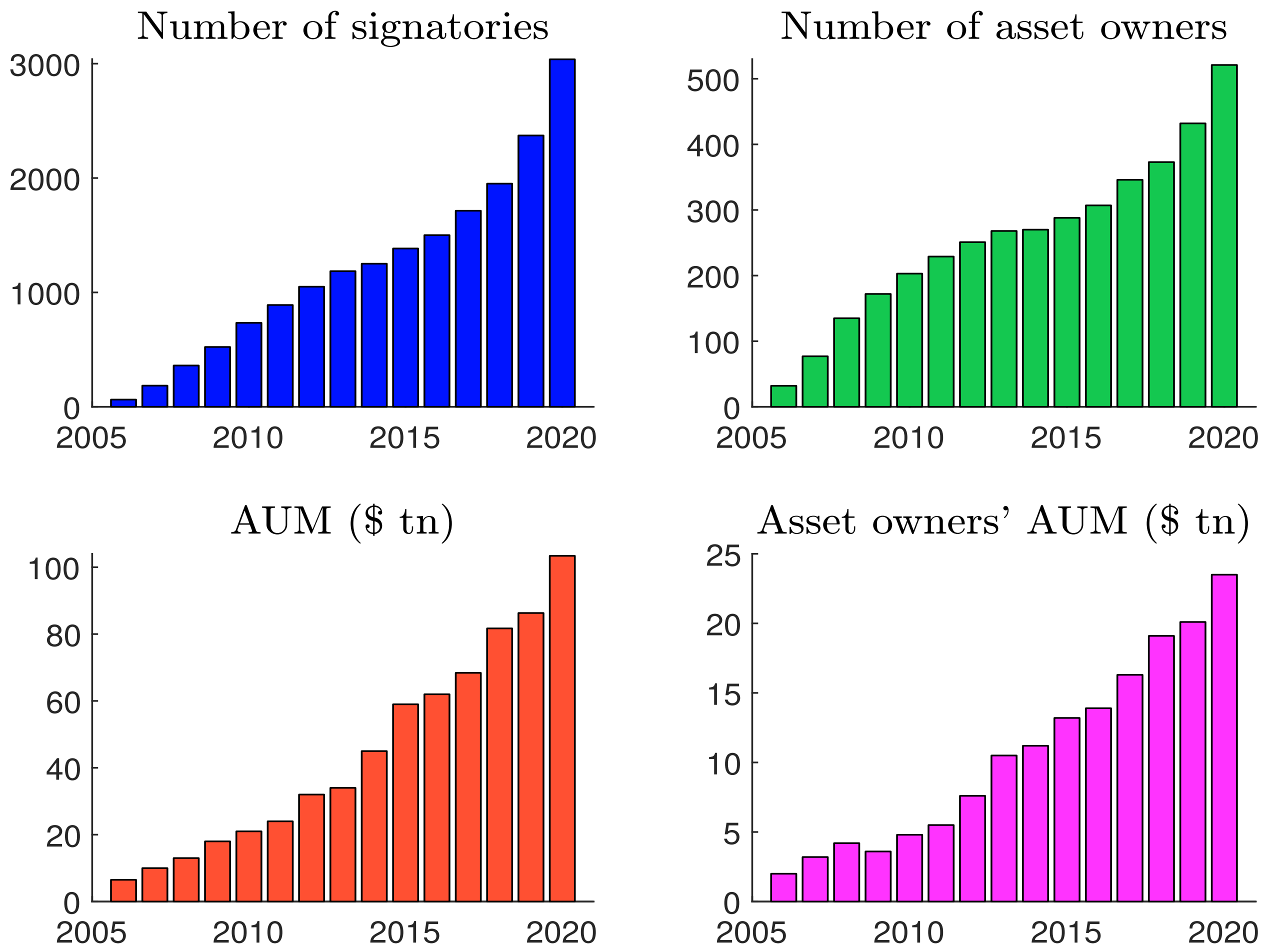

Figure 11: PRI Signatory growth

Source: `https://www.unpri.org`

Many collective initiatives

Responsible investment initiatives

- **SIFs: Sustainable Investment Forums**
- **PRI: Principles For Responsible Investment**
- **Finance for Tomorrow**
- Embankment Project for Inclusive Capitalism
- Pensions For Purpose
- St. Gallen Symposium
- Positive Economy Institute
- Institute for Responsible Capitalism
- Chair Sustainable Finance and Responsible Investment
- C3D: College of Sustainable Development Directors
- Swiss Sustainable Finance Association, FIR: French Sustainable Investment Forum, Medici Committee, ORSE: Observatory on Corporate Social Responsibility

Many collective initiatives

Environmental initiatives

- **TCFD: Task Force on Climate-related Financial Disclosures**
- **CDP: Carbon Disclosure Project**
- **PDC: Portfolio Decarbonization Coalition**
- **NZAOA: Net Zero Asset Owner Alliance**
- **NZAMI: Net Zero Asset Manager Initiative**
- GBP: Green Bonds Principles
- IIGCC: Institutional Investors Group on Climate Change
- OPS: One Planet Sovereign Wealth Fund Asset Manager
- CBI: Climate Bonds Initiative
- FAIRR: Farm Animal Investment Risk & Return
- Climate Action 100+, Act4nature, Japan TCFD Consortium, Montreal Carbon Pledge, EPE: Entreprises pour l'Environnement, Fondation de la Mer

Many collective initiatives

Social initiatives

- **SBP: Social Bonds Principles**
- **PLWF: Platform Living Wage Financials**
- PRI Human Rights Engagement
- Clinical Trials Transparency
- Access to Medicine Foundation
- Access to Nutrition Index
- RAFI: Human Rights Reporting and Assurance Frameworks Initiative
- Finansol
- Tobacco-Free Finance Pledge

Many collective initiatives

Governance initiatives

- ICGN: International Corporate Governance Network

The issuer point of view of ESG

Corporate financial performance (CFP)

- Friedman (2007)
- Shareholder theory
- Corporations have no social responsibility to the public or society
- Their only responsibility is to its shareholders (profit maximization)

Corporate social responsibility (CSR)

- Freeman (2010)
- Stakeholder theory
- Corporations create negative externalities
- They must have social and moral responsibilities
- Impact on the cost-of-capital and business risk

ESG strategies

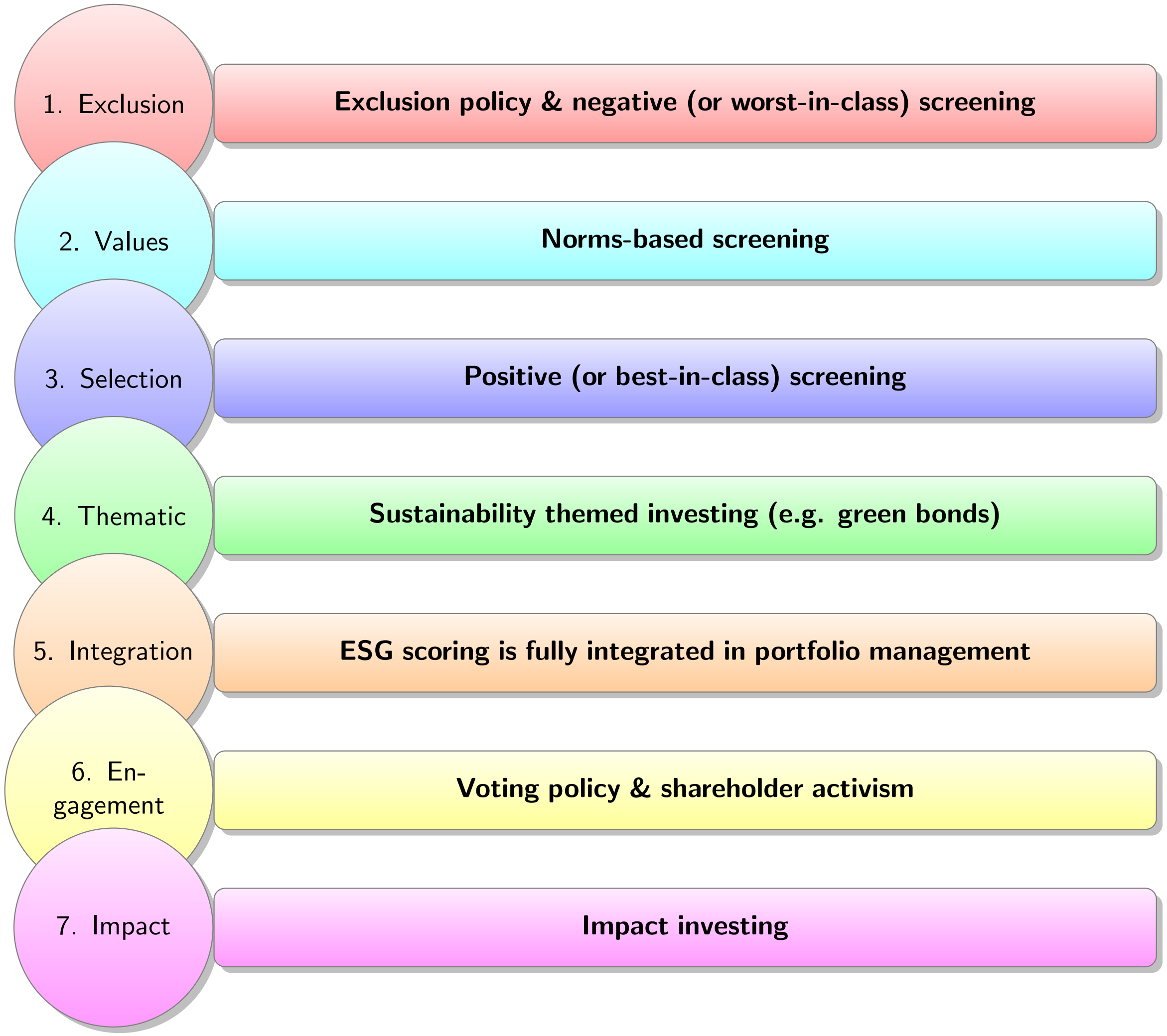

Figure 12: Categorisation of ESG strategies (Eurosif, 2019)

ESG strategies

Exclusion/Negative Screening

The exclusion from a fund or portfolio of certain sectors, companies or practices based on specific ESG criteria (worst-in-class)

Source: Global Sustainable Investment Alliance (2019)

Examples:

- Systematic exclusion of issuers rated **CCC**
- Exclusion of issuers rated **BB**, **B** and **CCC**
- Sector exclusion (e.g., Energy)
- Sub-industry exclusion (e.g. Coal & Consumable Fuels)
- Exclusion list of individual issuers

ESG strategies

Values/Norms-based Screening (and Red Flags)

Screening of investments against minimum standards of business practice based on international norms, such as those issued by the OECD, ILO, UN (Global Compact) and UNICEF[a]

[a] In Europe, the top exclusion criteria are (1) controversial weapons (Ottawa and Oslo treaties), (2), tobacco, (3) all weapons, (4) gambling, (5) pornography, (6) nuclear energy, (7) alcohol, (8) GMO and (9) animal testing (Eurosif, 2019)

Source: Global Sustainable Investment Alliance (2019)

Examples:

- Controversial sectors: controversial weapons, conventional weapons, civilian firearms, nuclear weapons, nuclear power, thermal coal, tobacco, alcohol, gambling, adult entertainment, genetically modified, fossil fuels production & reserves
- Many ETF funds

ESG strategies

Selection/Positive Screening

Investment in sectors, companies or projects selected for positive ESG performance relative to industry peers (best-in-class)

Source: Global Sustainable Investment Alliance (2019)

Examples:

- Selection of issuers rated **AAA**, **AA** and **A**
- Selection of issuers that have improved their rating (Momentum ESG strategy)

ESG strategies

Thematic/Sustainability Themed Investing

Investment in themes or assets specifically related to sustainability (for example clean energy, green technology or sustainable agriculture)

Source: Global Sustainable Investment Alliance (2019)

Examples:

- Funds invested in Green Bonds
- Funds invested in Social Bonds
- Funds invested in Sustainable Infrastructure
- Funds invested in Natural Ressources

ESG strategies

ESG Integration

The systematic and explicit inclusion by investment managers of environmental, social and governance factors into financial analysis

Source: Global Sustainable Investment Alliance (2019)

Examples:

- The stock picking score is a mix (50/50) of a fundamental score and an ESG score
- The fund must have an ESG score greater than the score of its benchmark

ESG strategies

Corporate Engagement/Shareholder Action

The use of shareholder power to influence corporate behavior, including through direct corporate engagement (i.e., communicating with senior management and/or boards of companies), filing or co-filing shareholder proposals, and proxy voting that is guided by comprehensive ESG guidelines.

Source: Global Sustainable Investment Alliance (2019)

Examples:

- Voting policy
- Public divestment
- Biodiversity and deforestation financing
- Engagement with target companies on a specific subject (e.g., pay ratio or living wage)
- Escalated engagement: concerns public, proposing shareholder resolutions & litigation

ESG strategies

Impact Investing

Targeted investments aimed at solving social or environmental problems, and including community investing, where capital is specifically directed to traditionally underserved individuals or communities, as well as financing that is provided to businesses with a clear social or environmental purpose

Source: Global Sustainable Investment Alliance (2019)

Examples:

- Funds with a Social Impact objective
- Funds invested in Green Bonds
- PAB and CTB ETFs

ESG strategies

Impact Investing/Community Investing

- Impact Investing
  Investing to achieve positive, social and environmental impacts – requires measuring and reporting against these impacts, demonstrating the intentionality of investor and underlying asset/investee, and demonstrating the investor contribution
- Community Investing
  Where capital is specifically directed to traditionally underserved individuals or communities, as well as financing that is provided to businesses with a clear social or environmental purpose. Some community investing is impact investing, but community investing is broader and considers other forms of investing and targeted lending activities.

Source: Global Sustainable Investment Alliance (2021)

The market of ESG investing

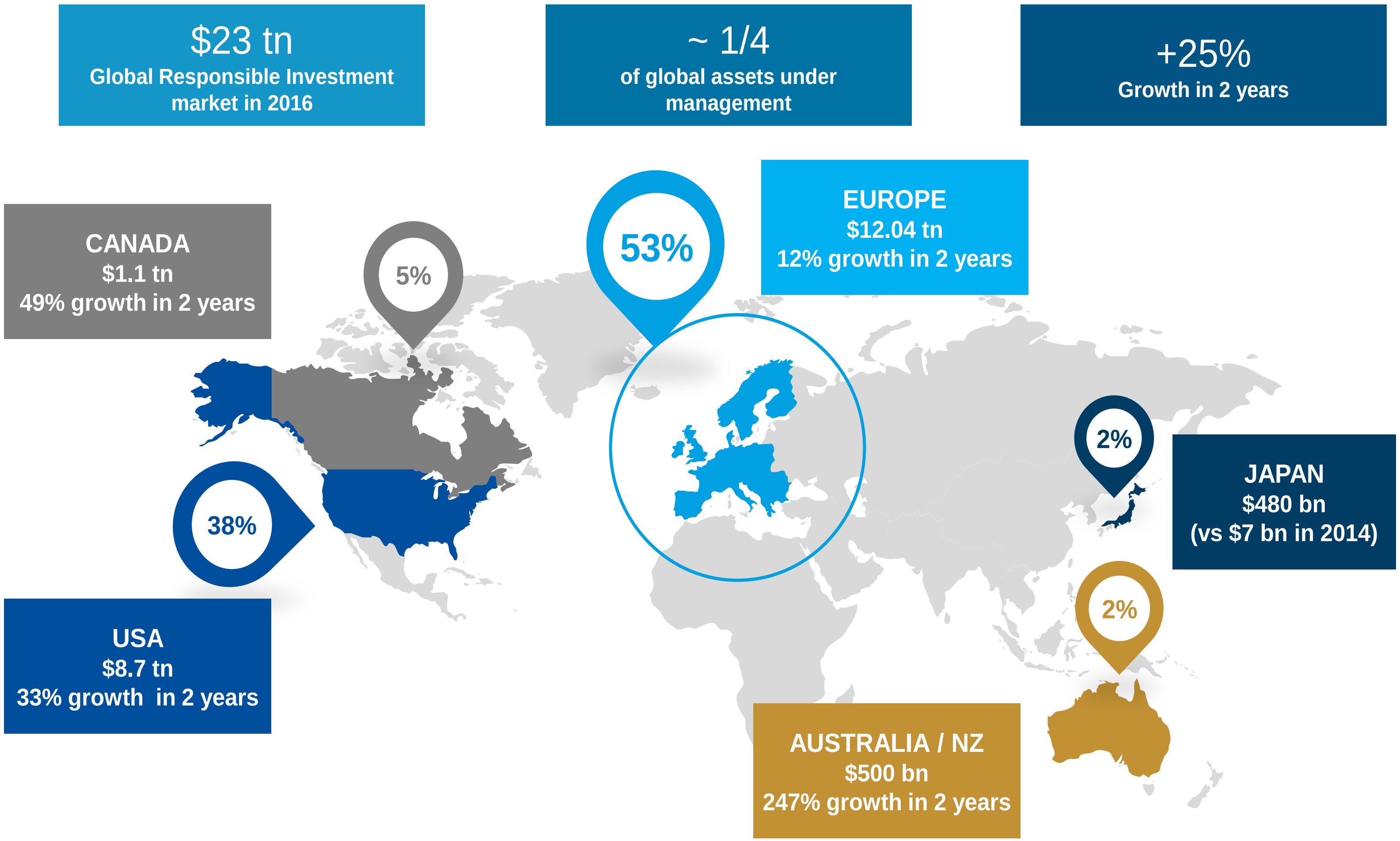

Figure 13: ESG at the start of 2016

Source: Global Sustainable Investment Alliance (2017)

The market of ESG investing

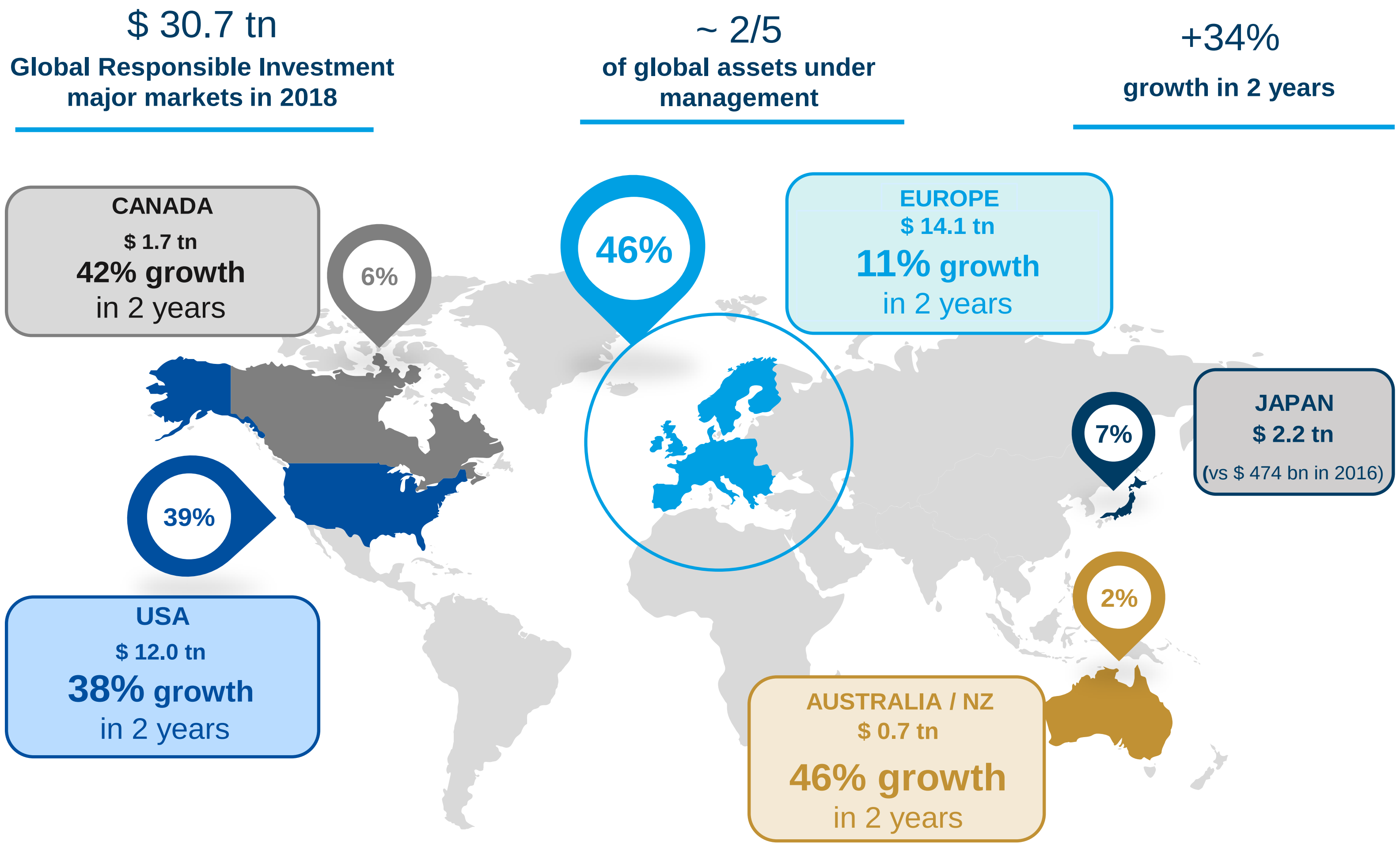

Figure 14: ESG at the start of 2018

Source: Global Sustainable Investment Alliance (2019)

The market of ESG investing

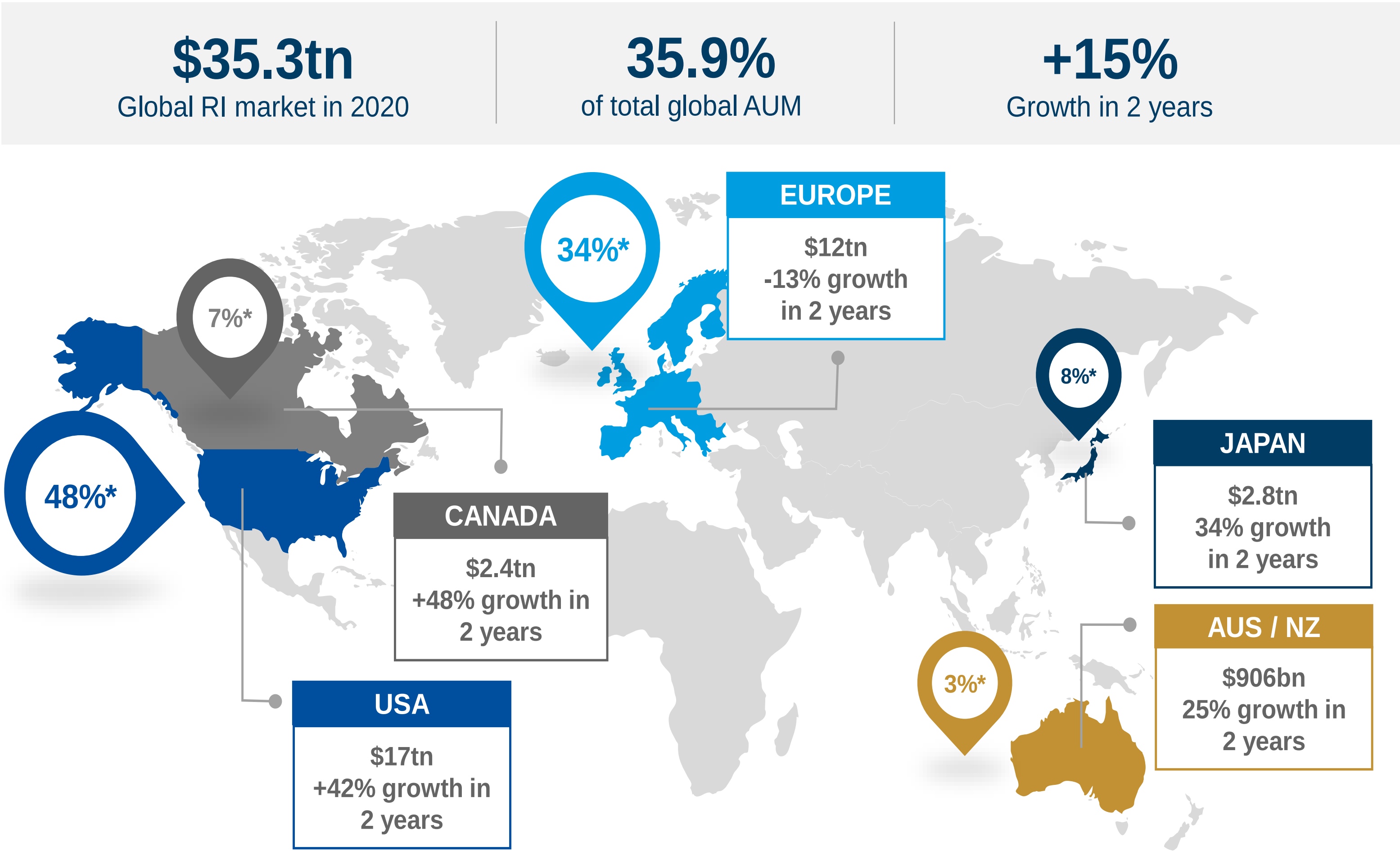

Figure 15: ESG at the start of 2020

Source: Global Sustainable Investment Alliance (2021)

The market of ESG investing

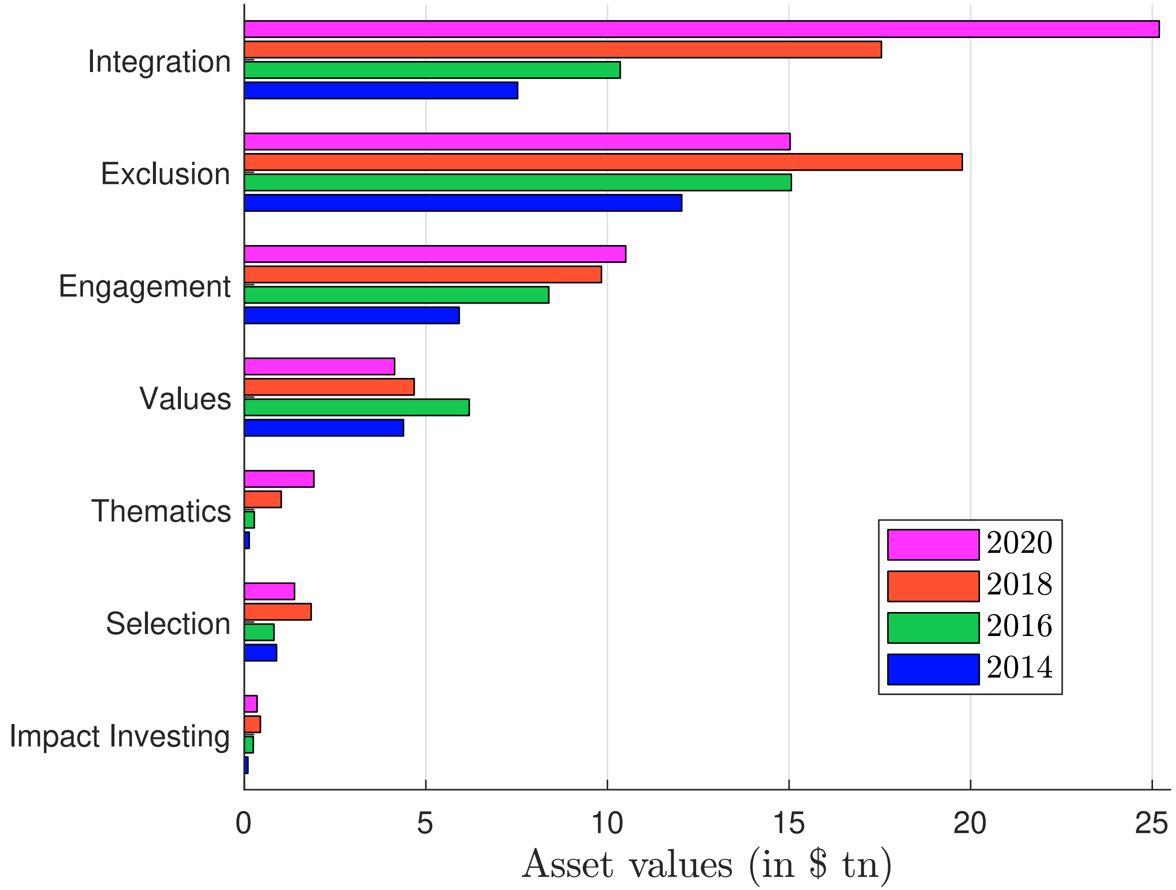

Figure 16: Asset values of ESG strategies between 2014 and 2018

Source: Global Sustainable Investment Alliance (2015, 2017, 2019, 2021)

The market of ESG investing

Table 1: Annual growth of ESG strategies

	2014-2016	2016-2018	2018-2020
Integration	17.4%	30.2%	43.6%
Exclusion	11.7%	14.6%	−24.0%
Engagement	18.9%	8.3%	6.8%
Values	19.0%	−13.1%	−11.5%
Thematics	55.1%	92.0%	91.4%
Selection	7.6%	50.1%	−24.9%
Impact Investing	56.8%	33.7%	−20.8%

Source: Global Sustainable Investment Alliance (2015, 2017, 2019)

The concept of ESG investing

Environmental, **S**ocial and **G**overnance (ESG)

- ESG **analysis**: extra-financial analysis $\neq$ financial analysis
- ESG **scoring**: quantitative measures of ESG dimensions
- ESG **ratings**: provide a grade (e.g. AAA, AA, A, etc.) to an issuer ($\approx$ credit ratings)
- ESG **screening**: process of scanning and filtering issuers based on ESG analysis and scoring ($\approx$ stock screening, bond screening, stock picking)
- ESG **investment process**: define how the investment process integrates ESG
- ESG **reporting**: provide ESG information and measures on the investment portfolio (e.g. ESG risk of the portfolio vs ESG risk of the benchmark, repartition of ESG ratings, top/bottom ESG issuers, etc.)

Course 2021-2022 in ESG and Climate Risks
Lecture 2. ESG Investing

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February 2022

[4] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

ESG rating agencies

Major players

- ISS ESG (Deutsche Börse)
- MSCI ESG
- Sustainalytics (Morningstar)
- Thomson Reuters (Refinitiv)
- Vigeo-Eiris (Moody's)

Other players

- Beyond Ratings (LSE)
- Bloomberg ESG
- FTSE Russell
- RobecoSAM (S&P)
- TrueValue Labs (Factset)

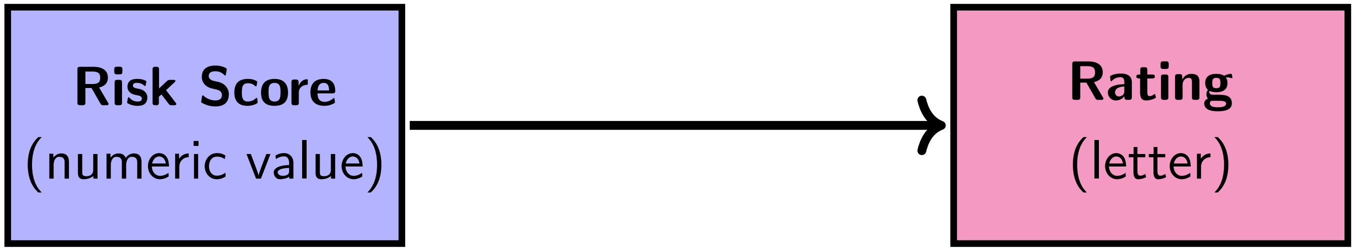
Specialized climate data providers

- CDP
- Iceberg Data Lab
- Trucost (S&P)

Specialized data providers

- EthiFinance
- Factiva
- RepRisk
- Verisk Maplecroft

The construction of ESG ratings

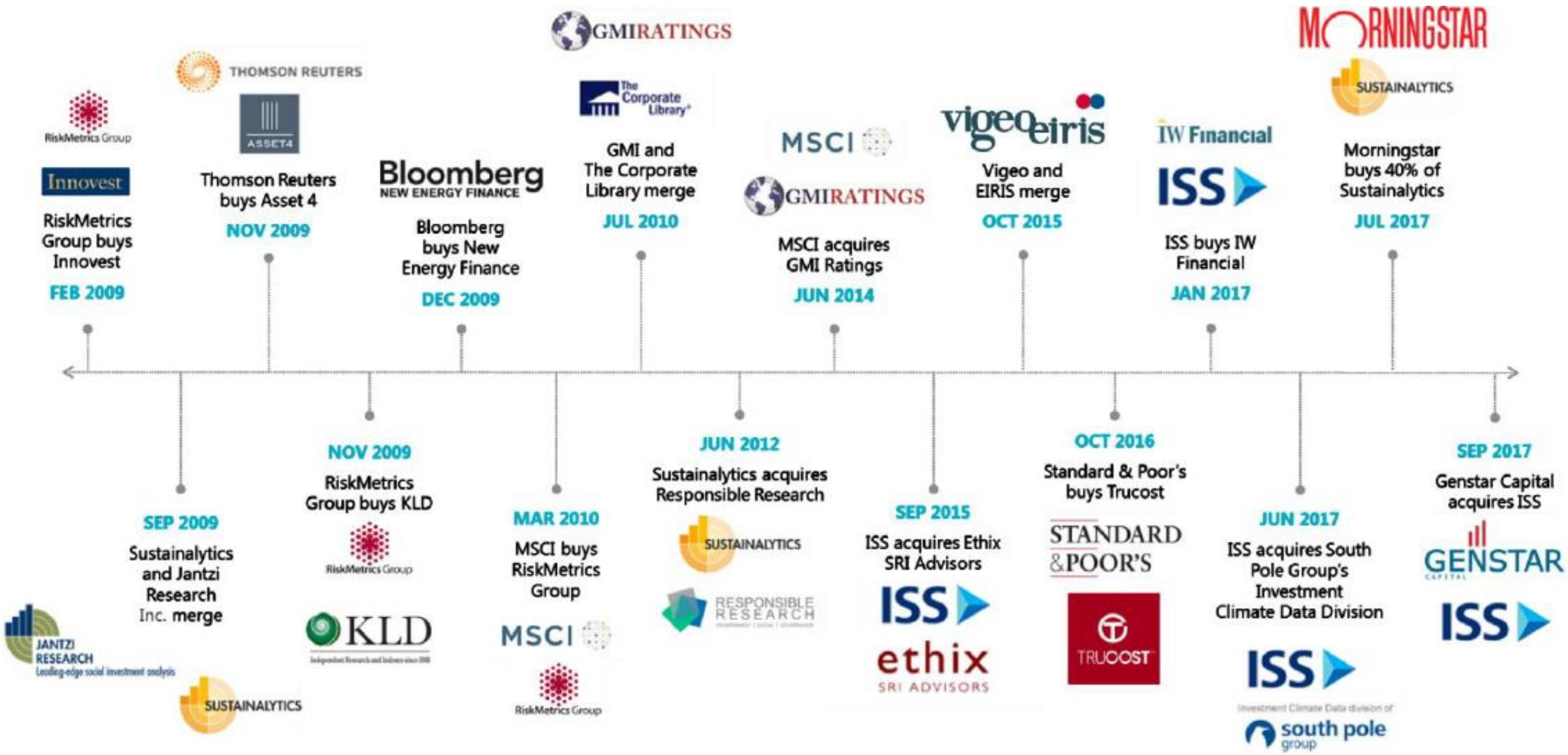


- In the case of credit risk, the estimate of the one-year probability of default is converted into credit ratings
  - For instance, a **CCC**-rated company has a 1Y PD of 25%; a **B**-rated company has a 1Y PD of 5%; a **BB**-rated company has a 1Y PD of 1%; etc.
- In the case of ESG risk, the ESG score is converted into ESG ratings
  - The best scores correspond to the best ratings
  - The worst scores correspond to the worst ratings

Examples of ESG ratings

- Amundi: -3 to $+3$ and **A** (high) to **G** (low)
- Bloomberg ESG Data Service: 0 to 100
- DowJones Sustainability Index: 0 to 100
- FTSE Russell: 0 (low) to 5 (high)
- ISS Quality Score: 1 (high) to 10 (low)
- MSCI: 0 to 10 and **AAA** (high) to **CCC** (low)
- RepRisk: **AAA** (high) to **D** (low)
- RobecoSAM: 0 to 100
- Sustainanalytics: 0 to 100 and 1 (low) to 5 -high)
- Thomson Reuters: 1 to 100 and **A+** (high) to **D-** (low)

Merger & acquisition activity



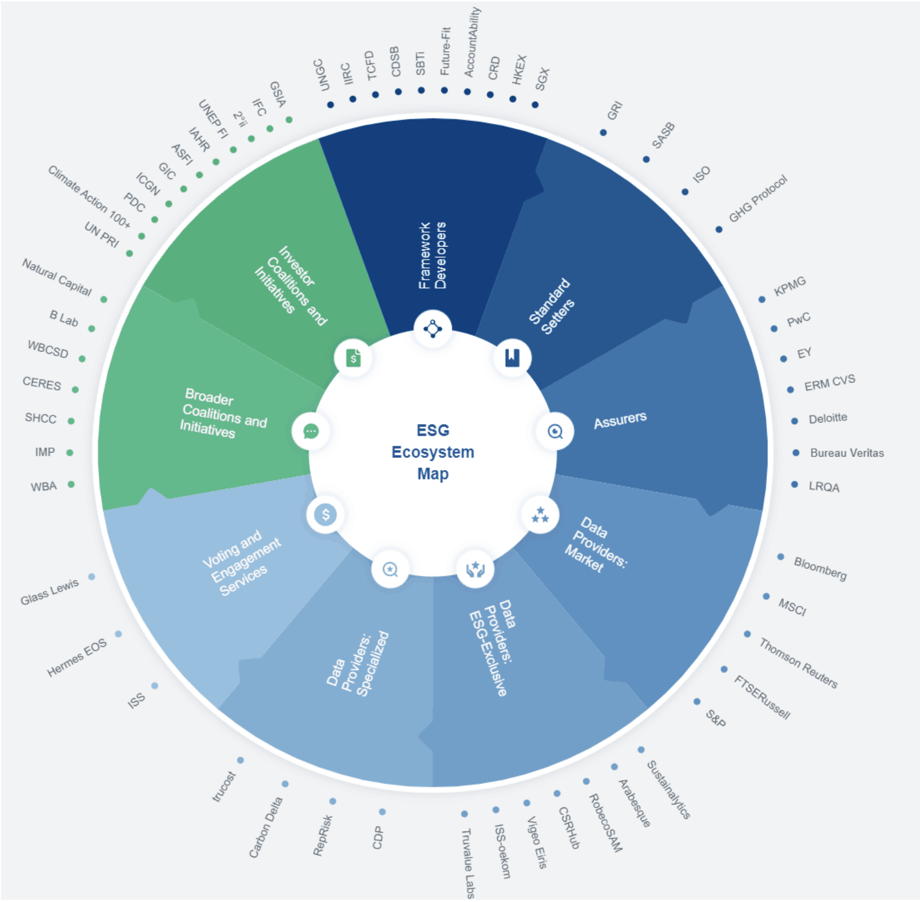
Source: Brown Flynn (2018)

Merger & acquisition activity

- 1983: Creation of Ethical Investment Research Services Ltd. (EIRIS, UK)
- 1988: Creation of KLD (US)
- 1995: Creation of Innovest (Canada) and SAM (Switzerland)
- 2002: Creation of Vigeo (France)
- At the end of 2000s: Bloomberg (US), MSCI (US) and Thomson Reuters (US)
- At the beginning of 2010s: the leading ESG rating agencies were EIRIS (UK), GMI Ratings (US), Inrate (Switzerland), oekom (Germany), Sustainalytics (Netherlands) and Vigeo (France)
- 2010s: Sustainalytics $\rightarrow$ Morningstar (2017), oekom $\rightarrow$ ISS (2018), Vigeo-EIRIS $\rightarrow$ Moody's (2019), RobecoSAM $\rightarrow$ S&P, Beyond Ratings $\rightarrow$ LSE

Ecosystem of ESG ratings

Figure 17: `https://widgets.weforum.org/esgecosystemmap`



ESG data

- ESG requires a lot of data and **alternative** data
- For example, Sustainalytics ESG Data includes 220 ESG indicators and 450 fields, and covers over 12 000 companies
- Where to find the data?
  - Public data
    - Standardized data (regulatory reporting)
    - Non-standardized data (self reporting)
  - Private data
  - Proprietary data
  - Questionnaire/survey
  - Analyst scores
  - Data from other ESG rating agencies

ESG data

Examples of data

- Corporate annual reports
- Corporate environmental and social reports
- Carbon Disclosure Project (CDP) responses
- US Bureau of Labor Statistics
- Thomson Financial
- World Bank (WB)

ESG data

The example of MSCI ESG data

MSCI data sources used to determine characteristics of a company's operations

- Annual reports
- Investor presentations
- Financial and regulatory filings

ESG data

The example of MSCI ESG data

MSCI data sources used to map macro-level risk exposure

Comprehensive Environmental Data Archive (CEDA); US Department of Energy; International Council on Clean Transportation; Lamont-Doherty Earth Observatory, Columbia University; Organization of Economic Co-Operation and Development (OECD); Canadian Industrial Water Survey; University of New Hampshire's Water Systems Analysis Group (country data); Hoekstra, A.Y. and Mekonnen, M.M. (2011); Ecorisk; World Development Indicators (WDI); Annual Change of Forest Resources Food and Agriculture Organization (FAO); World Wildlife Fund (WWF); US EPAs Toxics Release Inventory (TRI); Risk-Screening Environmental Indicators (RSEI); US Bureau of Labor Statistics (BLS); International Labour Organization (ILO); US Occupational Health & Safety Administration (OSHA); UK Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR); International Chemical Secretariat (ChemSec) Substitute It Now (SIN) List; International Monetary Fund (IMF); World Health Organization (WHO); UN Principles for Responsible Investments (UN PRI); World Resource Institute (WRI); Consultative Group to Assist the Poor (CGAP); US Census Bureau Current Population Survey Supplement; World Bank Governance Indicators (WGI); Transparency International (TI); World Bank (WB); SNL Financial; Thomson Financial;

ESG data

The example of MSCI ESG data

MSCI data sources used to assess risk management capabilities

- Corporate documents: annual reports, proxy filings, environmental and social reports, securities filings, websites and CDP responses
- Government data: central bank data, U.S. Toxic Release Inventory, Comprehensive Environmental Response and Liability Information System (CERCLIS), RCRA Hazardous Waste Data Management System, etc.
- Popular, trade, and academic journals: accessed through websites, subscriptions and searches of online databases
- News media: major news publications globally, including local-language sources across a range of markets
- Relevant organizations and professionals: reports from and interviews with trade groups, industry experts and nongovernmental organizations familiar with the companies' operations and any related controversies.

ESG data

The example of Amundi ESG scoring system

General scope

TRUCOST MSCI ISS ESG V.E
REFINITIV EthiFinance SUSTAINALYTICS

Controversies / controversial weapons

SUSTAINALYTICS RepRisk MSCI
ISS-Ethix

Climate

MSCI TRUCOST
FTSE Russell Climate Bonds CDP Iceberg Data Lab

Sovereigns

Verisk Maplecroft

ESG data

Examples of alternative data

- Energy Data Analytics Lab research (Duke university)
  https://energy.duke.edu/research/energy-data/resources
- Food and Agriculture Organization (FAO)
  http://www.fao.org
- UK Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)
  https://www.hse.gov.uk/riddor
- World Health Organization (WHO)
  https://www.who.int
- World Bank Governance Indicators (WGI)
  https://info.worldbank.org/governance/wgi
- World Resources Institute (WRI)
  https://www.wri.org

ESG (alternative) data

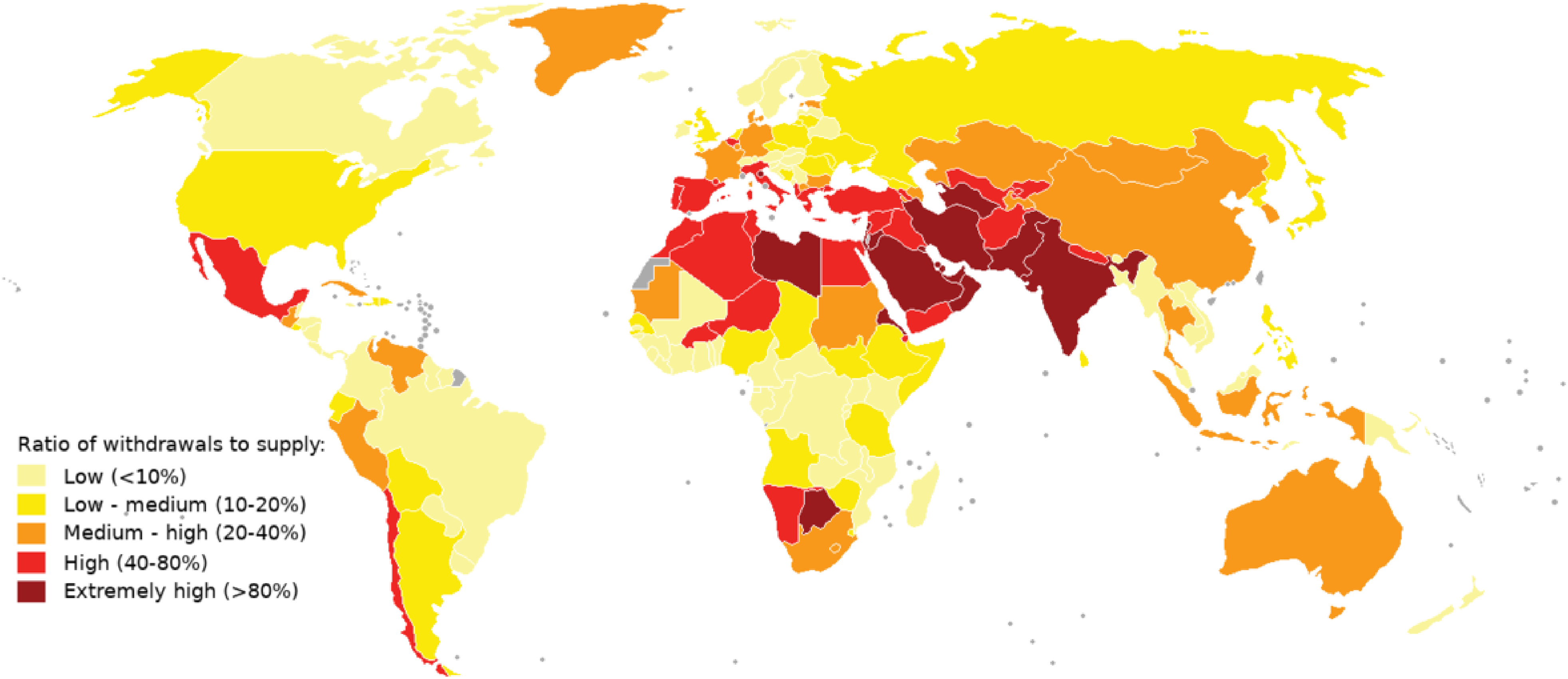


Figure 18: WRI water stress 2019

Source: World Resources Institute (WRI), www.wri.org

ESG (alternative) data

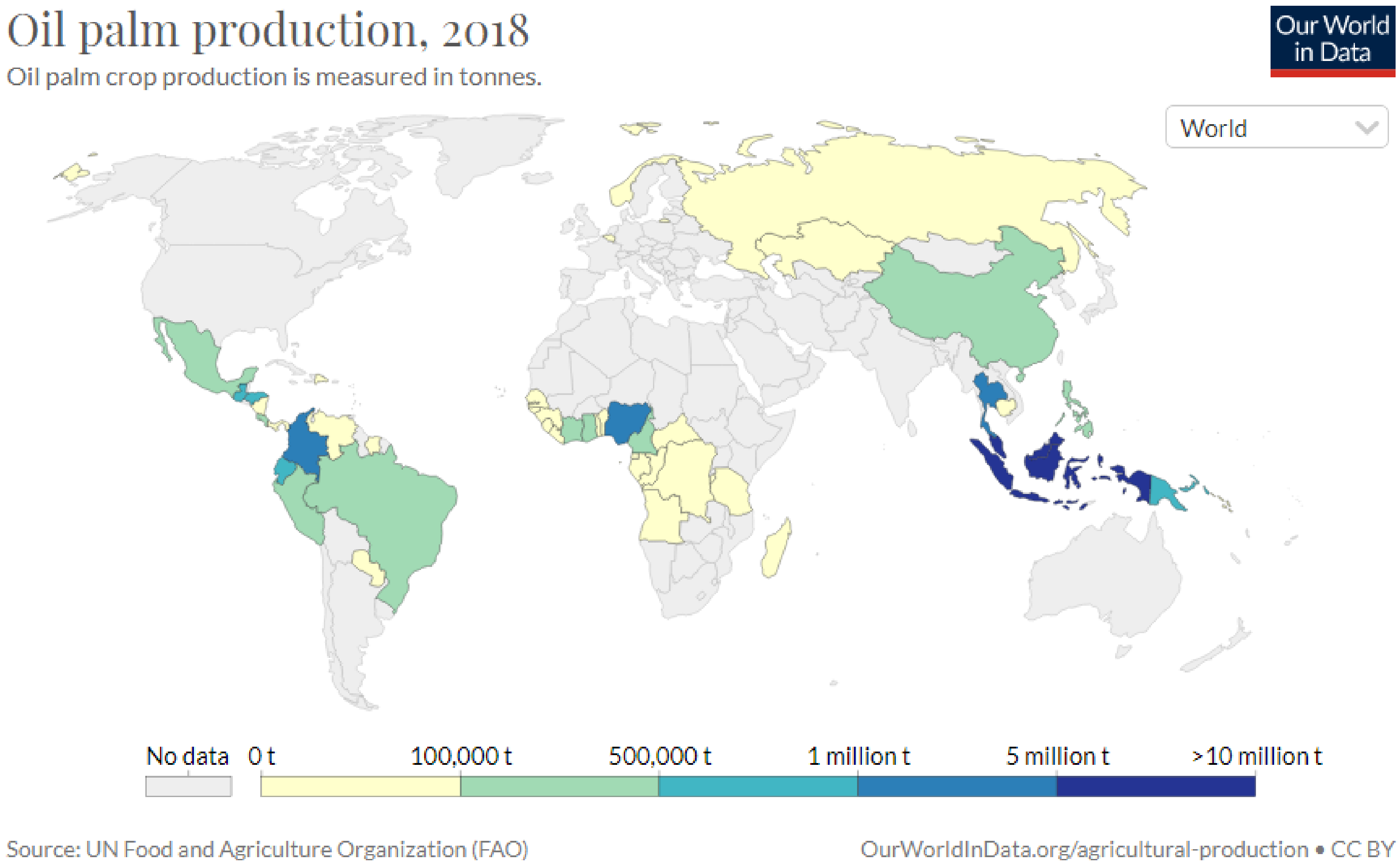


Figure 19: Oil palm production in 2018

Source: Our World in Data, `https://ourworldindata.org/grapher/palm-oil-production`

ESG (alternative) data

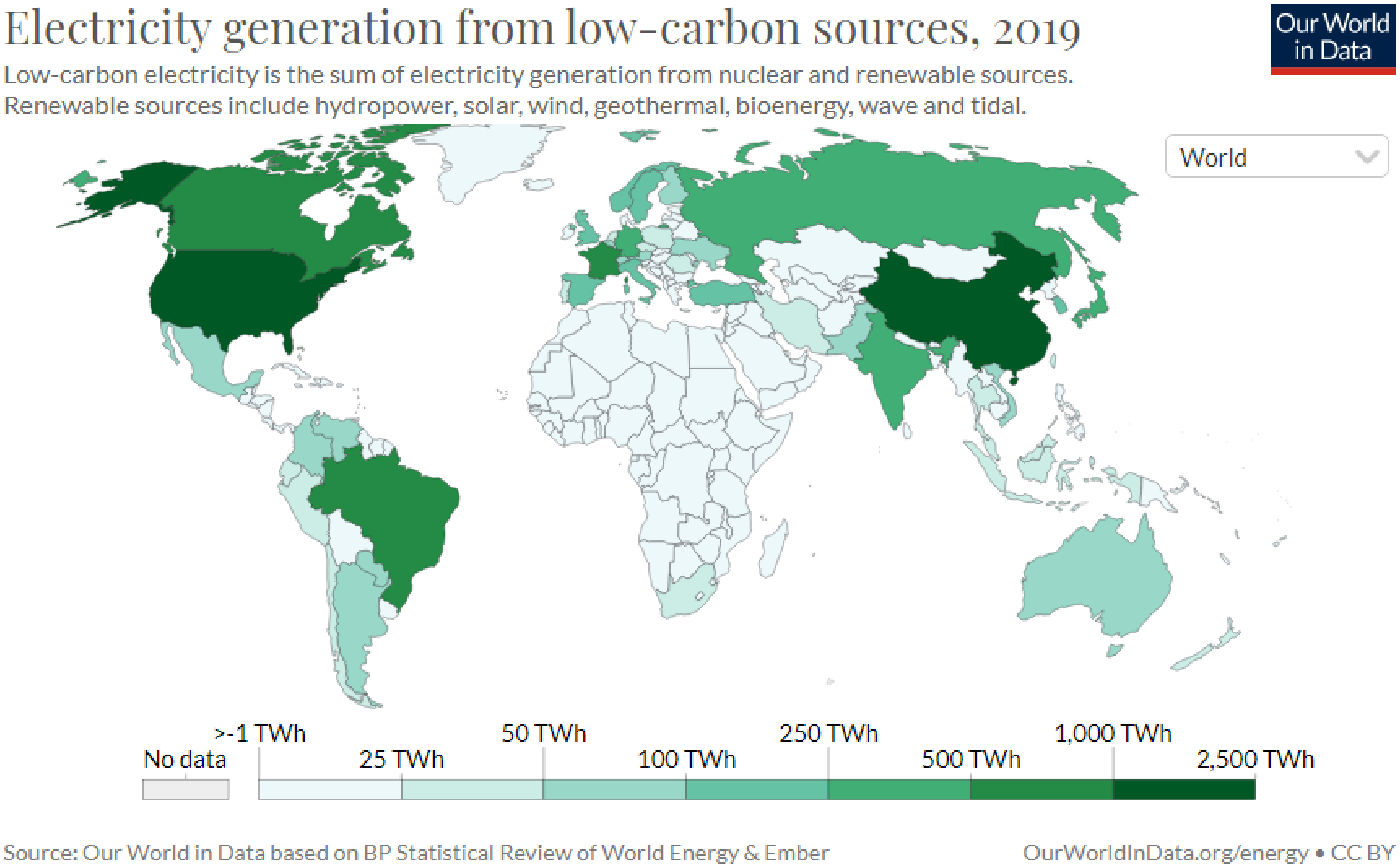


Figure 20: Electricity generation from low-carbon sources in 2019

Source: Our World in Data, https://ourworldindata.org/grapher/low-carbon-electricity

ESG (alternative) data

$$\text{Country} \Leftrightarrow \text{Corporate}$$

Some examples:

- Chairman of the Board $\neq$ CEO
- CO_2 emissions

ESG scoring system

Table 2: An example of ESG criteria (corporate issuers)

Environmental	Social	Governance
Carbon emissions	Employment conditions	Board independence
Energy use	Community involvement	Corporate behaviour
Pollution	Gender equality	Audit and control
Waste disposal	Diversity	Executive compensation
Water use	Stakeholder opposition	Shareholder' rights
Renewable energy	Access to medicine	CSR strategy
Green cars*		
Green financing*		

$^{(\star)}$means a specific criterion related to one or several sectors (Green cars $\Rightarrow$ Automobiles, Green financing $\Rightarrow$ Financials)

ESG scoring system

Table 3: An example of ESG criteria (sovereign issuers)

Environmental	Social	Governance
Carbon emissions	Income inequality	Political stability
Energy transition risk	Living standards	Institutional strength
Fossil fuel exposure	Non-discrimination	Levels of corruption
Emissions reduction target	Health & security	Rule of law
Physical risk exposure	Local communities and human rights	Government and regulatory effectiveness
Green economy	Social cohesion	Rights of shareholders
	Access to education	

ESG scoring system

Sovereign ESG Data Framework

- World Bank
- Data may be download at the following webpage:
  `https://datatopics.worldbank.org/esg/framework.html`
- E: 27 variables
- S: 22 variables
- G: 18 variables

ESG scoring system

Table 4: Sovereign ESG Data Framework (World Bank)

Environmental

- Emissions & pollution (5)
- Natural capital endowment and management (6)
- Energy use & security (7)
- Environment/ climate risk & resilience (6)
- Food security (3)

Social

- Education & skills (3)
- Employment (3)
- Demography (3)
- Poverty & inequality (4)
- Health & nutrition (5)
- Access to services (4)

Governance

- Human rights (2)
- Government effectiveness (2)
- Stability & rule of law (4)
- Economic environment (3)
- Gender (4)
- Innovation (3)

ESG scoring system

- Most of ESG scoring systems are based on scoring trees
- Raw data are normalized in order to obtain features $X_1, \ldots, X_m$
- Features $X_1, \ldots, X_m$ are aggregated to obtain sub-scores $\mathcal{S}_1, \ldots, \mathcal{S}_n$:

$$\mathcal{S}_i = \sum_{j=1}^{m} \omega_{i,j}^{(1)} X_j$$

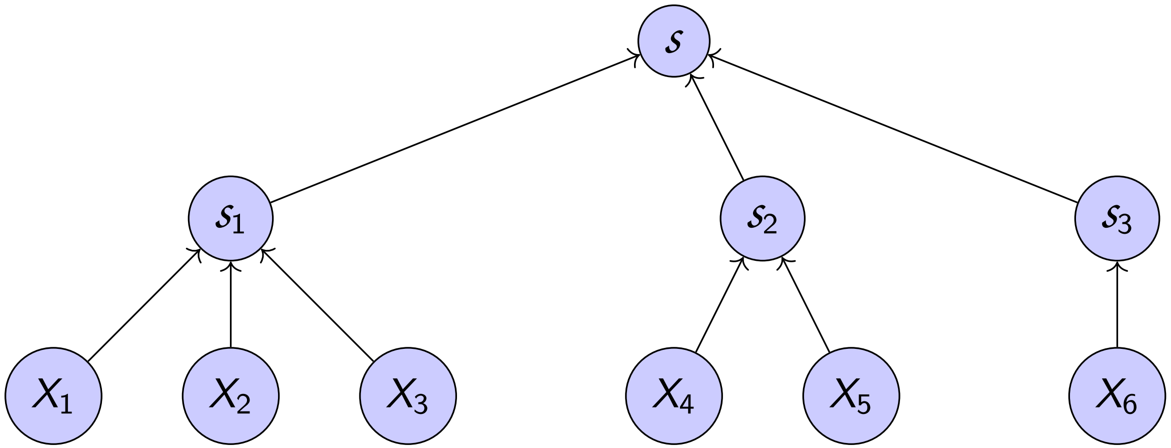
- Sub-scores $\mathcal{S}_1, \ldots, \mathcal{S}_n$ are aggregated to obtain the final score $\mathcal{S}$:

$$\mathcal{S} = \sum_{i=1}^{n} \omega_{i}^{(2)} \mathcal{S}_i$$

The two-level tree structure can be extended to multi-level tree structures
For example, in the case of a three-level tree structure, we have:

Raw data $\Rightarrow$ features $\Rightarrow$ sub-sub-scores $\Rightarrow$ sub-scores $\Rightarrow$ final score

ESG scoring system



We assume that:

- Level 1
  1. $\omega_{1,1}^{(1)} = 50\%$
     $\omega_{2,1}^{(1)} = 25\%$
     $\omega_{3,1}^{(1)} = 25\%$
  2. $\omega_{4,2}^{(1)} = 50\%$
     $\omega_{5,2}^{(1)} = 50\%$
  3. $\omega_{6,3}^{(1)} = 100\%$
- Level 2: $\omega_{1}^{(2)} = \omega_{2}^{(2)} = \omega_{3}^{(2)} = 33.33\%$

Figure 21: A two-level tree structure

ESG scoring system

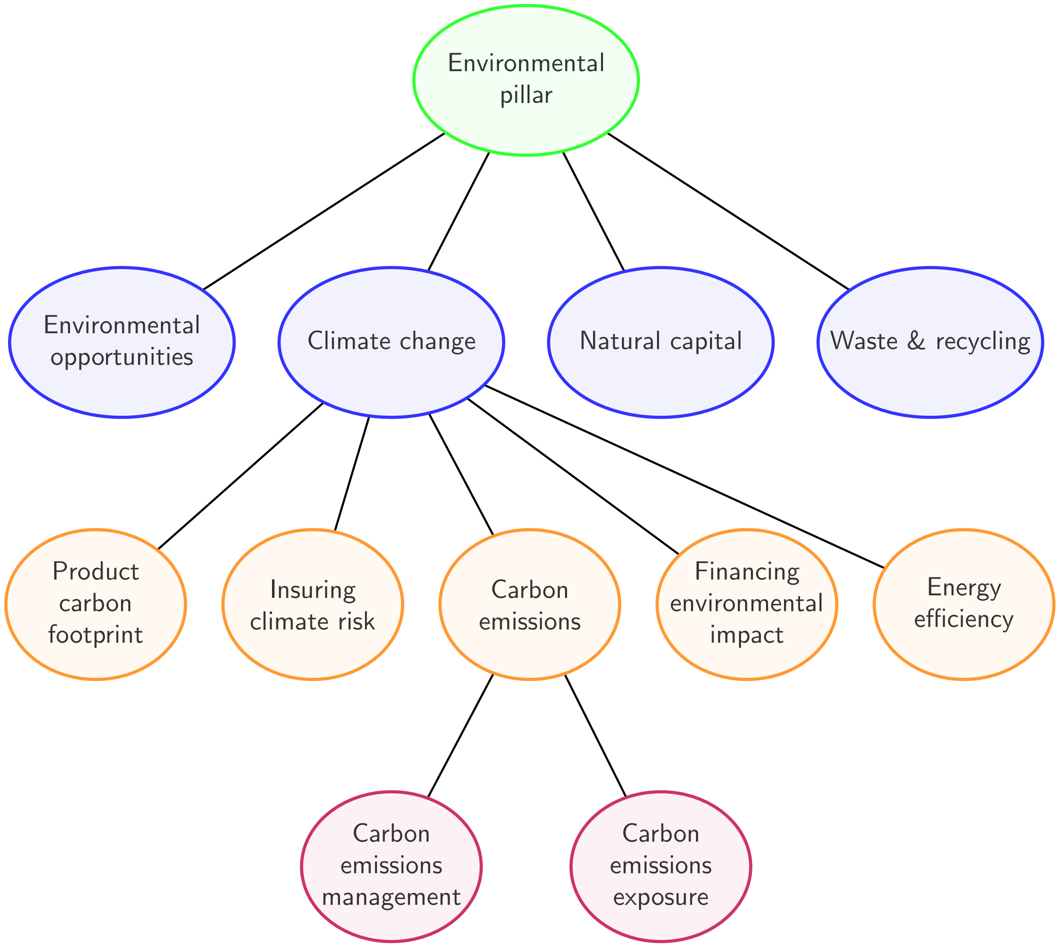


Figure 22: An example of ESG scoring tree (MSCI methodology)

Source: MSCI (2020)

ESG scoring system

Raw data have to be normalized

Why? Because to facilitate the comparison

Some examples:

- Carbon emissions ⇒ carbon intensity ⇒ E
- Income inequalities ⇒ Gini index ⇒ S
- CEO compensation ⇒ CEO pay ratio ⇒ G or S ?

ESG scoring system

Remark

The Dodd-Frank Act requires that publicly traded companies disclose:

1. The median total annual compensation of all employees other than the CEO
2. The ratio of the CEO's annual total compensation to that of the median employee
3. The wage ratio of the CEO to the median employee

ESG scoring system

Table 5: Examples of CEO pay ratio

Company name	Median Worker Pay (in $)	CEO Pay Ratio
Abercrombie & Fitch Co.	1 954	4,293
McDonald's Corporation	9 291	1,939
The Coca-Cola Company	11 285	1,657
The Gap, Inc.	6 177	1,558
Alphabet Inc.	258 708	1,085
Walmart Inc.	22 484	983
The Estee Lauder Companies, Inc.	30 733	697
Ralph Lauren Corporation	21 358	570
NIKE, Inc.	25 386	550
Citigroup Inc.	52 988	482
PepsiCo, Inc.	45 896	368
Microsoft Corporation	172 512	249
Apple Inc.	57 596	201

Source: https://aflcio.org (June 2021)

ESG scoring system

Table 6: Examples of CEO pay ratio

Company name	Median Worker Pay (in $)	CEO Pay Ratio
Netflix, Inc.	202 931	190
BlackRock, Inc.	133 644	182
Pfizer Inc.	98 972	181
The Goldman Sachs Group, Inc.	138 854	178
MSCI Inc.	55 857	165
Verisk Analytics, Inc.	77 055	117
Facebook, Inc.	247 883	94
Invesco Ltd.	125 282	92
The Boeing Company	158 869	90
Citrix Systems, Inc.	181 769	80
Harley-Davidson, Inc.	187 157	59
Amazon.com, Inc.	28 848	58
Berkshire Hathaway Inc.	65 740	6

Source: https://aflcio.org (June 2021)

ESG scoring system

Scores have also to be normalized

Why? Because to facilitate the aggregation process

Several normalization approaches:

- q-score normalisation:
  - $0-1$ normalization: $q_i \in [0,1]$
  - $0-10$ normalization: $q_i \in [0,10]$
  - $0-100$ normalization: $q_i \in [0,100]$

$$q_i = \hat{\mathbf{F}}(x_i)$$

  where $\hat{\mathbf{F}}$ is the empirical probability distribution ($q_i \in [0,1]$)

- z-score normalisation:

$$z_i = \frac{x_i - \hat{\mu}(X)}{\hat{\sigma}(X)}$$

ESG scoring system

Let $\{x_1, x_2, \ldots, x_n\}$ be the sample. We have:

$$q_i = \hat{\mathbf{F}}(x_i) = \Pr\{X \leq x_i\} = \frac{\#\{x_j \leq x_i\}}{n_q}$$

We can use two normalization factors:

1. $n_q = n$
2. $n_q = n + 1$

For example, if $n = 4$, we have:

- $q_i \in \{0.25, 0.5, 0.75, 1\}$ if $n_q = n$
- $q_i \in \{0.2, 0.4, 0.6, 0.8\}$ if $n_q = n + 1$

Remark (probability integral transform)

The second solution is better because $q_i \in \left]0, 1\right[$. Therefore, we can transform q_i using any probability distribution $\mathbf{G}^{-1}(q_i)$

ESG scoring system

Table 7: How to make two scores comparable?

Observation	X_1	$\mathcal{S}_1$	X_2	$\mathcal{S}_2$
1	94.0000		−0.0300	
2	38.6000		−0.0550	
3	30.6000		0.0560	
4	74.4000		−0.0130	
5	97.1000		−0.1680	
6	57.1000		−0.0350	
7	132.4000		0.0850	
8	92.5000		−0.0910	
9	64.9000		−0.0460	
Mean	75.7333		−0.0330	
Standard deviation	31.9466		0.0746	

How to create the synthetic score $30\% \cdot X_1 + 70\% \cdot X_2$?

ESG scoring system

Table 8: Computation of q-score $(0 - 100$ normalization$)$

Observation	X_1	q_1	X_2	q_2
1	94.0000	70.0000	−0.0300	60.0000
2	38.6000	20.0000	−0.0550	30.0000
3	30.6000	10.0000	0.0560	80.0000
4	74.4000	50.0000	−0.0130	70.0000
5	97.1000	80.0000	−0.1680	10.0000
6	57.1000	30.0000	−0.0350	50.0000
7	132.4000	90.0000	0.0850	90.0000
8	92.5000	60.0000	−0.0910	20.0000
9	64.9000	40.0000	−0.0460	40.0000
Mean	75.7333	50.0000	−0.0330	50.0000
Standard deviation	31.9466	27.3861	0.0746	27.3861

ESG scoring system

Table 9: Computation of z-score

Observation	X_1	z_1	X_2	z_2
1	94.0000	0.5718	−0.0300	0.0402
2	38.6000	−1.1624	−0.0550	−0.2950
3	30.6000	−1.4128	0.0560	1.1933
4	74.4000	−0.0417	−0.0130	0.2682
5	97.1000	0.6688	−0.1680	−1.8101
6	57.1000	−0.5833	−0.0350	−0.0268
7	132.4000	1.7738	0.0850	1.5821
8	92.5000	0.5248	−0.0910	−0.7777
9	64.9000	−0.3391	−0.0460	−0.1743
Mean	75.7333	0.0000	−0.0330	0.0000
Standard deviation	31.9466	1.0000	0.0746	1.0000

We have $z_{1,8} = \frac{92.5-75.73}{31.95} = 0.5248$ and $z_{2,1} = \frac{-0.055-(-0.033)}{0.0746} = -0.295$

ESG scoring system

Table 10: From z-score to q-score

Observation	X_1	z_1	qz_1	X_2	z_2	qz_2
1	94.0000	0.5718	71.6267	−0.0300	0.0402	51.6043
2	38.6000	−1.1624	12.2545	−0.0550	−0.2950	38.4006
3	30.6000	−1.4128	7.8861	0.0560	1.1933	88.3627
4	74.4000	−0.0417	48.3354	−0.0130	0.2682	60.5712
5	97.1000	0.6688	74.8196	−0.1680	−1.8101	3.5141
6	57.1000	−0.5833	27.9857	−0.0350	−0.0268	48.9303
7	132.4000	1.7738	96.1951	0.0850	1.5821	94.3192
8	92.5000	0.5248	70.0151	−0.0910	−0.7777	21.8383
9	64.9000	−0.3391	36.7264	−0.0460	−0.1743	43.0813

We transform the q-score:

$$qz_i = \Phi\left(z_i\right) \in [0, 1]$$

and then we normalize qz_i

ESG scoring system

Table 11: From q-score to z-score

Observation	X_1	q_1	zq_1	X_2	q_2	zq_2
1	94.0000	70.0000	0.5244	−0.0300	60.0000	0.2533
2	38.6000	20.0000	−0.8416	−0.0550	30.0000	−0.5244
3	30.6000	10.0000	−1.2816	0.0560	80.0000	0.8416
4	74.4000	50.0000	0.0000	−0.0130	70.0000	0.5244
5	97.1000	80.0000	0.8416	−0.1680	10.0000	−1.2816
6	57.1000	30.0000	−0.5244	−0.0350	50.0000	0.0000
7	132.4000	90.0000	1.2816	0.0850	90.0000	1.2816
8	92.5000	60.0000	0.2533	−0.0910	20.0000	−0.8416
9	64.9000	40.0000	−0.2533	−0.0460	40.0000	−0.2533

We normalize the q-score such that $q_i \in [0, 1]$, and then we have:

$$zq_i = \Phi^{-1}\left(q_i\right) \in [-3, 3]$$

ESG scoring system

Table 12: Score aggregation: $30\% \cdot s_1 + 70\% \cdot s_2$

Observation	X_1	X_2	q_{12}	qz_{12}	z_{12}	zq_{12}
1	94.0000	−0.0300	63.0000	57.6110	0.1997	0.3347
2	38.6000	−0.0550	27.0000	30.5568	−0.5552	−0.6196
3	30.6000	0.0560	59.0000	64.2197	0.4115	0.2047
4	74.4000	−0.0130	64.0000	56.9005	0.1752	0.3671
5	97.1000	−0.1680	31.0000	24.9058	−1.0664	−0.6446
6	57.1000	−0.0350	44.0000	42.6469	−0.1938	−0.1573
7	132.4000	0.0850	90.0000	94.8820	1.6396	1.2816
8	92.5000	−0.0910	32.0000	36.2913	−0.3869	−0.5131
9	64.9000	−0.0460	40.0000	41.1748	−0.2237	−0.2533
Mean	75.7333	0.0000	50.0000	49.9099	0.0000	0.0000
Standard deviation	31.9466	1.0000	20.6034	21.3591	0.7592	0.6207

We have $q_{12} = 0.3 \cdot q_1 + 0.7 \cdot q_2$, $qz_{12} = 0.3 \cdot qz_1 + 0.7 \cdot qz_2$, $z_{12} = 0.3 \cdot z_1 + 0.7 \cdot z_2$ and $zq_{12} = 0.3 \cdot zq_1 + 0.7 \cdot zq_2$

ESG scoring system

Sector neutrality

- Most of ESG scoring systems are sector neutral
- The normalization is done at the sector level, not at the universe level
- ESG scores are then **relative** (with respect to a sector), not **absolute**
- **Best-in-class/worst-in-class issuers** $\neq$ best/worst issuers

Example

- Corporate A: E $= +2$ vs Corporate B: E $= +1$
- If A and B belong to the same sector, we have $A \succ B$ (A is more green than B)
- If A and B belong to the two different sectors, we can have $A \succ B$ or $B \succ A$

ESG rating system

We need a mapping function $\mathcal{M}_{\text{apping}}$ to transform the ESG score $\mathcal{S}$ into an ESG rating $\mathcal{R}$

MSCI methodology

$$\begin{array}{rccc} \mathcal{M}_{\text{apping}} : & [0, 10] & \longrightarrow & \{\text{AAA}, \text{AA}, \text{A}, \text{BBB}, \text{BB}, \text{B}, \text{CCC}\} \\ & \mathcal{S} & \longmapsto & \mathcal{R} = \mathcal{M}_{\text{apping}}(\mathcal{S}) \end{array}$$

- If $\mathcal{S} \in \left[0, \frac{10}{7}\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **CCC**
- If $\mathcal{S} \in \left[\frac{10}{7}, \frac{2 \times 10}{7}\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **B**
- If $\mathcal{S} \in \left[\frac{2 \times 10}{7}, \frac{3 \times 10}{7}\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **BB**
- If $\mathcal{S} \in \left[\frac{3 \times 10}{7}, \frac{4 \times 10}{7}\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **BBB**
- If $\mathcal{S} \in \left[\frac{4 \times 10}{7}, \frac{5 \times 10}{7}\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **A**
- If $\mathcal{S} \in \left[\frac{5 \times 10}{7}, \frac{6 \times 10}{7}\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **AA**
- If $\mathcal{S} \in \left[\frac{6 \times 10}{7}, 10\right]$, $\mathcal{M}_{\text{apping}}(\mathcal{S}) =$ **AAA**

ESG rating system

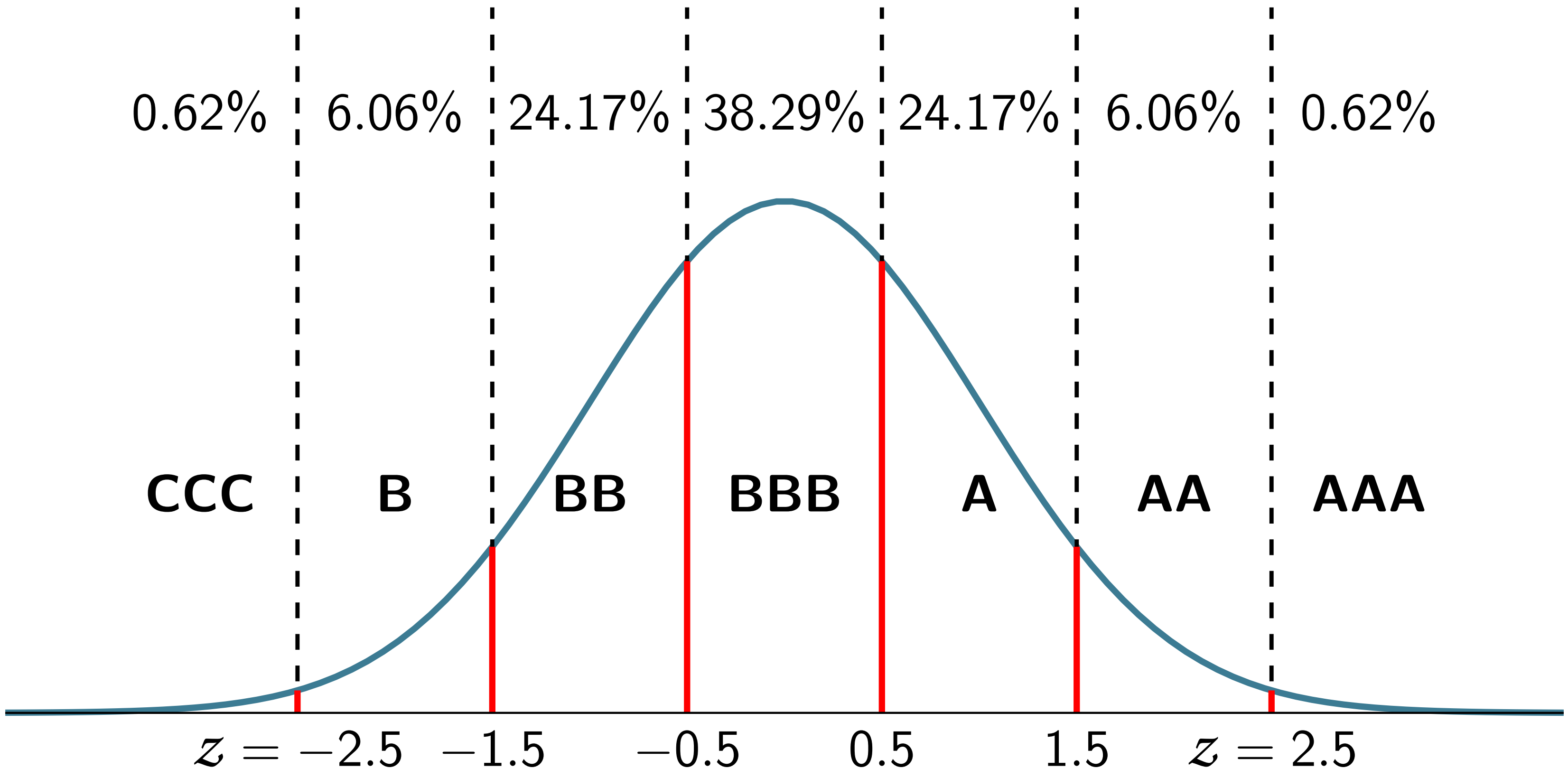
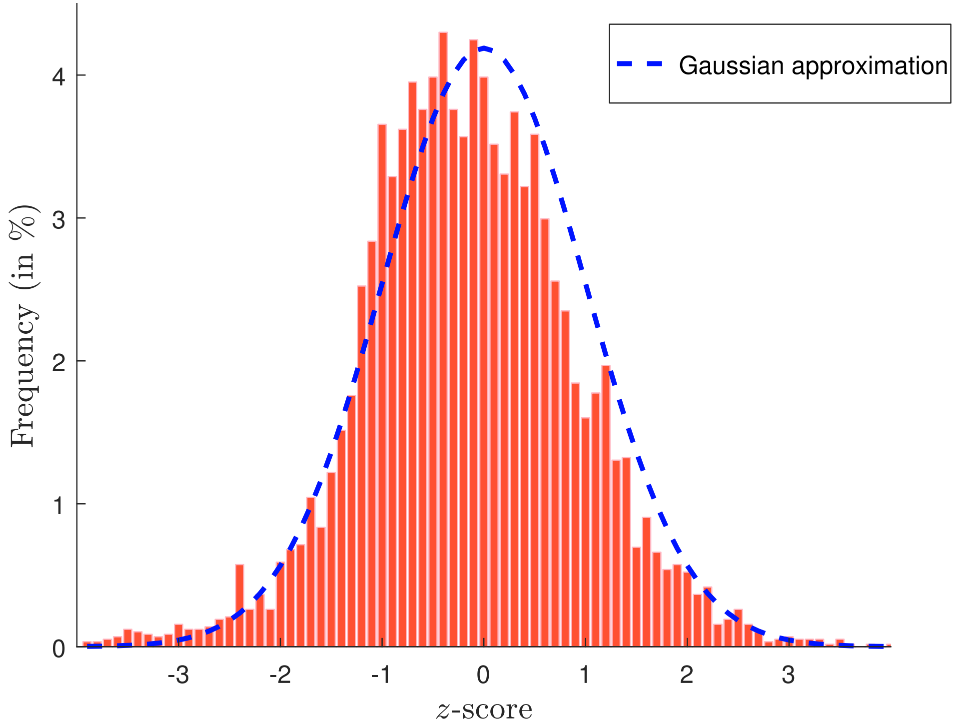


Figure 23: From ESG scores to ESG ratings (Gaussian mapping* of the z-score)

*We have $\Phi(-2.5) = 0.62\%$, $\Phi(-1.5) - \Phi(-2.5) = 6.06\%$, $\Phi(-0.5) - \Phi(-1.5) = 24.17\%$, $\Phi(0.5) - \Phi(-0.5) = 38.29\%$, $\Phi(1.5) - \Phi(0.5) = 24.17\%$, $\Phi(2.5) - \Phi(1.5) = 6.06\%$ and $1 - \Phi(2.5) = 0.62\%$

ESG rating system

Figure 24: Distribution of Amundi ESG scores (December 2018)



Source: Amundi ESG Research (2018)

Table 13: Empirical frequencies of Amundi ESG ratings

	Frequencies	
Rating	Theoretical	Empirical
A	0.62%	1%
B	6.06%	4%
C	24.17%	28%
D	38.29%	38%
E	24.17%	22%
F	6.06%	6%
G	0.62%	1%

Source: Amundi ESG Research (2018)

ESG rating system

Why?

Because ESG analyst can modify
the systematic rating deduced from the quantitative score

ESG rating system

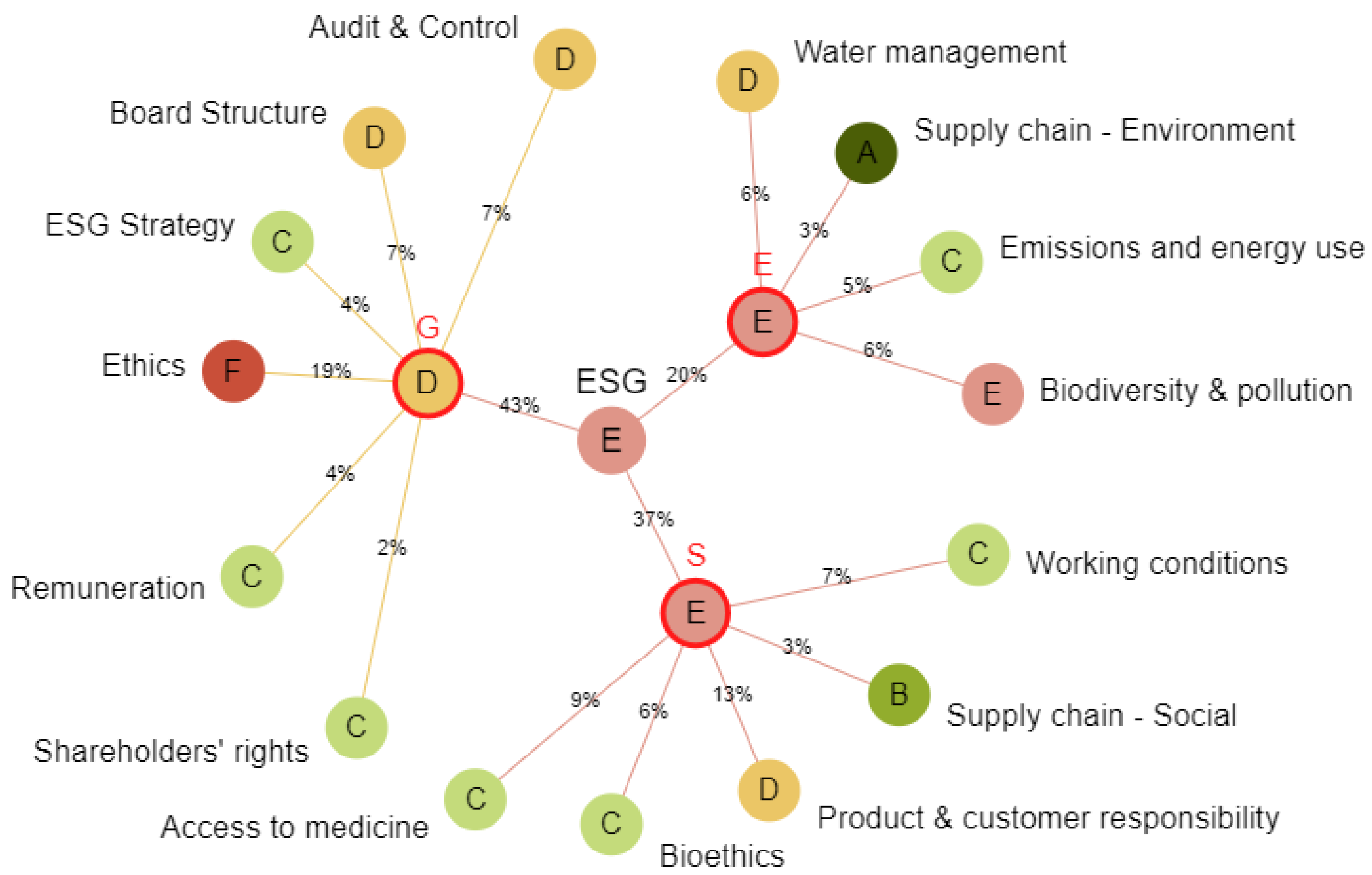


Figure 25: ESG rating tree of Company **B** (Amundi, May 2021)

Source: Amundi ALTO* SRI (2021)

ESG rating system

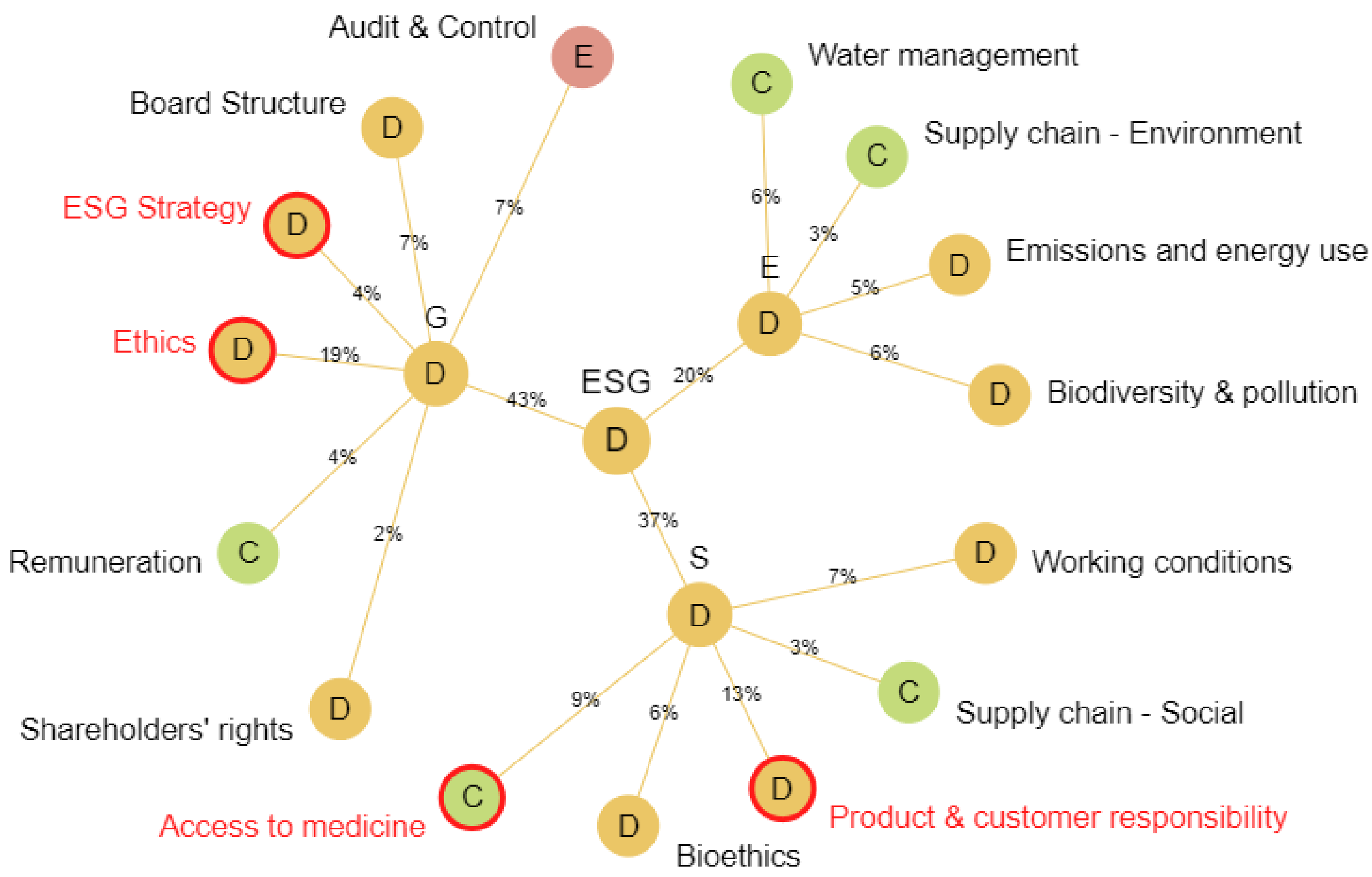


Figure 26: ESG rating tree of Company **P** (Amundi, May 2021)

Source: Amundi ALTO* SRI (2021)

ESG scores, ESG ratings and ESG strategies

Beating the benchmark

- The goal is to have a portfolio, whose ESG score is greater than that of the benchmark index
- Two ways to improve a global ESG score:
  - Overweight issuers with the best ESG scores
  - Underweight or remove issuers with the worst ESG scores

ESG Score

SRI strategy

- The goal is to systematically exclude issuers, whose rating is too bad
- For example, we can exclude:
  - Ratings **CCC**
  - Ratings **B**

ESG Rating

ESG ratings versus credit ratings

Credit rating

- What is the question?
  Measuring the 1Y PD
- Rating correlation $\geq 90\%$
  Convergence in the 1990s
- **Absolute** rating
  $\Rightarrow$ Facilitates comparison
- More stable
- Accounting standards

ESG rating

- What is the question?
  ???
- Rating correlation $\leq 40\%$
  European issuers $>$ American issuers $>$ Japanese issuers (≈ 0)
- **Relative** rating
  $\Rightarrow$ Complicates comparison
- Less stable
- ESG standardization and the issue of self-reporting

What can we anticipate? $\Rightarrow$ Strong convergence for subcomponents, (more or less) convergence for **E**, **S**, and **G** ratings, but not for **ESG** ratings

The example of Tesla!

The divergence of ESG ratings

Berg, F., Koelbel, J.F., and Rigobon, R. (2019), Aggregate Confusion: The Divergence of ESG Ratings, MIT Sloan School of Management, www.ssrn.com/abstract=3438533

Three sources of divergence

1. Weights divergence (3%)
   Rating agencies take different views on the relative importance of attributes
2. Scope divergence (44%)
   Ratings agencies rely on a different set of attributes
3. Measurement divergence (53%)
   Rating agencies measure the same attribute using different indicators
   Rater Effect accounts for one fifth of the variation

The robustness of ESG ratings

How to measure the robustness of ratings?

1. Backtesting
2. Probabilistic properties of the rating migration matrix

$\Rightarrow$ These two tools are extensively used in credit scoring models and credit ratings

What is a good ESG rating system?

The robustness of ESG ratings

Table 14: An example of rating migration matrix (in %)

	AAA	AA	A	BBB	BB	B	CCC
AAA	80%	3%	2%	5%	5%	5%	
AA	5%	85%	3%	3%	2%	2%	
A		5%	90%	5%			
BBB		5%	5%	80%	5%	5%	
BB				7%	85%	8%	
B				1%	9%	80%	9%
CCC				5%	8%	20%	67%

Do you think that it is a good or bad rating system?

$\Rightarrow$ A rating migration matrix must satisfy a lot of mathematical properties (Markov property, time-consistency, lack-of-memory, stationarity, etc.)

The mapping function is key!

What is the performance of ESG investing?

Academic findings

- Relationship between shareholder rights and "*higher firm value, higher profits, higher sales growth, lower capital expenditures, and [...] fewer corporate acquisitions*" (Gompers *et al.*, 2003)
- Positive relation between high corporate social responsibility and low cost of equity capital (El Ghoul *et al.*, 2011): "*Employee Relations, Environmental Policies, Product Strategies lower the firms' cost of equity*"
- Corporate financial performance is a U-shape function of corporate social performance (Barnett and Salomon, 2012)
- Cultural differences explain the diversity and differences in intentions ('Value' or 'Values' oriented) of the currently available ESG data (Eccles and Stroehle, 2018)
- Negative/neutral impact: Schröder (2007), Hong and Kacperczyk (2009)

Mixed results

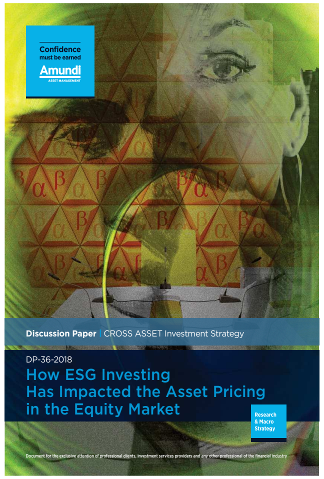
What is the performance of ESG investing?

- Generally, academic studies that analyze the relationship between ESG and performance are based on long-term historical data, typically the last 20 years or the last 30 years.
- Two issues:
  1. ESG investing was marginal 15+ years ago
  2. ESG data are not robust or relevant before 2010
- The relationship between ESG and performance is dynamic
- Sometimes, ESG may create performance, but sometimes not
- Few academic research on corporate bonds

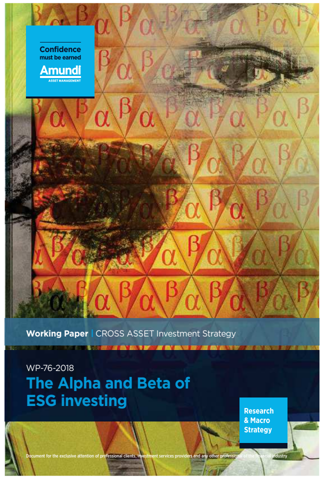
What is the performance of ESG investing?

Amundi findings

2010 – 2017
Equity



DP

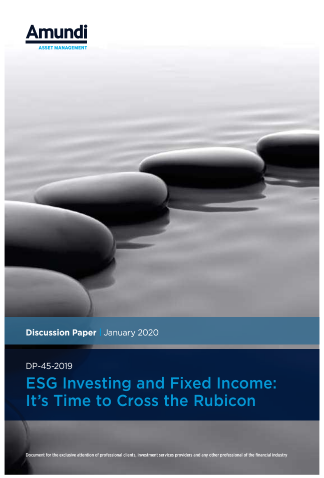


WP

2018 – 2019
Equity

DP

2010 – 2019
Fixed-income



DP

WP

2010 – 2017: From hell to heaven

- ESG investing tended to penalize both passive and active ESG investors between 2010 and 2013
- Contrastingly, ESG investing was a source of outperformance from 2014 to 2017 in Europe and North America
- Two success stories between 2014 and 2017: **E**nvironmental in North America and **G**overnance in the Eurozone
- ESG is a risk factor (or a beta strategy) in the Eurozone, whereas it is an alpha strategy in North America

Active management

Sorted portfolio methodology

Sorted-portfolio approach

- Sorted-based approach of Fama-French (1992)
- At each rebalancing date t, we rank the stocks according to their Amundi **ESG** z-score $s_{i,t}$
- We form the five quintile portfolios Q_i for $i = 1, \ldots, 5$
- The portfolio Q_i is invested during the period $]t, t+1]$:
  - Q_1 corresponds to the best-in-class portfolio (best scores)
  - Q_5 corresponds to the worst-in-class portfolio (worst scores)
- Quarterly rebalancing
- Universe: MSCI World Index
- Equally-weighted and sector-neutral portfolio (and region-neutral for the world universe)

Performance of ESG active management (2010 – 2017)

North America

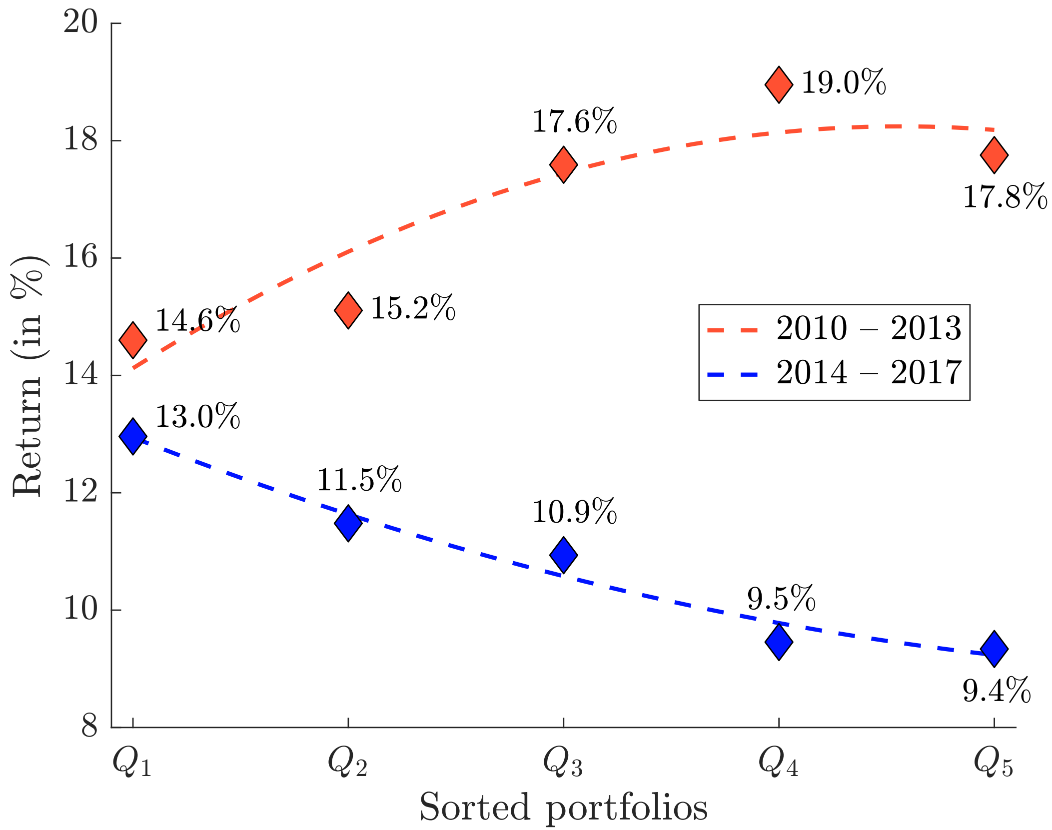


Figure 27: Annualized return of **ESG** sorted portfolios (North America)

Source: Amundi Quantitative Research (2018)

Performance of ESG active management (2010 – 2017)

Eurozone

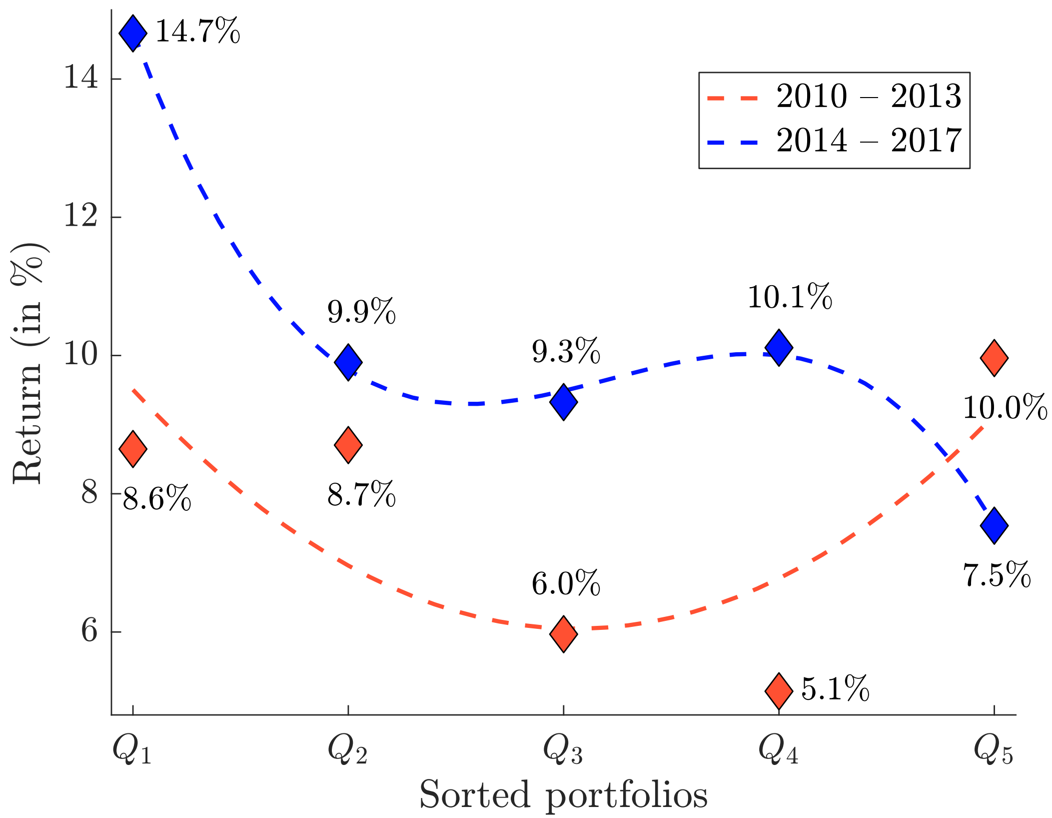


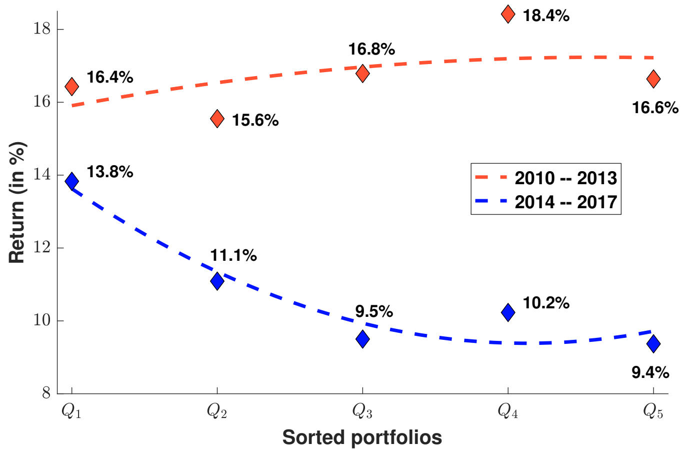
Figure 28: Annualized return of **ESG** sorted portfolios (Eurozone)

Source: Amundi Quantitative Research (2018)

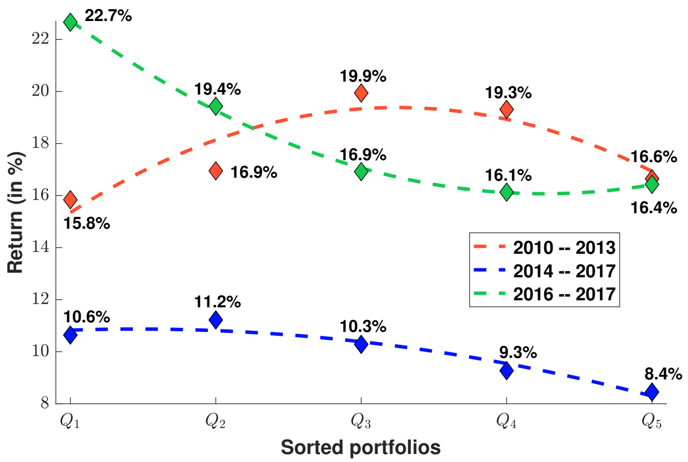
Performance of ESG active management (2010 – 2017)

North America

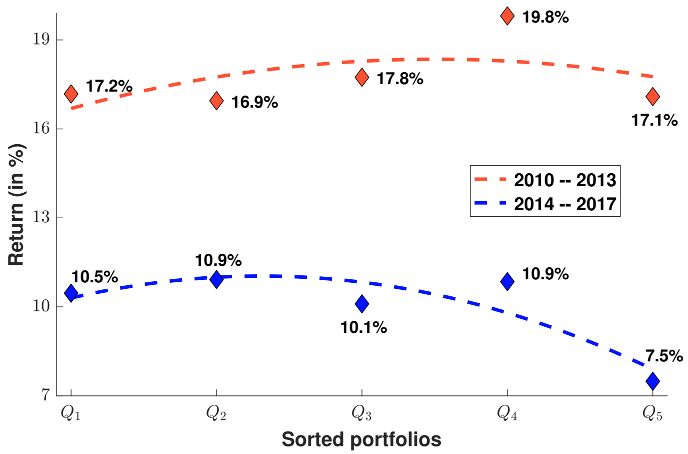
Environmental



Social



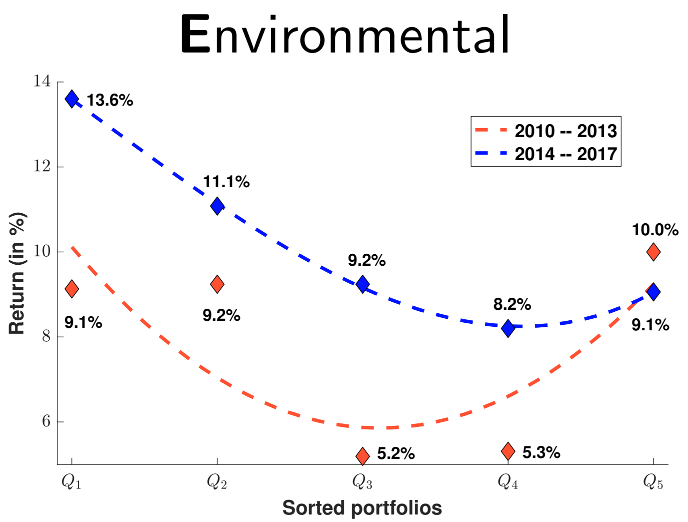
Governance

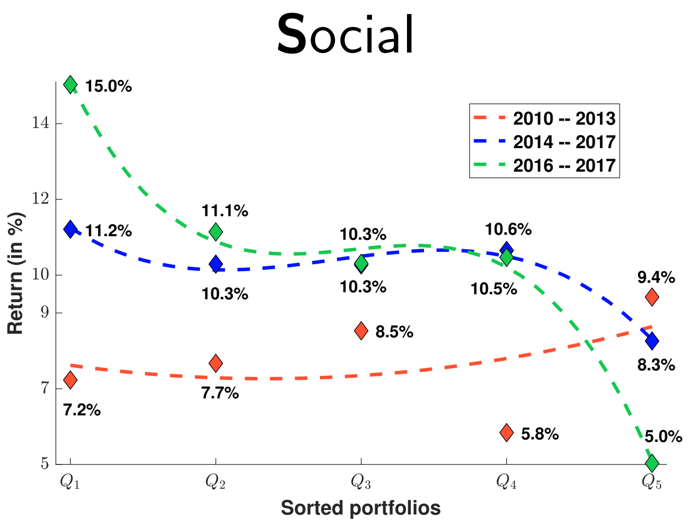


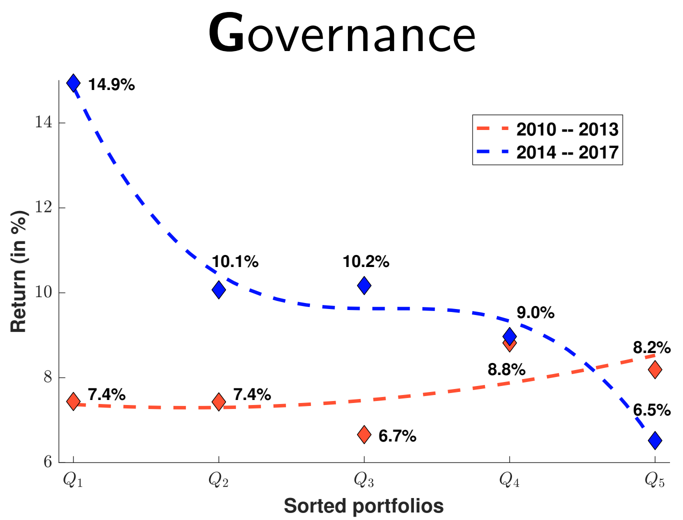
Source: Amundi Quantitative Research (2018)

Performance of ESG active management (2010 – 2017)

Eurozone







Source: Amundi Quantitative Research (2018)

Performance of ESG active management (2010 – 2017)

The 2014 break

Table 15: Summary of the results

Before 2014					
Factor	North America	Eurozone	Europe ex-EMU	Japan	World DM
ESG	−−	−	0	+	0
E	−	0	+	−	0
S	−	−	0	−	−
G	−	0	+	0	+
Since 2014					
Factor	North America	Eurozone	Europe ex-EMU	Japan	World DM
ESG	++	++	0	−	+
E	++	++	−	+	++
S	+	+	0	0	+
G	+	++	0	+	++

Source: Amundi Quantitative Research (2018)

The 2014 break

How to explain the 2014 break?

1. **The intrinsic value of ESG screening** or **the materiality of ESG**

> *"Since we observe a feedback loop between extra-financial risks and asset pricing, we may also wonder whether the term 'extra' is relevant, because ultimately, we can anticipate that these risks may no longer be extra-financial, but simply financial" (Bennani et al., 2018).*

ESG risks $\Rightarrow$ Asset pricing

2. **The extrinsic value of ESG investing** or **the supply/demand imbalance**

Investment flows matter!

The steamroller of ESG for institutional investors

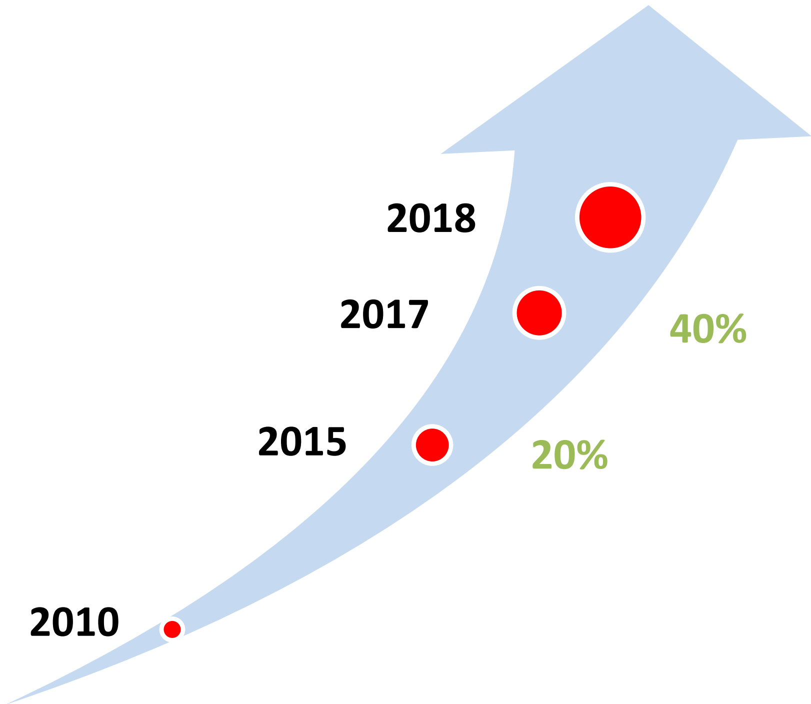


Figure 29: Frequency of institutional RFPs that require ESG filters

Source: Based on RFPs received at Amundi.

- In some countries, 100% of RFPs require ESG filters
- For some institutional investors, 100% of RFPs require ESG filters (public, para-public and insurance investors)
- For some strategies, 100% of RFPs require ESG filters (index tracking)

Passive management (optimized portfolios)

Portfolio optimization with a benchmark

We consider the following optimization problem[5]:

$$x^{\star}(\gamma) = \arg\min \frac{1}{2}\sigma^{2}(x \mid b) - \gamma \mathcal{S}(x \mid b)$$

where $\sigma(x \mid b)$ is the ex-ante tracking error (TE) of Portfolio x with respect to the benchmark b:

$$\sigma(x \mid b) = \sqrt{(x-b)^{\top}\Sigma(x-b)}$$

and $\mathcal{S}(x \mid b)$ is the excess score (ES) of Portfolio x wrt the benchmark b:

$$\begin{aligned} \mathcal{S}(x \mid b) &= (x-b)^{\top}\mathcal{S} \\ &= \mathcal{S}(x) - \mathcal{S}(b) \end{aligned}$$

[5]We note b the benchmark, $\mathcal{S}$ the vector of scores and Σ the covariance matrix.

Passive management (optimized portfolios)

Portfolio optimization with a benchmark

The objective is to find the optimal portfolio with the minimum TE for a given ESG excess score

This is a standard γ-problem where the expected returns are replaced by the ESG scores

Performance of ESG passive management (2010-2017)

Arbitrage between ESG and TE

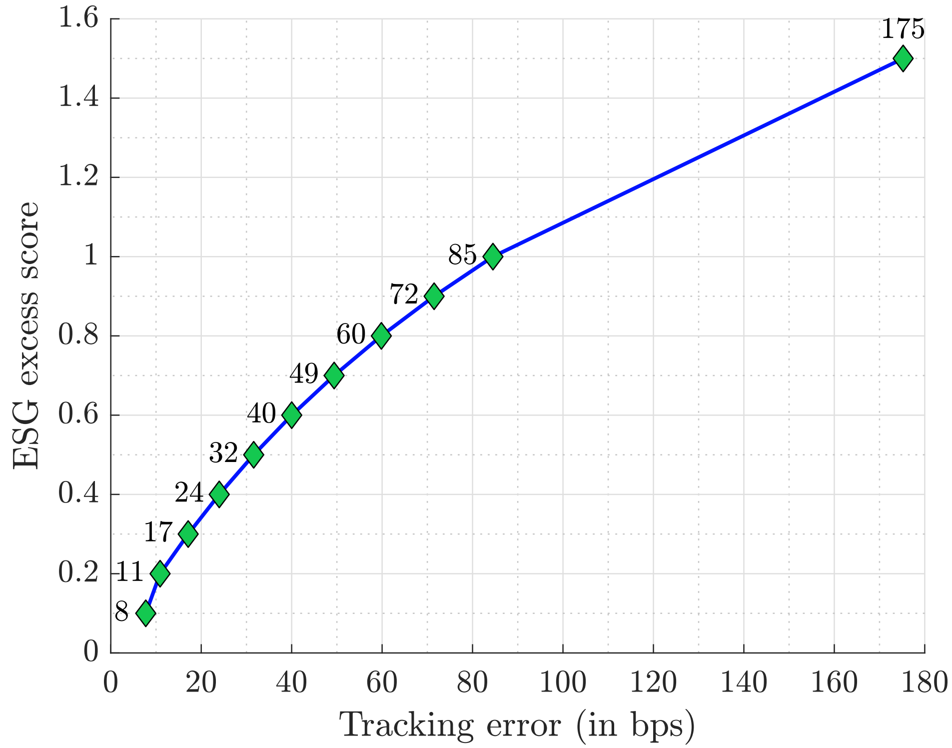


Figure 30: Efficient frontier of **ESG** optimized portfolios (World DM)

Source: Amundi Quantitative Research (2018)

No free lunch: **ESG investing implies to take a tracking-error risk!**

Performance of ESG passive management (2010-2017)

Performance of optimized portfolios

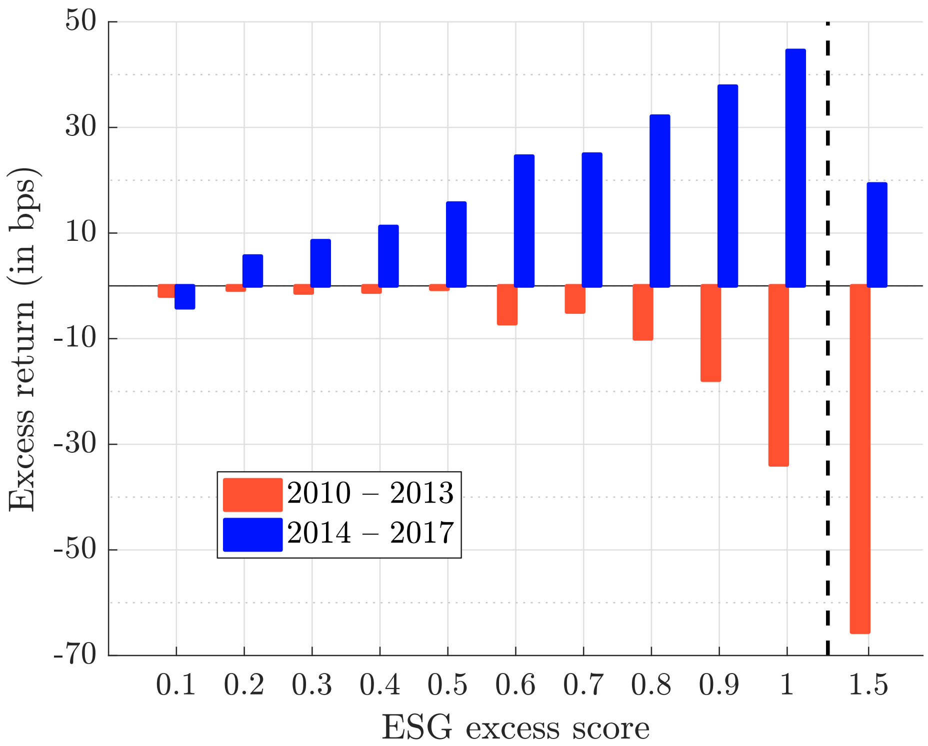


Figure 31: Annualized excess return of **ESG** optimized portfolios (World DM)

Source: Amundi Quantitative Research (2018)

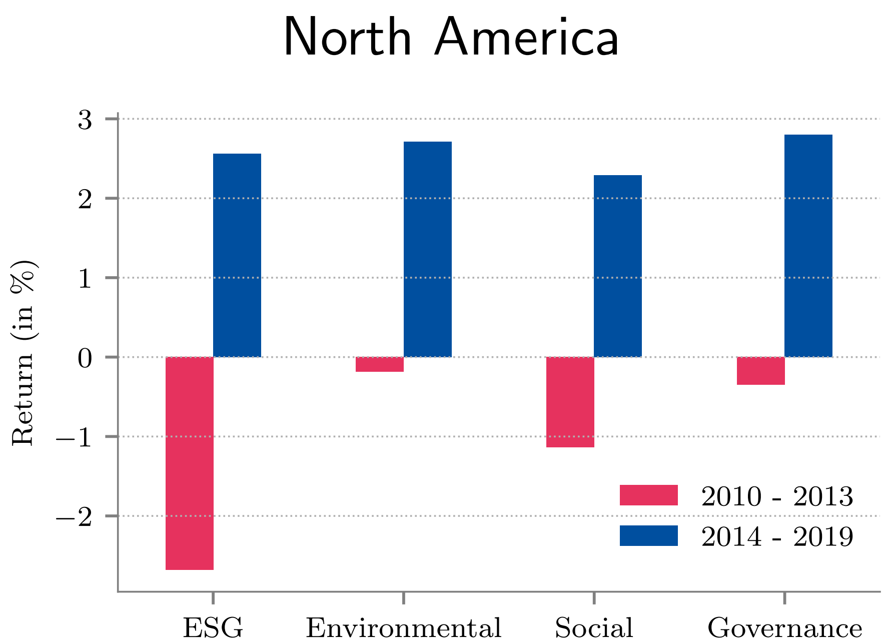
ESG investing & diversification: **Mind the gap**

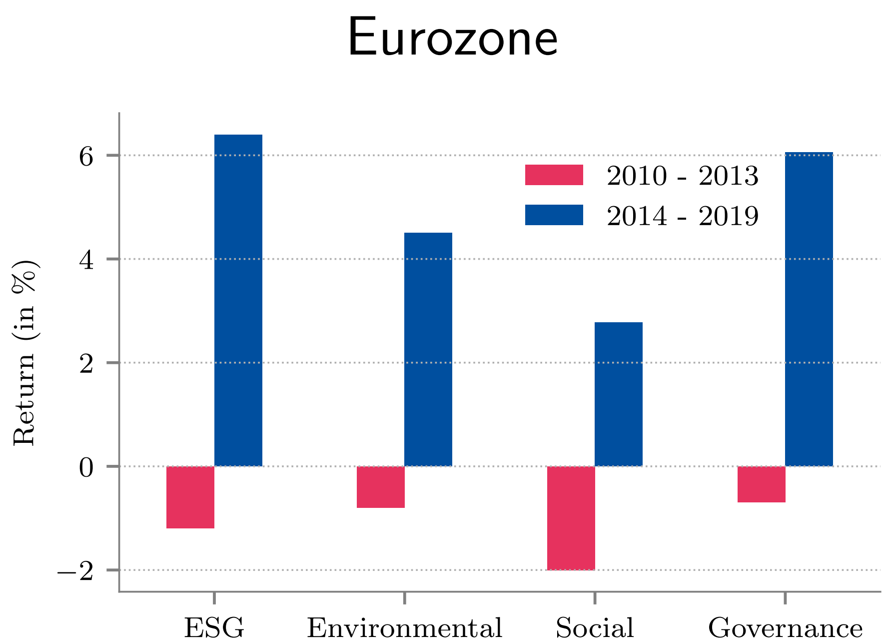
Performance of ESG active management (2018-2019)

On the road again

Main result

The 2018 – 2019 period seems to be a continuity of the 2014 – 2017 period rather than another distinctive phase





Source: Amundi Quantitative Research (2020)

Performance of ESG active management (2018-2019)

New findings in the stock market

1. **The transatlantic divide**

$$\text{Eurozone} \succ \text{North America}$$

2. **Social: from laggard to leader**[6]

$$\textbf{S} \succ \textbf{E}, \textbf{G}$$

3. **ESG investing: growing in complexity**

Beyond worst-in-class exclusion and best-in-class selection strategies

[6] In the Eurozone: 2010 – 2013: **E**, then 2014 – 2017: **G**, then 2018 – 2019: **S**
In North America: 2010 – 2013: **G**, then 2014 – 2017: **E**, then 2018 – 2019: **S**

Performance of ESG active management (2018-2019)

The transatlantic divide: the case of the Eurozone

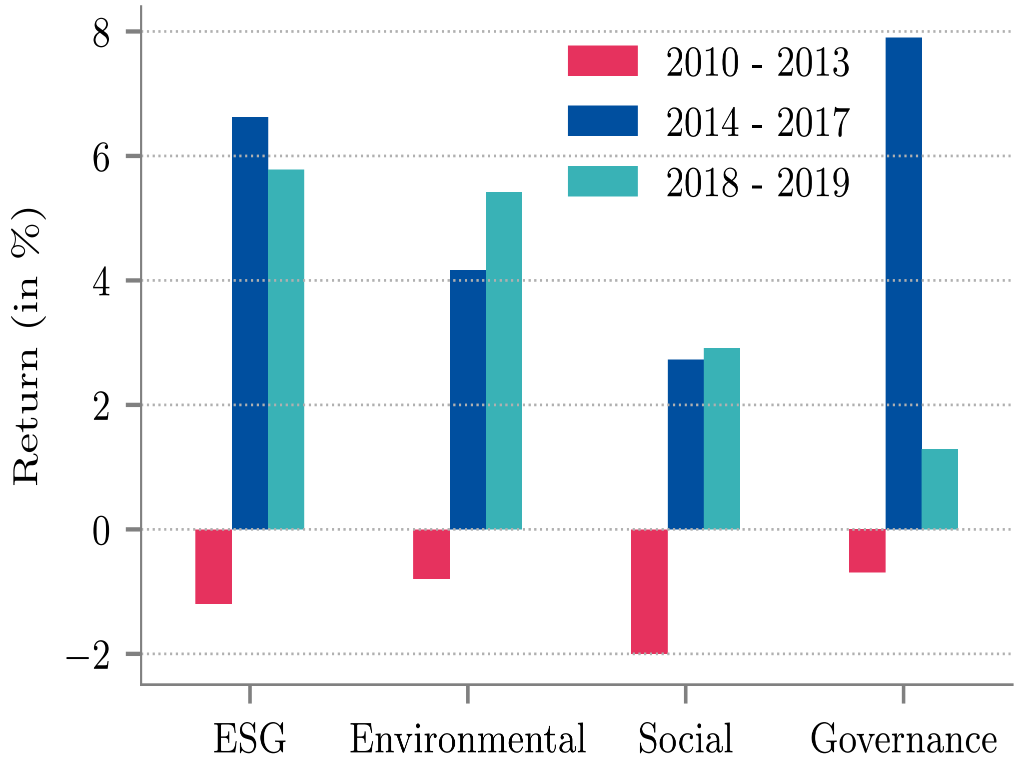


Figure 32: Annualized return of long/short $Q_1 - Q_5$ sorted portfolios

Source: Amundi Quantitative Research (2020)

$\Rightarrow$ Performance remains highly positive, and is improved for **E** and **S**

Performance of ESG active management (2018-2019)

The transatlantic divide: the case of North America

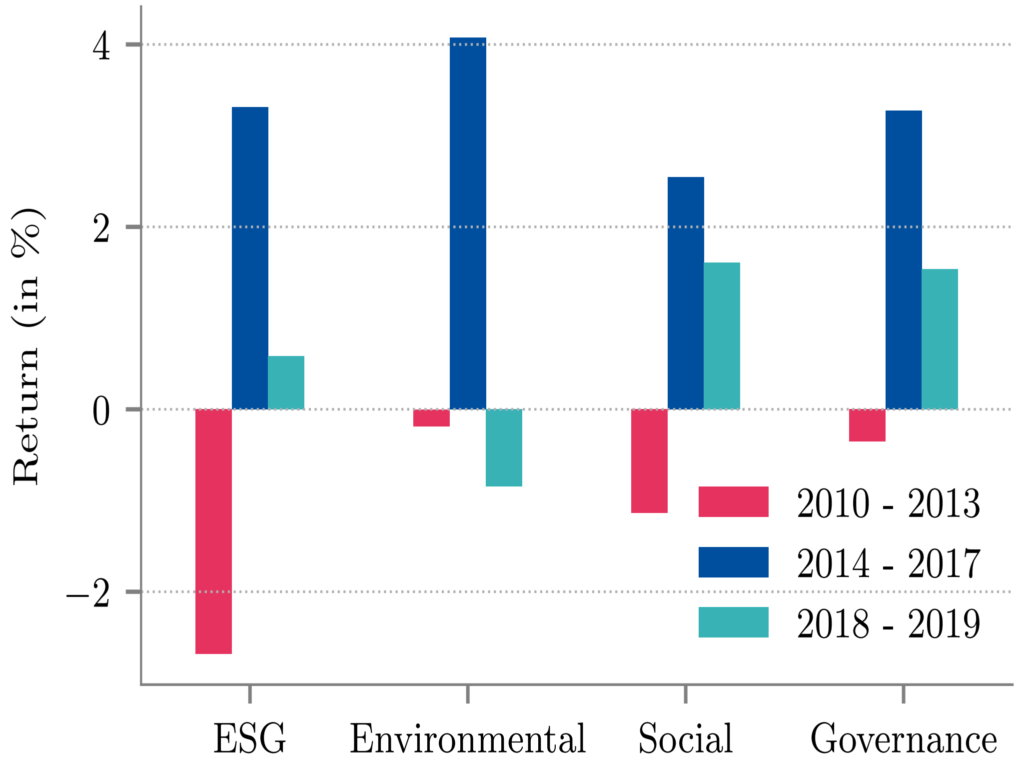


Figure 33: Annualized return of long/short $Q_1 - Q_5$ sorted portfolios

Source: Amundi Quantitative Research (2020)

$\Rightarrow$ Performance is positive, but reduced for **S** and **G**, whereas **E** is negative

Performance of ESG active management (2018-2019)

How to explain the American setback?

The regulatory value of ESG investing (or the intrinsic value *revisited*)

- Trump election effect
- Regulatory environment

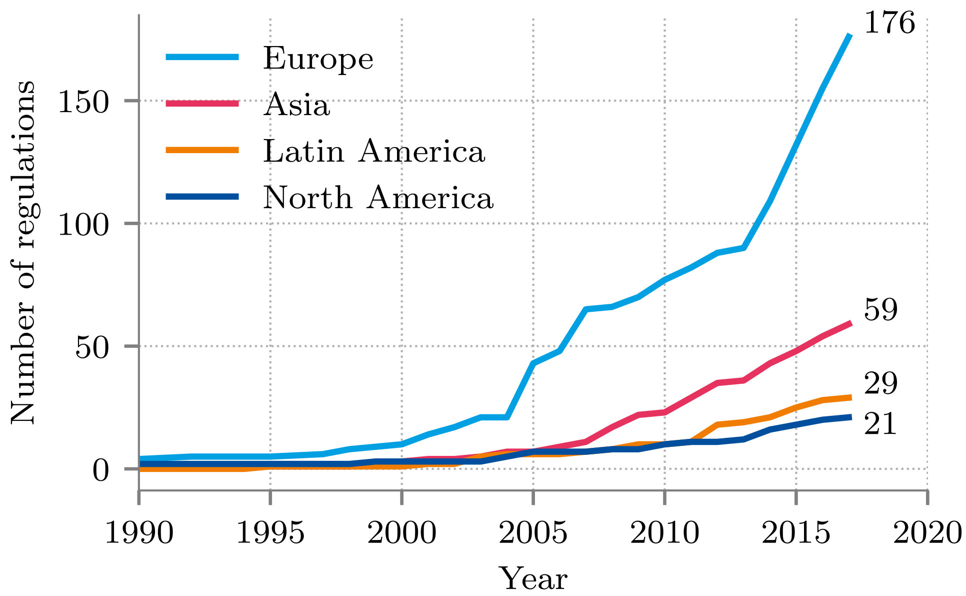


Figure 34: Number of ESG regulations

- ESG regulations are increasing, with a strong momentum in Europe but a weaker one in North America
- US withdrawal from Paris Climate Agreement

Source: PRI, responsible investment regulation database, 2019.

Performance of ESG active management (2018-2019)

How to explain the American setback?

The extrinsic value of ESG investing

- The 2014 break
  - November 2013: Responsible Investment and the Norwegian Government Pension Fund Global (2013 Strategy Council)
  - Strong mobilization of the largest institutional European investors: NBIM, APG, PGGM, ERAFP, FRR, etc.
  - They are massively invested in European stocks and America stocks:
    $$\text{NBIM} \succ \text{CalPERS} + \text{CalSTRS} + \text{NYSCRF for U.S. stocks}$$
- The 2018-2019 period
  - Implication of U.S. investors continues to be weak
  - Strong mobilization of medium (or tier two) institutional European investors, that have a low exposure on American stocks
  - Mobilization of European investors is not sufficient

$\Rightarrow$ The extrinsic value of ESG investing is temporary, and a new equilibrium will be found on the long run

Performance of ESG active management (2018-2019)

Social is strong in Eurozone

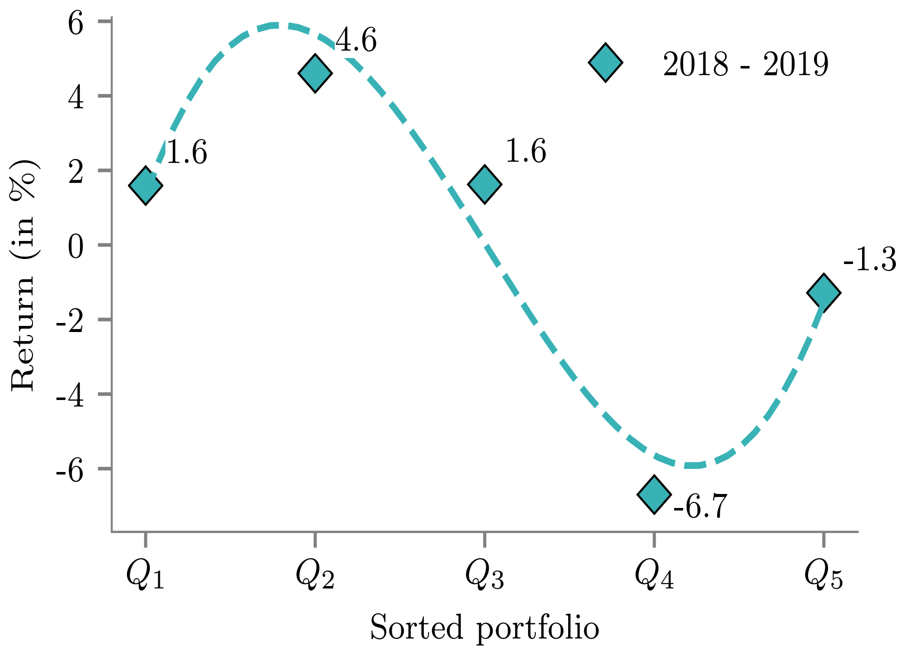


Figure 35: Sorted portfolios

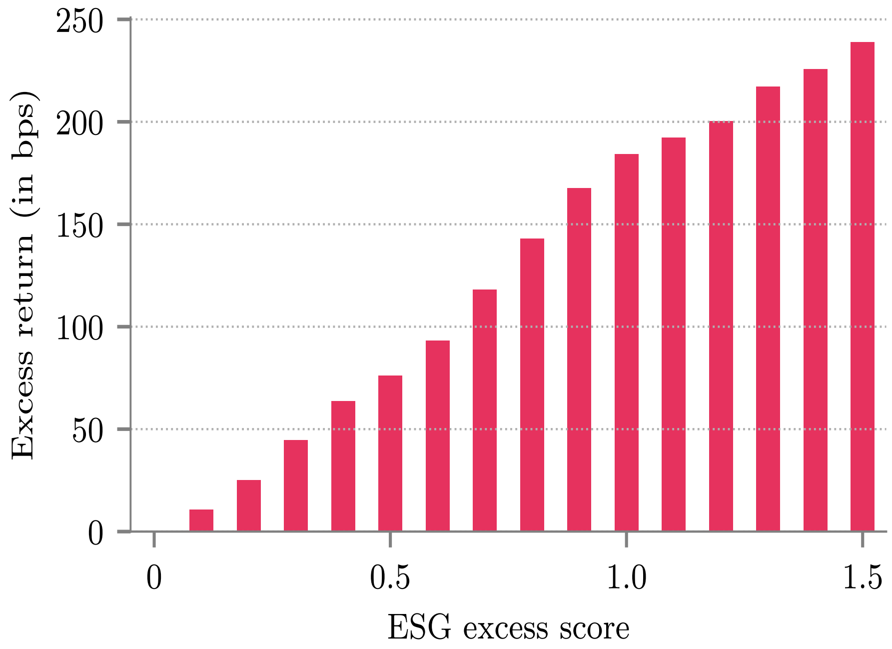


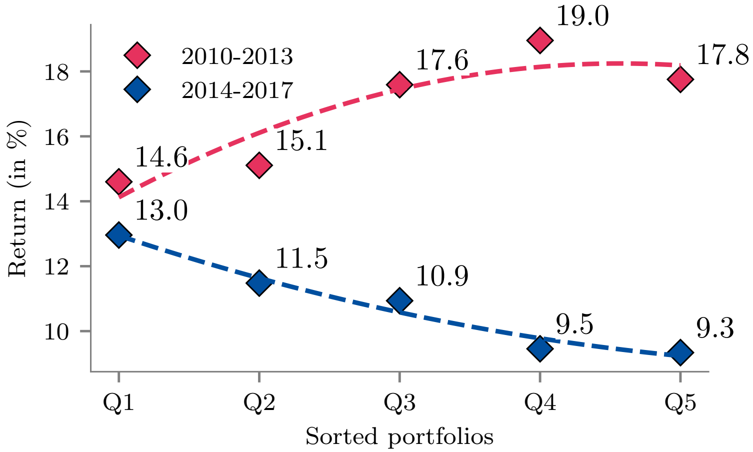
Figure 36: Optimized portfolios

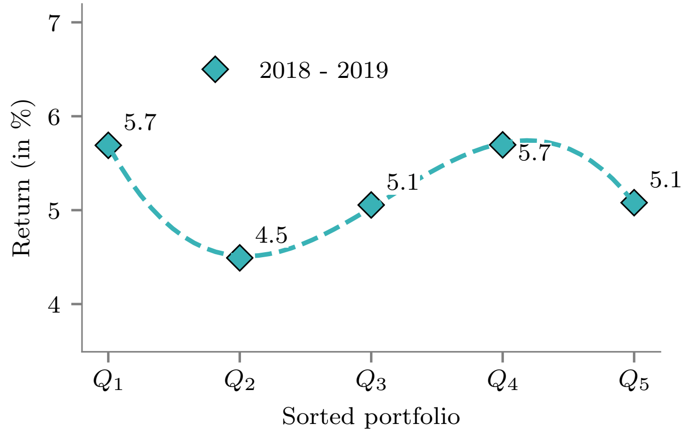
Source: Amundi Quantitative Research (2020)

Performance of ESG active management (2018-2019)

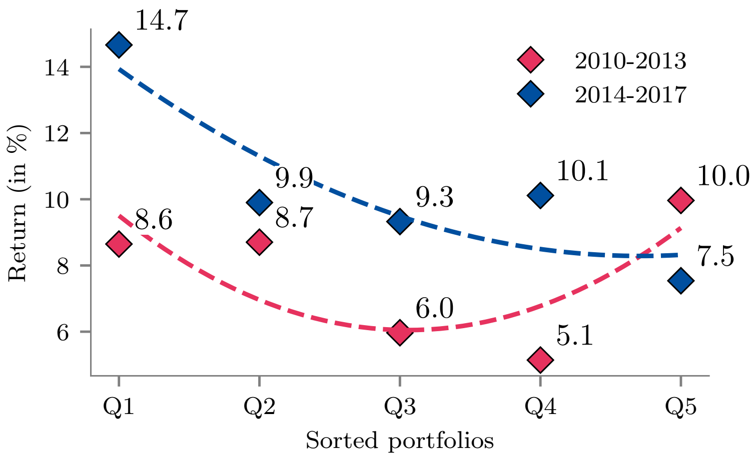
ESG investing: growing in complexity

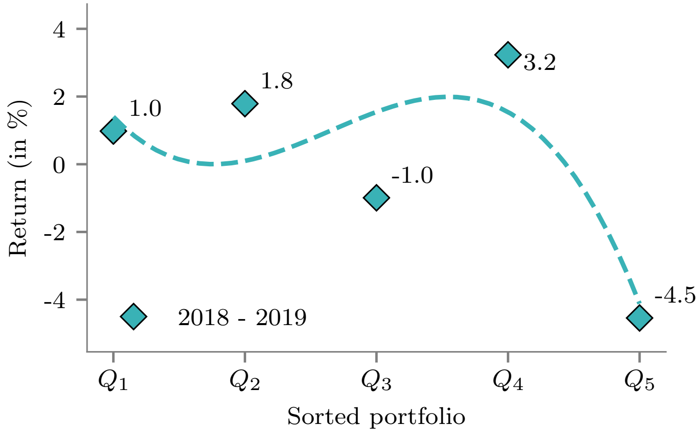
North America, **ESG**-Sorted portfolios, 2010 – 2019





Eurozone, **ESG**-Sorted portfolios, 2010 – 2019

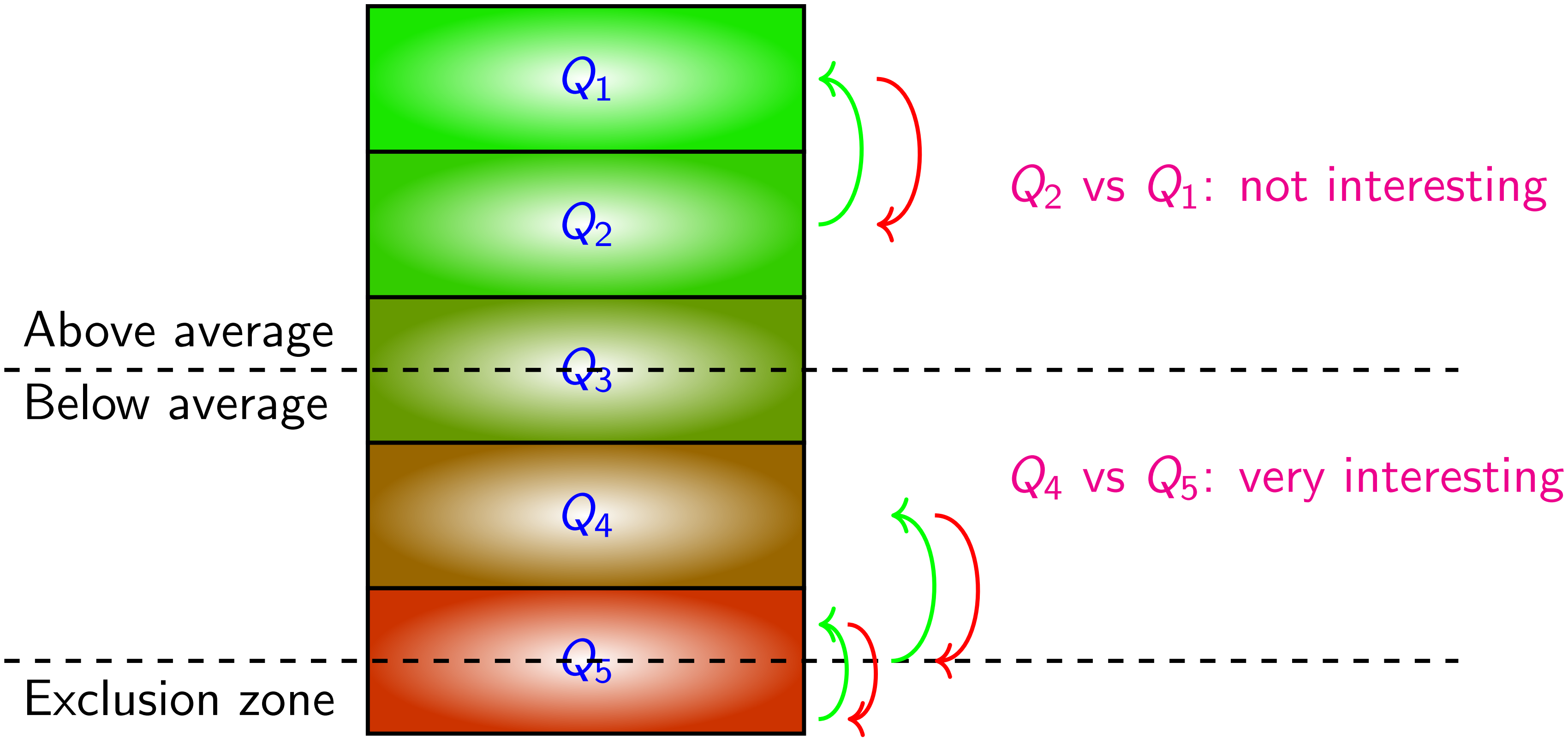




Performance of ESG active management (2018-2019)

The dynamic view of ESG investing

Figure 37: How to play ESG momentum?



The 2020-2021 period

- Reverse transatlantic divide?
- Covid-19 catalyst
- Biden puzzle
- Rise of EM ESG investing

Single-factor model

Regression model

We have:

$$R_{i,t} = \alpha_i + \beta_i^j \mathcal{F}_{j,t} + \varepsilon_{i,t}$$

where $\mathcal{F}_{j,t}$ can be: market, size, value, momentum, low-volatility, quality or ESG.

Single-factor model

Table 16: Results of cross-section regressions with long-only risk factors (average R^2)

Factor	North America		Eurozone	
	2010 – 2013	2014 – 2019	2010 – 2013	2014 – 2019
Market	40.8%	28.6%	42.8%	36.3%
Size	39.3%	26.1%	37.1%	23.3%
Value	38.9%	26.7%	41.6%	33.6%
Momentum	39.6%	26.3%	40.8%	34.1%
Low-volatility	35.8%	25.1%	38.7%	33.4%
Quality	39.1%	26.6%	42.4%	34.6%
ESG	40.1%	27.4%	42.6%	35.3%

- Specific risk has increased during the period 2014 – 2019
- Since 2014, we find that:
  - ESG $\succ$ Value $\succ$ Quality $\succ$ Momentum $\succ \ldots$ (North America)
  - ESG $\succ$ Quality $\succ$ Momentum $\succ$ Value $\succ \ldots$ (Eurozone)

Multi-factor model

Regression model

We have:

$$R_{i,t} = \alpha_i + \sum_{j}^{n_{\mathcal{F}}} \beta_i^j \mathcal{F}_{j,t} + \varepsilon_{i,t}$$

- 1F = market
- 5F = size + value + momentum + low-volatility + quality
- 6F = 5F + ESG

Multi-factor model

Table 17: Results of cross-section regressions with long-only risk factors (average R^2)

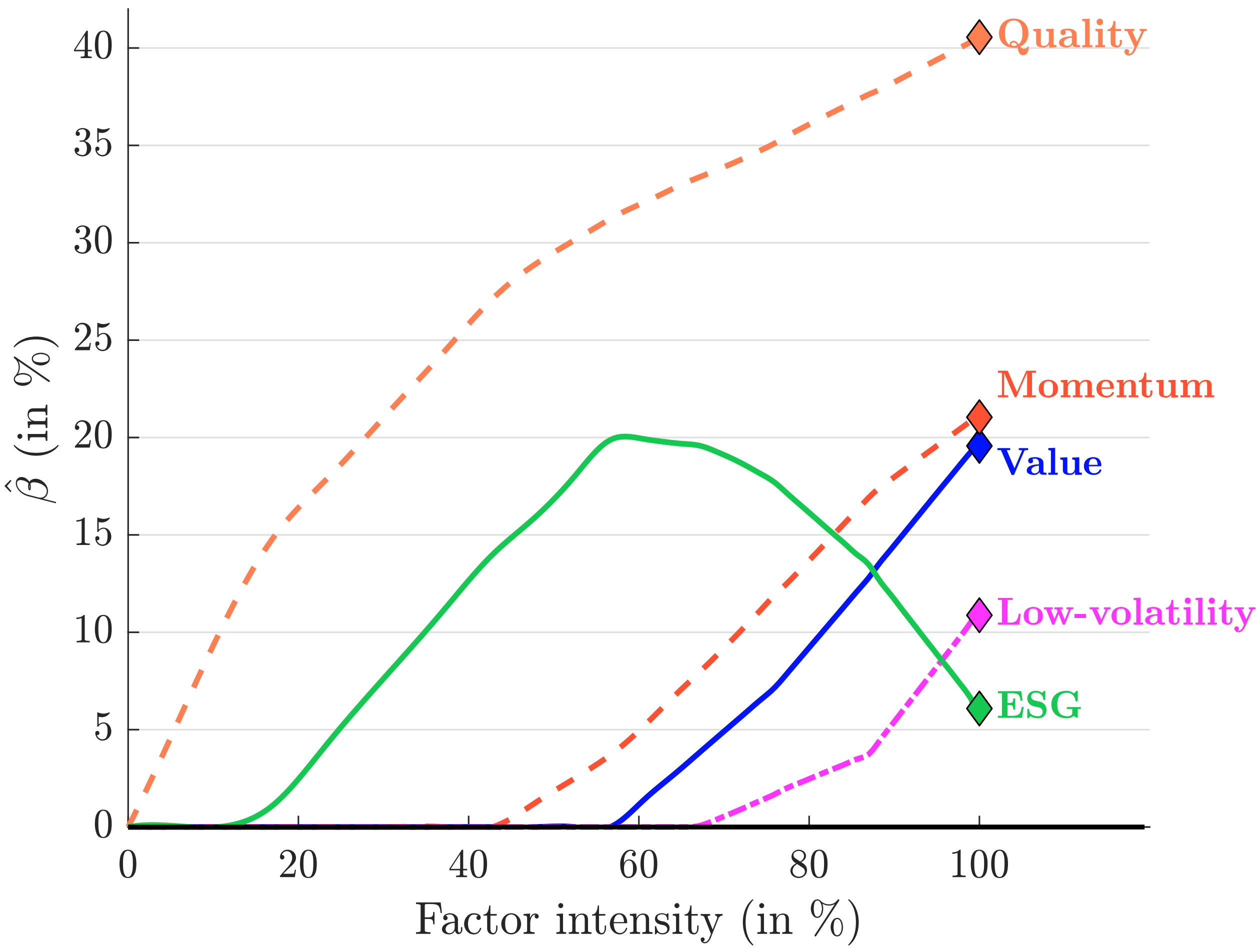
Factor	North America		Eurozone	
	2010 – 2013	2014 – 2019	2010 – 2013	2014 – 2019
Market	40.8%	28.6%	42.8%	36.3%
5F model	46.1%	38.4%	49.5%	45.0%
6F model (5F + ESG)	46.7%	39.7%	50.1%	45.8%

***p-value statistic for the MSCI Index (time-series, 2014 – 2019):

- 6F = ~~Size~~, Value, Momentum, Low-volatility, Quality, ~~ESG~~ (North America)
- 6F = Size, Value, Momentum, ~~Low-volatility~~, Quality, ESG (Eurozone)

Factor selection

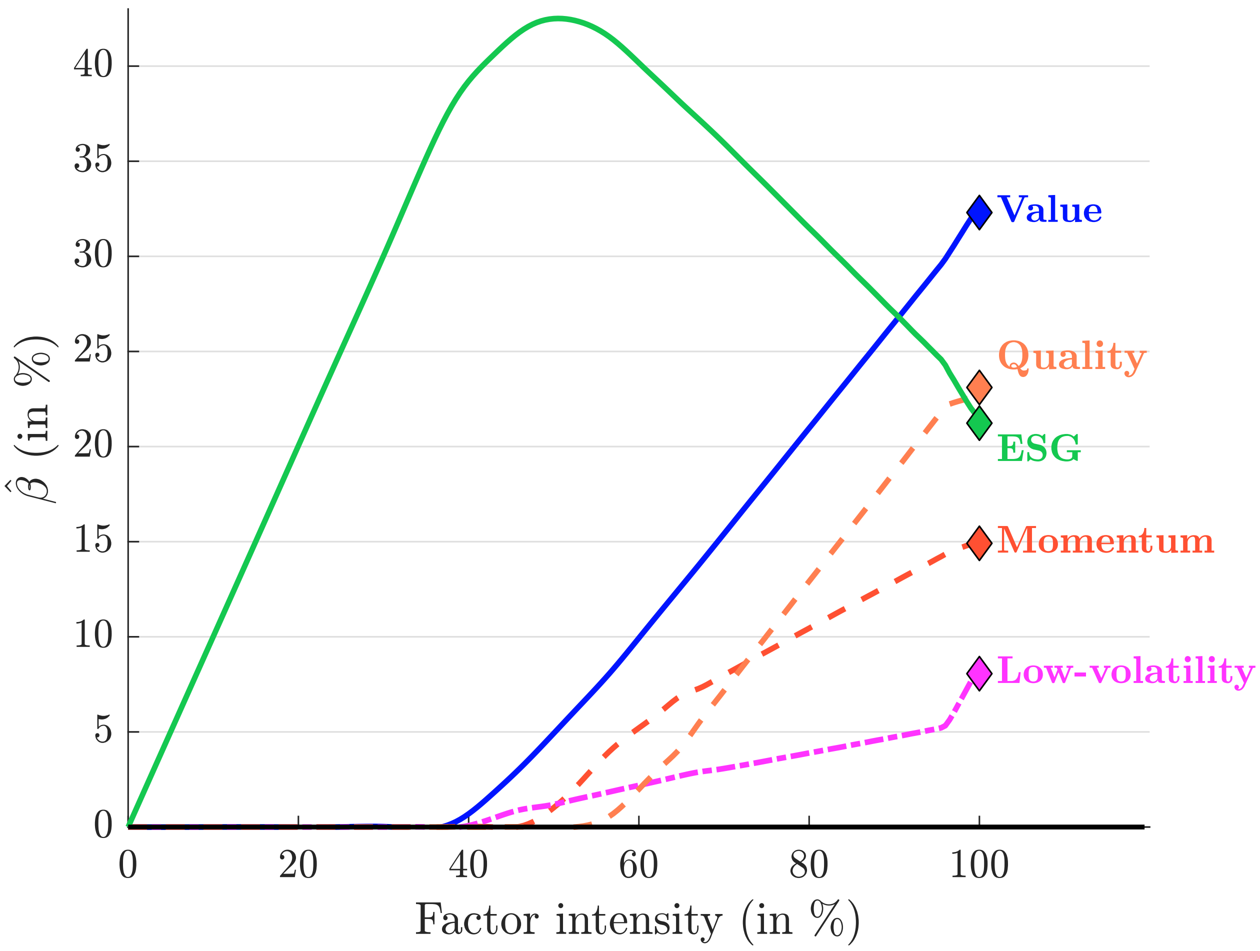
Figure 38: North America



Source: Amundi Quantitative Research (2020)

Factor selection

Figure 39: Eurozone



Source: Amundi Quantitative Research (2020)

What is the difference between alpha and beta?

α or β?

"[...] When an alpha strategy is massively invested, it has an enough impact on the structure of asset prices to become a risk factor.
[...] Indeed, an alpha strategy becomes a common market risk factor once it represents a significant part of investment portfolios and explains the cross-section dispersion of asset returns" (Roncalli, 2020)

- ESG remains an alpha strategy in North America
- ESG becomes a beta strategy (or a risk factor) in Europe
- Forward looking, ESG will be a beta strategy in North America

Is ESG a risk factor?

- Of course, **ESG is a risk factor that explains the cross-section of stock returns**
- ESG investing is correlated with Quality investing
- But ESG $\neq$ Value, Quality, Low volatility, etc.
  - The motivation of ESG Investing is not the performance
  - The motivation of Value or Quality Investing is the performance

$\Rightarrow$ Investment flows on ESG investing are more stable than investment flows on the other factors (in particular value, momentum and low volatility)

The question of the ESG risk premium is different from the question of the ESG risk factor

Why ESG investing in bond markets is different than ESG investing in stock markets

Stocks

- ESG scoring is incorporated in portfolio management
- ESG = long-term business risk $\Rightarrow$ strongly impacts the equity
- Portfolio integration
- Managing the business risk

Bonds

- ESG integration is generally limited to exclusions
- ESG lowly impacts the debt
- Portfolio completion
- Fixed income = impact investing
- Development of pure play ESG securities (green and social bonds)

$\Rightarrow$ Stock holders are more ESG sensitive than bond holders because of the capital structure

Why ESG investing in bond markets is different than ESG investing in stock markets

ESG investment flows affect asset pricing differently

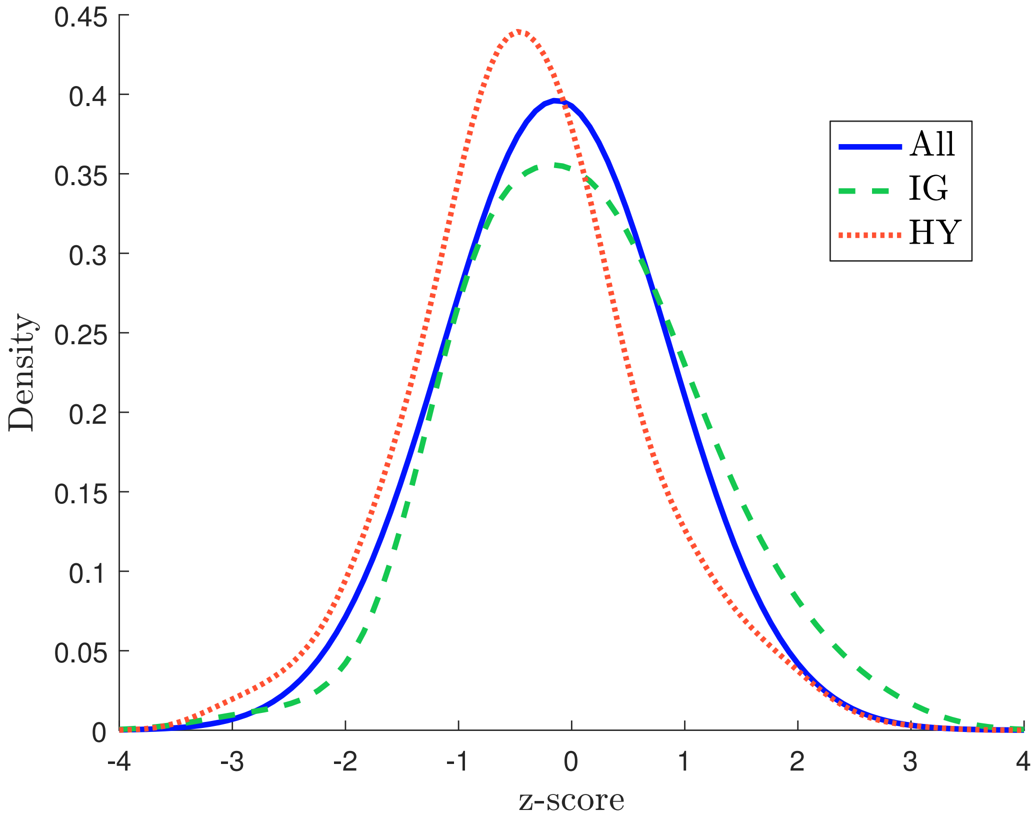
- Impact on carry (coupon effect)?
- Impact on price dynamics (credit spread/mark-to-market effect)?
- Buy-and-hold portfolios $\neq$ managed portfolios

The distinction between IG and HY bonds

- ESG and credit ratings are correlated
- There are more worst-in-class issuers in the HY universe, and best-in-class issuers in the IG universe
- Non-neutrality of the bond universe (bonds $\neq$ stocks)

Why ESG investing in bond markets is different than ESG investing in stock markets

Figure 40: Density function of the z-score



- The average z-score for IG bonds is positive
- The average z-score for HY bonds is negative

Sorted portfolio methodology

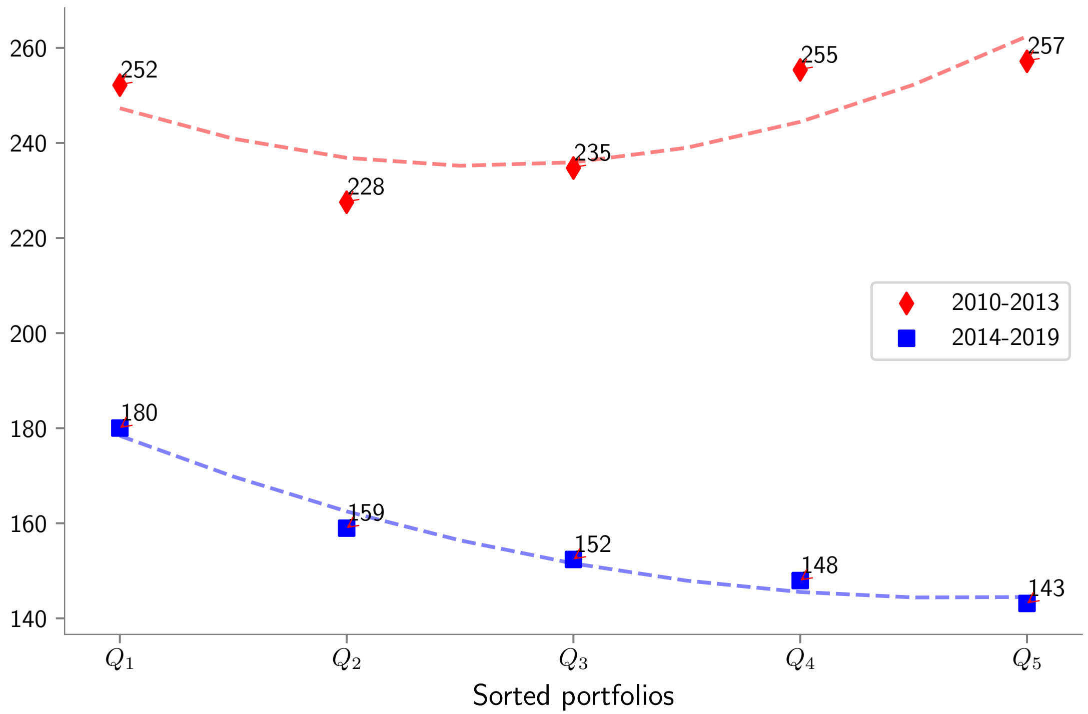
Sorted-portfolio approach

- Sorted-based approach of Fama-French (1992)
- At each rebalancing date t, we rank the bonds according to their Amundi **ESG** z-score
- We form the five quintile portfolios Q_i for $i = 1, \ldots, 5$
- The portfolio Q_i is invested during the period $]t, t+1]$:
  - Q_1 corresponds to the best-in-class portfolio (best scores)
  - Q_5 corresponds to the worst-in-class portfolio (worst scores)
- Monthly rebalancing
- Universe: ICE (BofAML) Large Cap IG EUR Corporate Bond
- Sector-weighted and sector-neutral portfolio
- Within a sector, bonds are equally-weighted

What is the performance of ESG investing?

Sorted portfolios

Figure 41: Annualized credit return in bps of **ESG** sorted portfolios (EUR IG, 2010 – 2019)



Source: Amundi Quantitative Research (2020)

Table 18: Carry statistics (in bps)

Period	Q_1	Q_5
2010-2013	175	192
2014-2019	113	128

- Negative carry (coupon level)
- Positive mark-to-market (dynamics of credit spreads and bond prices)

Bond portfolio optimization

We consider the following optimization problem:

$$x^{\star}(\gamma) = \arg\min \mathcal{R}(x \mid b) - \gamma \cdot \mathcal{S}(x \mid b)$$

where:

$$\mathcal{R}(x \mid b) = \frac{1}{2}\mathcal{R}_{\mathrm{MD}}(x \mid b) + \frac{1}{2}\mathcal{R}_{\mathrm{DTS}}(x \mid b)$$

and:

- $\mathcal{R}_{\mathrm{MD}}(x \mid b)$ and $\mathcal{R}_{\mathrm{DTS}}(x \mid b)$ are the interest rate and credit **active risk** measures wrt the benchmark b
- $\mathcal{S}(x \mid b)$ is the ESG excess score of Portfolio x wrt the benchmark b

The objective is to find the optimal portfolio minimizing interest rate and credit active risk for a given ESG excess score

What is the performance of ESG investing?
Optimized portfolios

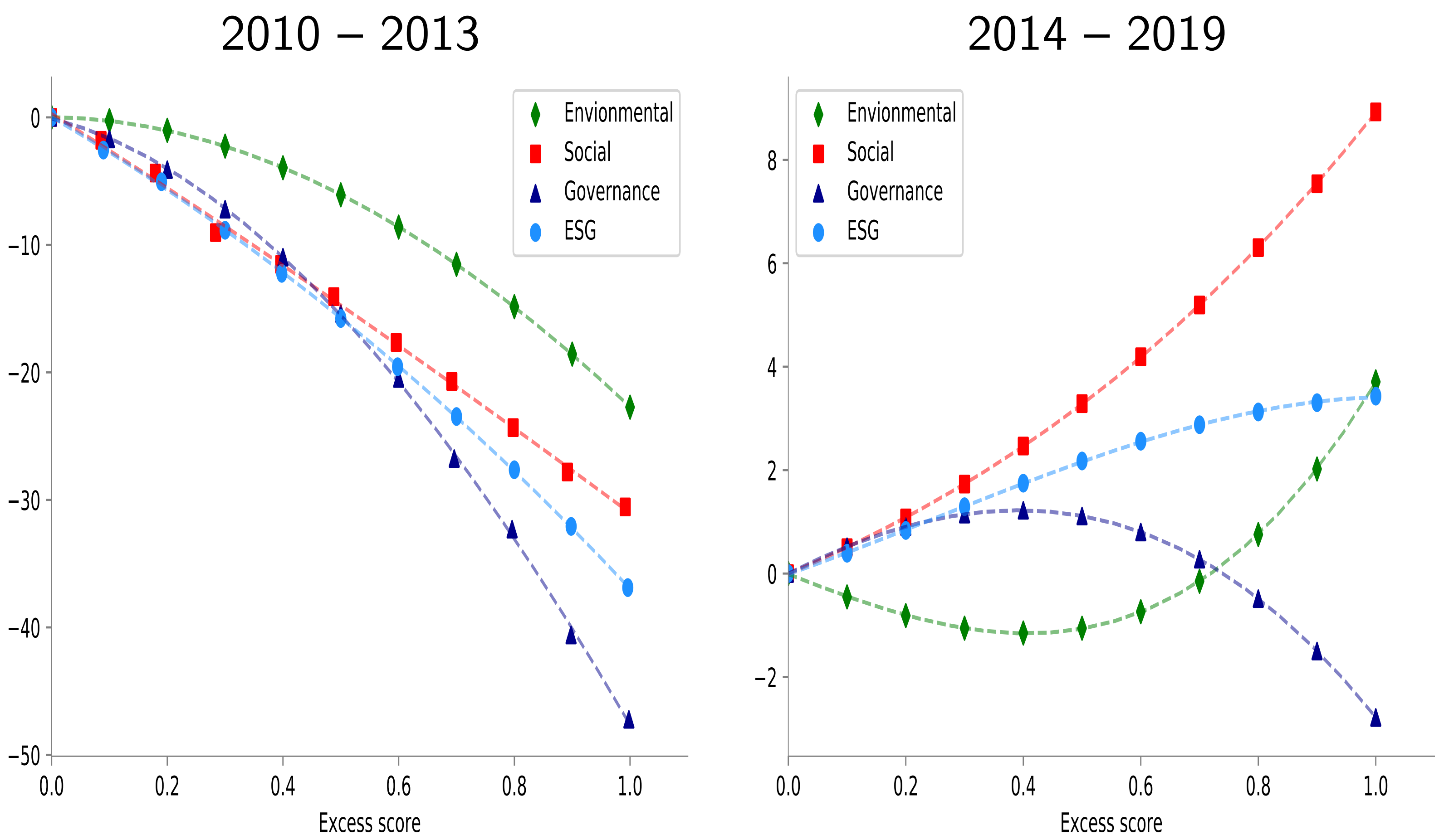


Figure 42: Excess credit return in bps of optimized portfolios (EUR IG)

Source: Amundi Quantitative Research (2020)

What is the performance of ESG investing?

Optimized portfolios

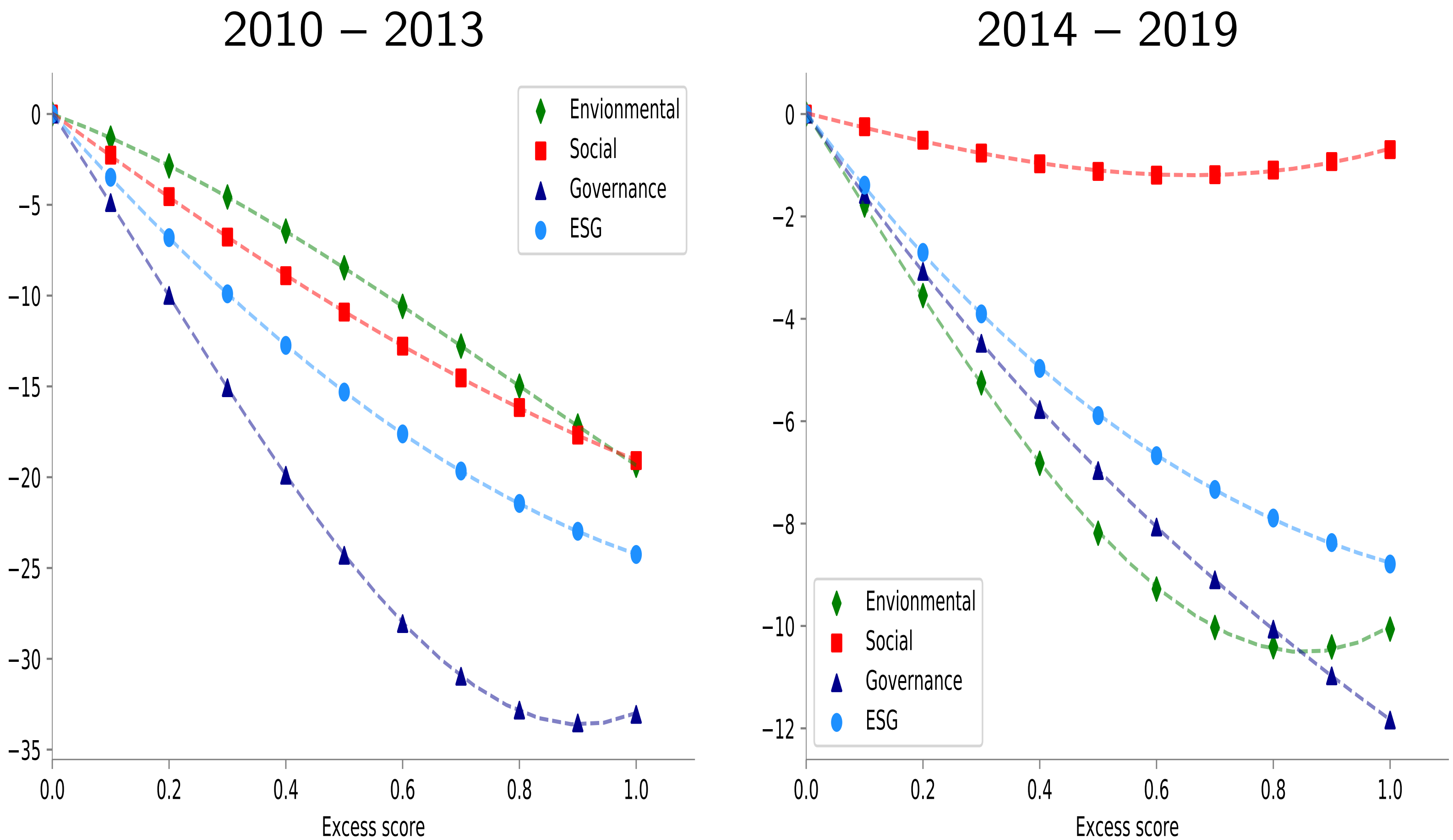


Figure 43: Excess credit return in bps of optimized portfolios (USD IG)

Source: Amundi Quantitative Research (2020)

Correlation between Credit ratings and ESG ratings

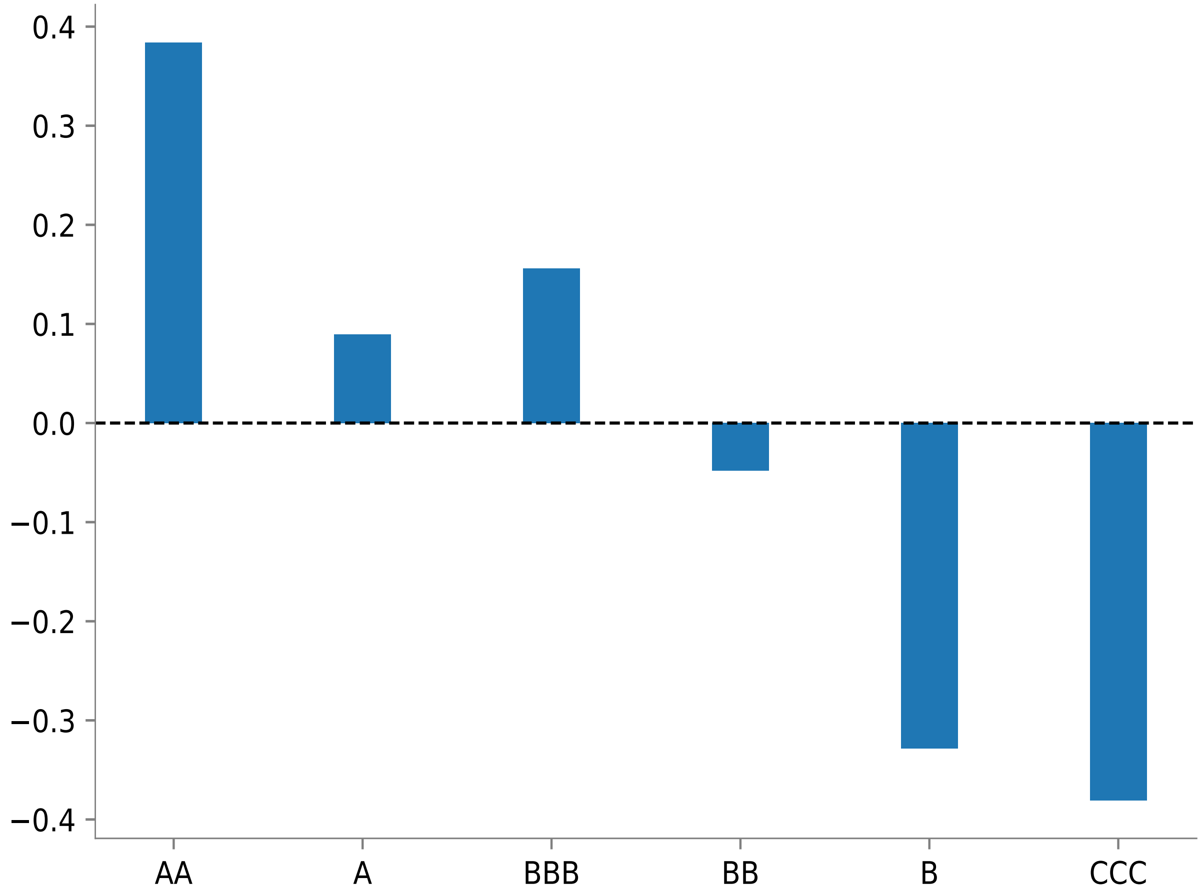


Figure 44: Average **ESG** z-score with respect to the credit rating (2010 – 2019)

Source: Amundi Quantitative Research (2020)

An integrated Credit-ESG model

We consider the following regression model:

$$\begin{aligned} \ln \mathrm{OAS}_{i,t} &= \alpha_t + \beta_{esg} \cdot \mathcal{S}_{i,t} + \beta_{md} \cdot \mathrm{MD}_{i,t} + \sum_{j=1}^{N_{\mathcal{S}ector}} \beta_{\mathcal{S}ector}(j) \cdot \mathcal{S}ector_{i,t}(j) + \\ & \beta_{sub} \cdot \mathrm{SUB}_{i,t} + \sum_{k=1}^{N_{\mathcal{R}ating}} \beta_{\mathcal{R}ating}(k) \cdot \mathcal{R}ating_{i,t}(k) + \varepsilon_{i,t} \end{aligned}$$

where:

- $\mathcal{S}_{i,t}$ is the **ESG** *z*-score of Bond *i* at time *t*
- $\mathrm{SUB}_{i,t}$ is a dummy variable accounting for subordination of the bond
- $\mathrm{MD}_{i,t}$ is the modified duration
- $\mathcal{S}ector_{i,t}(j)$ is a dummy variable for the j^{th} sector
- $\mathcal{R}ating_{i,t}(k)$ is a dummy variable for the k^{th} rating

An integrated Credit-ESG model

Table 19: Results of the panel data regression model (EUR IG, 2010 – 2019)

	2010–2013				2014–2019			
	ESG	**E**	**S**	**G**	**ESG**	**E**	**S**	**G**
R^2	60.0%	59.4%	59.5%	60.3%	66.3%	65.0%	65.2%	64.6%
Excess R^2 of ESG	0.6%	0.0%	0.2%	1.0%	4.0%	2.6%	2.9%	2.3%
$\hat{\beta}_{esg}$	-0.05	-0.01	-0.02	-0.07	-0.09	-0.08	-0.08	-0.08
t-statistic	-32	-7	-16	-39	-124	-98	-104	-92

Source: Amundi Quantitative Research (2020)

The assumption $\mathcal{H}_0 : \beta_{esg} < 0$ is not rejected

ESG cost of capital with min/max score bounds

We calculate the difference between:

(1) the funding cost of **the worst-in-class issuer** and

(2) the funding cost of **the best-in-class issuer**

by assuming that:

- the two issuers have the same credit rating;
- the two issuers belong to the same sector;
- the two issuers have the same capital structure;
- the two issuers have the same debt maturity.

$\Rightarrow$ Two approaches:

1. Theoretical approach: ESG scores are set to -3 and $+3$ (not realistic)
2. Empirical approach: ESG scores are set to observed min/max score bounds (e.g. min/max $= -2.0/+1.9$ for Consumer Cyclical A-rated EUR, $-2.1/+3.2$ for Banking A-rated EUR, etc.)

ESG cost of capital with min/max score bounds

Table 20: **ESG** cost of capital (IG, 2014 – 2019)

	EUR				USD			
	AA	A	BBB	Average	AA	A	BBB	Average
Banking	23	45	67	45	11	19	33	21
Basic	9	25	44	26	5	15	34	18
Capital Goods	8	32	42	27	6	15	26	16
Communication		26	48	37	5	11	23	13
Consumer Cyclical	3	26	43	28	2	8	17	10
Consumer Non-Cyclical	15	29	31	25	6	12	19	12
Utility & Energy	12	32	56	33	9	14	31	18
Average	12	31	48	**31**	7	13	26	**15**

Source: Amundi Quantitative Research (2020)

ESG and sovereign risk

References

- Crifo, P., Diaye, M.A., and Oueghlissi, R. (2015), Measuring the Effect of Government ESG Performance on Sovereign Borrowing Cost, *Quarterly Review of Economics and Finance*, `hal.archives-ouvertes.fr/hal-00951304v3`
- Martellini, L., and Vallée, L. (2021), Measuring and Managing ESG Risks in Sovereign Bond Portfolios and Implications for Sovereign Debt Investing, *Journal of Portfolio Management*, `www.risk.edhec.edu/measuring-and-managing-esg-risks-sovereign-bond`
- Semet, R., Roncalli, T., and Stagnol, L. (2021), ESG and Sovereign Risk: What is Priced in by the Bond Market and Credit Rating Agencies?, *Working Paper*, `www.ssrn.com/abstract=3940945`

$\Rightarrow$ We present the results of Semet *et al.* (2021)

ESG and sovereign risk

Motivation

- Financial analysis **versus/and** extra-financial analysis
- Sovereign risk $\neq$ Corporate risk
- Which ESG metrics are priced and not priced in by the market?
- What is the nexus between ESG analysis and credit analysis?

The economics of sovereign risk

A Tale of Two Countries

- Henry, P.B., and Miller, C. (2009), Institutions versus Policies: A Tale of Two Islands, *American Economic Review*, 99(2), pp. 261-267.
- The example of Barbados and Jamaica
- Why the economic growth of two countries with the same economic development at time t is different 10, 20 or 30 years later?

Sovereign ESG themes

Environmental

- Biodiversity
- Climate change
- Commitment to environmental standards
- Energy mix
- Natural hazard
- Natural hazard outcome
- Non-renewable energy resources
- **Temperature**
- Water management

Social

- Civil unrest
- Demographics
- **Education**
- Gender
- Health
- Human rights
- **Income**
- Labour market standards
- Migration
- Water and electricity access

Governance

- Business environment and R&D
- **Governance effectiveness**
- Infrastructure and mobility
- International relations
- Justice
- **National security**
- **Political stability**

The economics of sovereign risk

Assessment of a country's creditworthiness

- Confidence in the country? Only financial reasons?
- Mellios, C., and Paget-Blanc, E. (2006), Which Factors Determine Sovereign Credit Ratings?, *European Journal of Finance*, 12(4), pp. 361-377 $\Rightarrow$ credit ratings are correlated to the corruption perception index
- Country default risk cannot be summarized by only financial figures!
- Why some rich countries have to pay a credit risk premium?
- How to explain the large differences in Asia?

ESG and sovereign risk

Summary of the results

What is directly priced in by the bond market?		What is indirectly priced in by credit rating agencies?
E $\succ$ G $\succ$ S Significant market-based ESG indicators	$\neq$	G $\succ$ S $\succ$ E Relevant CRA-based ESG indicators
High-income countries $\Rightarrow$ Transition risk $\succ$ Physical risk, Middle-income countries $\Rightarrow$ Physical risk $\succ$ Transition risk, S only matters for middle-income countries		Government effectiveness, Business environment and R&D for the G pillar, Education, Demographic and Human rights for the S pillar
Fundamental analysis: $\mathfrak{R}_c^2 \approx 70\%$ Extra-financial analysis: $\Delta\mathfrak{R}_c^2 \approx 13.5\%$		Accuracy $> 95\%$ Good and Bad ratings $\succ$ XO ratings

Single-factor analysis
Data

Endogenous variable

10Y sovereign bond yield

Explanatory variables

- 269 ESG variables grouped into 26 ESG thematics
- 183 indicators come from Verisk Maplecrof database, the 86 remaining metrics were retrieved from the World Bank, ILO, WHO, FAO, UN...
- 6 control variables: GDP Growth, Net Debt, Reserves, Account Balance, Inflation and **Credit Rating**

Panel dimensions

- 67 countries
- 2015–2020

Single-factor analysis
Regression model

Let $s_{i,t}$ be the bond yield spread of the country i at time t. We consider the following regression model estimated by OLS:

$$s_{i,t} = \alpha + \underbrace{\beta x_{i,t}}_{\text{ESG metric}} + \underbrace{\sum_{k=1}^{6} \gamma_k z_{i,t}^{(k)}}_{\substack{\text{Control variables/} \\ \textbf{Fundamental model}}} + \varepsilon_{i,t}$$

and:

$$\sum_{k=1}^{6} \gamma_k z_{i,t}^{(k)} = \gamma_1 g_{i,t} + \gamma_2 \pi_{i,t} + \gamma_3 d_{i,t} + \gamma_4 ca_{i,t} + \gamma_5 r_{i,t} + \gamma_6 \mathcal{R}_{i,t}$$

where $g_{i,t}$ is the economic growth, $\pi_{i,t}$ is the inflation, $d_{i,t}$ is the debt ratio, $ca_{i,t}$ is the current account balance, $r_{i,t}$ is the reserve adequacy and $\mathcal{R}_{i,t}$ is the credit rating

Single-factor analysis
Results

Table 21: 7 most relevant indicators of the single-factor analysis per pillar

Pillar	Thematic	Indicator	$\Delta\mathfrak{R}_c^2$	F-test	Rank
	Climate change	Climate change vulnerability (acute)	5.51%	57.19	1
	Climate change	Climate change exposure (extreme)	4.80%	48.60	2
	Water management	Agricultural water withdrawal	4.02%	47.10	3
E	Climate change	Climate change sensitivity (acute)	3.95%	38.79	4
	Biodiversity	Biodiversity threatening score	3.53%	35.32	5
	Climate change	Climate change exposure (acute)	3.39%	32.95	6
	Climate change	Climate change vulnerability (average)	3.11%	31.16	7
	Human rights	Freedom of assembly	8.74%	89.58	1
	Human rights	Extent of arbitrary unrest	8.04%	80.10	2
	Human rights	Extent of torture and ill treatment	7.63%	75.48	3
S	Labour market standards	Severity of working time violations	7.21%	70.46	4
	Labour market standards	Forced labour violations (extent)	6.10%	54.40	5
	Labour market standards	Child labour (extent)	5.83%	54.68	6
	Migration	Vulnerability of migrant workers	5.83%	53.76	7
	National security	Severity of kidnappings	6.80%	64.49	1
	Business environment and R&D	Ease of access to loans	6.77%	73.57	2
	Infrastructure and mobility	Roads km	6.45%	63.66	3
G	Business environment and R&D	Capacity for innovation	5.65%	58.58	4
	Business environment and R&D	Ethical behaviour of firms	5.37%	55.14	5
	National security	Frequency of kidnappings	5.27%	48.49	6
	Infrastructure and mobility	Physical connectivity	4.94%	50.76	7

Single-factor analysis
Results

Table 22: Summary of the results

	E	S	G
Relevant	**Temperature** Climate change Natural hazard outcome	Labour market standards Human rights Migration	Infrastructure and mobility **National security** Justice
Less relevant	Water management Energy mix	**Income** **Education** Water and electricity access	**Political stability**

Multi-factor analysis
Regression model

We consider the following multi-factor regression model:

$$s_{i,t} = \alpha + \underbrace{\sum_{j=1}^{m} \beta_j x_{i,t}^{(j)}}_{\substack{\text{ESG variables/} \\ \textbf{Extra-financial model}}} + \underbrace{\sum_{k=1}^{6} \gamma_k z_{i,t}^{(k)}}_{\substack{\text{Control variables/} \\ \textbf{Fundamental model}}} + \varepsilon_{i,t}$$

A 4-step process

1. We consider the significant variables of the single-factor analysis at the 1% level
2. We filter the variables selected at Step 1 in order to eliminate redundant variables (correlation greater than 80%) in each ESG theme
3. We perform a lasso regression to retain the seven most relevant variables within each ESG pillar
4. We perform a multi-factor analysis: (a) Lasso estimation to rank the seven E, S and G variables ($m = 21$) and (b) Panel estimation to estimate the final model ($m = 7$)

Multi-factor analysis

The collinearity issue

Table 23: Example of variables exhibiting high correlations

Variable	$\Delta\mathfrak{R}_c^2$	Correlation$_{i,j}$					
Climate change exposure (average)	2.12%	1.00	0.74	0.80	0.48	**0.92**	0.77
Climate change exposure (acute)	3.89%	0.74	1.00	0.65	0.51	0.73	**0.89**
Climate change exposure (extreme)	4.80%	**0.80**	0.65	1.00	0.54	0.79	0.71
Climate change sensitivty (average)	3.95%	0.48	0.51	0.54	1.00	0.76	**0.81**
Climate change vulnerability (average)	3.11%	**0.92**	0.73	0.79	0.76	1.00	0.89
Climate change vulnerability (acute)	5.51%	0.77	0.89	0.71	0.81	**0.89**	1.00

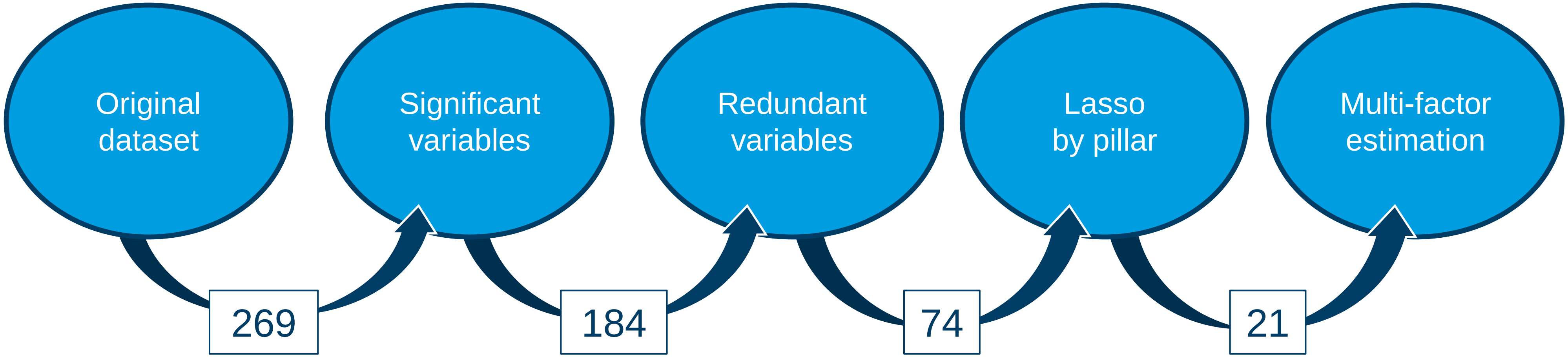
Selecting the variables

1. For each variable, we identify the highest pairwise correlation
2. Among each couple, we retain the variable showing the highest $\Delta\mathfrak{R}_c^2$
3. Among these variables, we select the variable with the lowest correlation

Multi-factor analysis

The collinearity issue

Figure 45: Filtering process



Multi-factor analysis

Results

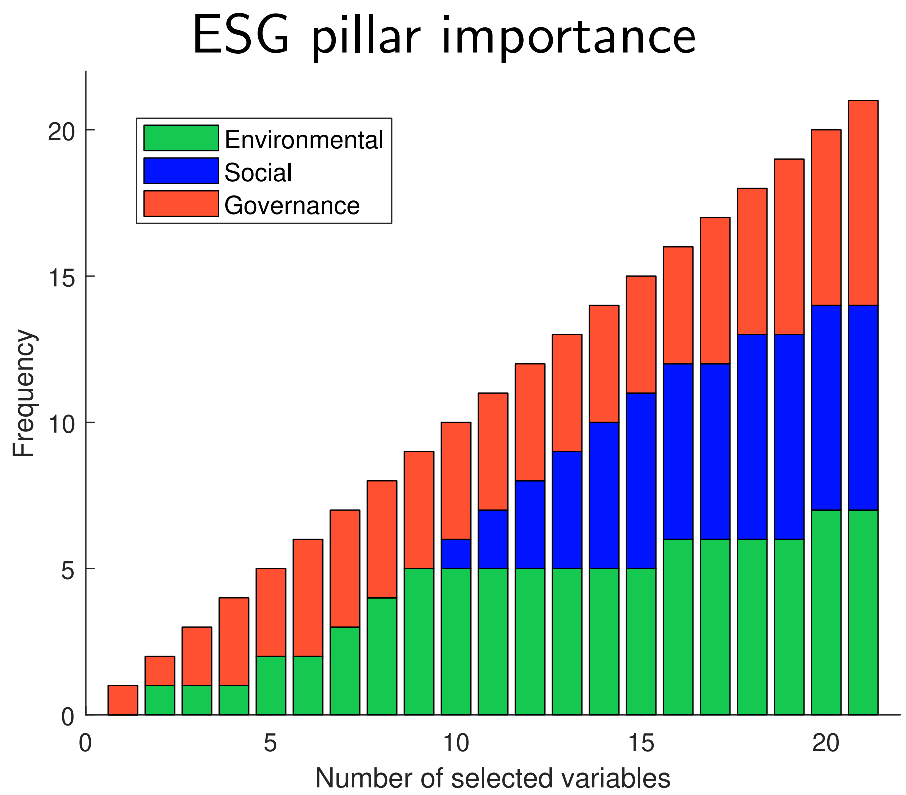
Table 24: Results after Step 3 : Lasso regression pillar by pillar

Rank	Pillar	Thematic	Variable	Sign
1		Non-renewable energy resources	Total GHG emissions	−
2		Biodiversity	Biodiversity threatening score	−
3		Natural hazard	Severe storm hazard (absolute high extreme)	−
4	E	Temperature	Temperature change	+
5		Non-renewable energy resources	Fossil fuel intensity of the economy	−
6		Natural hazard	Drought hazard (absolute high extreme)	−
7		Commitment to environmental standards	Paris Agreement	−
1		Migration	Vulnerability of migrant workers	−
2		Demographics	Projected population change (5 years)	+
3		Civil unrest	Frequency of civil unrest incidents	−
4	S	Labor market standards	Index of labor standards	−
5		Labor market standards	Right to join trade unions (protection)	−
6		Human rights	Food import security	−
7		Income	Average monthly wage	−
1		International relationships	Exporting across borders (cost)	+
2		Business environment and R&D	Ethical behaviour of firms	−
3		National security	Severity of kidnappings	−
4	G	Business environment and R&D	Capacity for innovation	−
5		Infrastructure and mobility	Physical connectivity	−
6		Infrastructure and mobility	Air transport departures	−
7		Infrastructure and mobility	Rail lines km	−

Multi-factor analysis

Global analysis - Lasso regression on the three pillars

Pillar	Indicator	Rank
G	Exporting across borders (cost)	1
E	Severe storm hazard	2
G	Capacity for innovation	3
G	Ethical behaviour of firms	4
E	Temperature change	5
G	Severity of kidnappings	6
E	Drought hazard	7
E	Fossil fuel intensity of the economy	8
E	Biodiversity threatening score	9
S	Index of labor standards	10



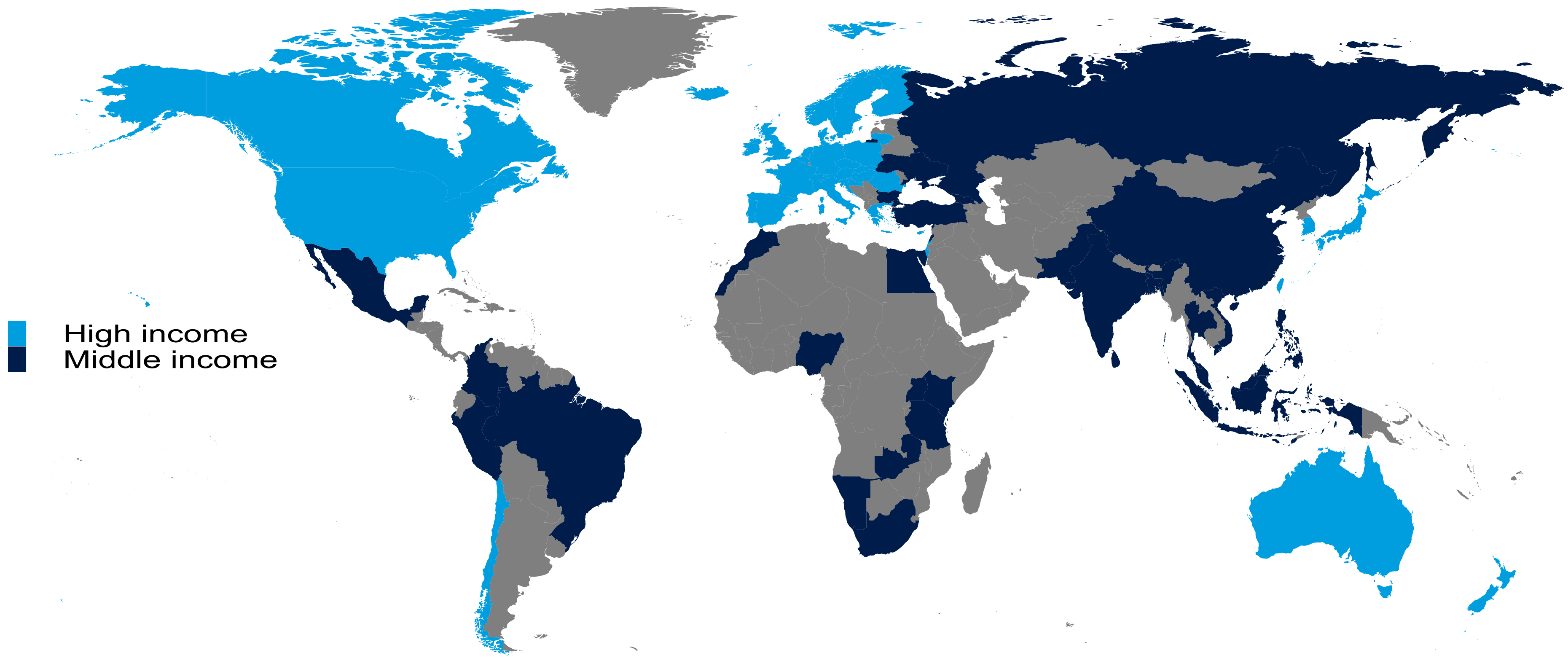
Multi-factor analysis
Global analysis

Table 25: Final multi-factor model

	Variable	$\hat{\beta}$	$\hat{\sigma}\left(\hat{\beta}\right)$	t-student	p-value
Financial	Intercept α	2.834	0.180	15.72^{***}	0.00
	GDP growth $g_{i,t}$	0.017	0.012	1.37	0.17
	Inflation $\pi_{i,t}$	0.048	0.007	6.64^{***}	0.00
	Debt ratio $d_{i,t}$	-0.001	0.001	-1.71^{*}	0.08
	Current account balance $ca_{i,t}$	-0.012	0.005	-2.45^{**}	0.01
	Reserve adequacy $r_{i,t}$	0.005	0.007	0.74	0.45
	Rating score $\mathcal{R}_{i,t}$	-0.013	0.001	-9.08^{***}	0.00
Extra-financial	Exporting across borders (cost)	$4.05e^{-04}$	$9.83e^{-05}$	4.11^{***}	0.00
	Severe storm hazard (absolute high extreme)	-0.015	0.009	-1.66^{*}	0.09
	Capacity for innovation	-0.004	0.001	-4.99^{***}	0.00
	Ethical behavior of firms	-0.061	0.021	-2.79^{***}	0.00
	Temperature change	-0.149	0.042	-3.50^{***}	0.00
	Severity of kidnappings	-0.032	0.007	-4.25^{***}	0.00
	Drought hazard (absolute high extreme)	$3.33e^{-08}$	$1.27e^{-08}$	2.60^{***}	0.00

$\Delta\mathfrak{R}_c^2 = 13.51\%$, F-test $= 29.28^{***}$

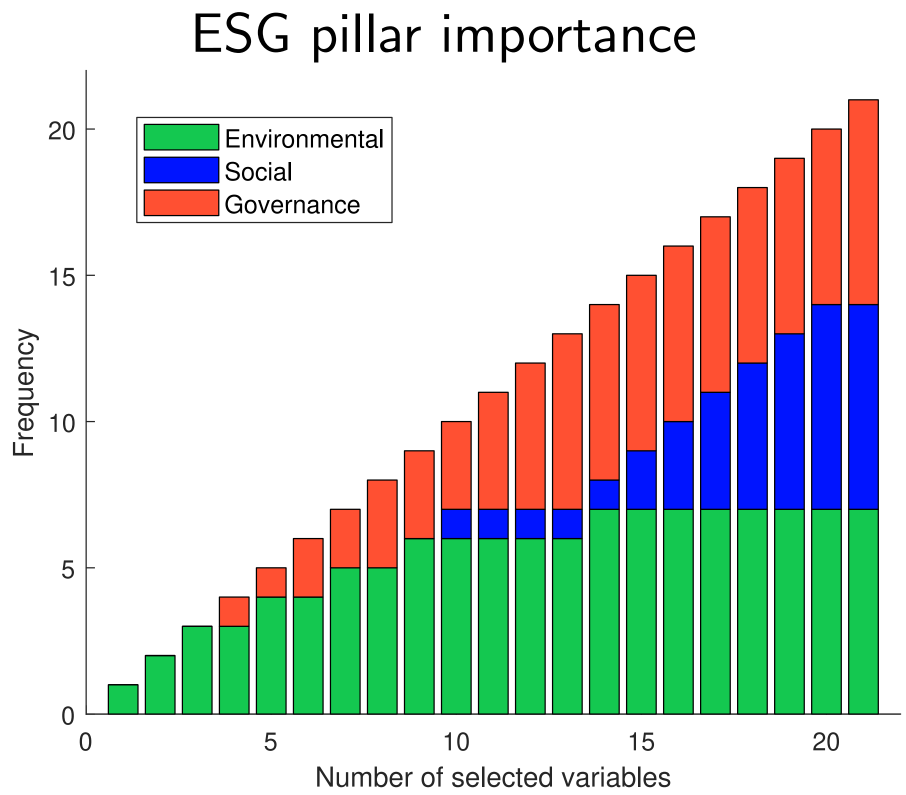
Multi-factor analysis
High income vs middle income countries



Multi-factor analysis

High income countries

Pillar	Indicator	Rank
E	Fossil fuel intensity of the economy	1
E	Temperature change	2
E	Cooling degree days annual average	3
G	Capacity for innovation	4
E	Heat stress (future)	5
G	Severity of kidnappings	6
E	Biodiversity threatening score	7
G	Efficacy of corporate boards	8
E	Total GHG emissions	9
S	Significant marginalized group	10

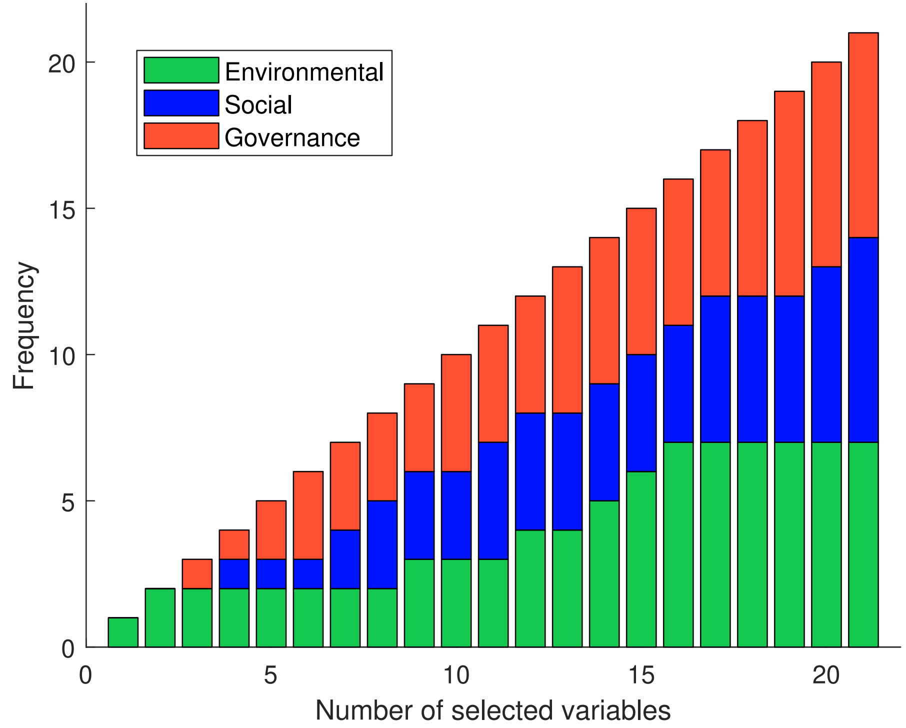


- Transition risk
- S is lagging

Multi-factor analysis
Middle income countries

Pillar	Indicator	Rank
E	Tsunami hazard	1
E	Transport infrastructure exposed to natural hazards	2
G	Severity of kidnappings	3
S	Discrimination based on LGBT status	4
G	Air transport departures	5
G	Exporting across borders (cost)	6
S	Index of labour standards	7
S	Vulnerability of migrant workers	8
E	Paris Agreement	9
G	Military expenditure (% of GDP)	10

ESG pillar importance



- Physical risk
- Social issues are priced

Explaining credit ratings with ESG metrics

Statistical framework

We consider the logit model:

$$\Pr\left\{\mathcal{G}_{i,t}=1\right\}=\mathbf{F}\left(\beta_0+\underbrace{\sum_{j=1}^{m}\beta_j x_{i,t}^{(j)}}_{\text{ESG variables}}\right)$$

where:

- $\mathcal{G}_{i,t}=1$ indicates if the country i is rated upper grade at time t
  - If the rating $\succeq$ A then $\mathcal{G}_{i,t}=1$
  - if the rating $\preceq$ BBB then $\mathcal{G}_{i,t}=0$
- $\mathbf{F}(z)$ is the logistic cumulative density function
- $x_{i,t}^{(j)}$ is the j^{th} selected indicator

We note $\theta_j=e^{\beta_j}$ is the odds-ratio coefficient

Lasso-penalized logit regression

Again, we perform a lasso regression to retain the seven most relevant variables for each ESG pillar and then we perform a multi-factor analysis

Explaining credit ratings with ESG metrics

Lasso selection process

Table 26: List of selected ESG variables for the logistic regression

Theme	Variable	Rank
Commitment to environmental standards	Domestic regulatory framework	1
Climate change	Climate change vulnerability (average)	2
Water management	Water import security (average)	3
Energy mix	Energy self sufficiency	4
Water management	Wastewater treatment index	5
Water management	Water intensity of the economy	6
Biodiversity	Biodiversity threatening score	7
Health	Health expenditure per capita	1
Water and electricity access	Public dissatisfaction with water quality	2
Education	Mean years of schooling of adults	3
Income	Base pay / value added per worker	4
Demographics	Urban population change (5 years)	5
Human rights	Basic food stuffs net imports per person	6
Human rights	Food import security	7
Government effectiveness	Government effectiveness index	1
Business environment and R&D	Venture capital availability	2
Business environment and R&D	R&D expenditure (% of GDP)	3
Infrastructure and mobility	Customs efficiency	4
Business environment and R&D	Enforcing a contract (time)	5
Business environment and R&D	Paying tax (process)	6
Business environment and R&D	Getting electricity (time)	7

Explaining credit ratings with ESG metrics

E pillar

Table 27: Logit model with environmental variables

Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Domestic regulatory framework	1.415	0.156	3.16^{***}	0.00
Climate change vulnerability (average)	2.929	0.572	5.51^{***}	0.00
Water import security (average)	1.385	0.147	3.07^{***}	0.00
Energy self sufficiency	0.960	0.033	-1.16	0.24
Wastewater treatment index	1.011	0.008	1.36	0.17
Water intensity of the economy	1.000	0.000	-1.02	0.30
Biodiversity threatening score	0.887	0.026	-4.02^{***}	0.00

$\ell\left(\hat{\beta}\right) = -107.60$, $\mathrm{AIC} = 231.19$, $\mathfrak{R}^2 = 49.1\%$, $\mathrm{ACC} = 83.6\%$

Explaining credit ratings with ESG metrics

S pillar

Table 28: Logit model with social variables

Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Health expenditure per capita	1.001	0.000	3.47^{***}	0.00
Public dissatisfaction with water quality	0.889	0.024	-4.27^{***}	0.00
Mean years of schooling of adults	2.710	0.583	4.64^{***}	0.00
Base pay / value added per worker	0.000	0.000	-5.13^{***}	0.00
Urban population change (5 years)	1.653	0.131	6.36^{***}	0.00
Basic food stuffs net imports per person	0.996	0.001	-3.58^{***}	0.00
Food import security	0.973	0.006	-4.33^{***}	0.00

$\ell\left(\hat{\beta}\right) = -72.41$, $\mathrm{AIC} = 160.83$, $\mathfrak{R}^2 = 65.6\%$, $\mathrm{ACC} = 87.9\%$

Explaining credit ratings with ESG metrics

G pillar

Table 29: Logit model with governance variables

Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Government effectiveness index	1.096	0.035	2.81***	0.00
Venture capital availability	1.020	0.005	4.16***	0.00
R&D expenditure (% of GDP)	2.259	1.006	1.83*	0.06
Customs efficiency	2.193	1.657	1.04	0.29
Enforcing a contract (time)	0.997	0.001	−3.69***	0.00
Paying tax (process)	0.914	0.031	−2.63***	0.00
Getting electricity (time)	0.989	0.004	−2.73***	0.00

$\ell\left(\hat{\beta}\right) = -67.78$, $\mathrm{AIC} = 151.57$, $\mathfrak{R}^2 = 67.9\%$, $\mathrm{ACC} = 90.1\%$

Explaining credit ratings with ESG metrics
E, S and G pillars

Table 30: Logit model with the ESG selected variables

Pillar	Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
E	Domestic regulatory framework	2.881	2.108	1.44	0.14
	Climate change vulnerability (average)	0.275	0.302	-1.17	0.24
	Water import security (average)	0.717	0.467	-0.50	0.61
	Biodiversity threatening score	1.029	0.199	0.14	0.88
S	Health expenditure per capita	0.998	0.002	-1.10	0.26
	Public dissatisfaction with water quality	1.332	0.269	1.41	0.15
	Mean years of schooling of adults	68.298	85.559	3.37^{***}	0.00
	Base pay / value added per worker	0.000	0.000	-1.07	0.28
	Urban population change (5 years)	3.976	1.857	2.95^{***}	0.00
	Basic food stuffs net imports per person	0.990	0.004	-2.07^{**}	0.03
	Food import security	0.803	0.067	-2.59^{***}	0.00
G	Government effectiveness index	1.751	0.412	2.37^{**}	0.01
	Venture capital availability	1.099	0.035	2.93^{***}	0.00
	Enforcing a contract (time)	0.999	0.004	-0.31	0.75
	Paying tax (process)	0.846	0.096	-1.47	0.14
	Getting electricity (time)	0.882	0.037	-2.95^{***}	0.00

$\ell\left(\hat{\beta}\right) = -18.91$, $\mathrm{AIC} = 71.83$, $\mathfrak{R}^2 = 91.1\%$, $\mathrm{ACC} = 96.7\%$

Explaining credit ratings with ESG metrics

Prediction accuracy of credit ratings

Table 31: Summary of the results

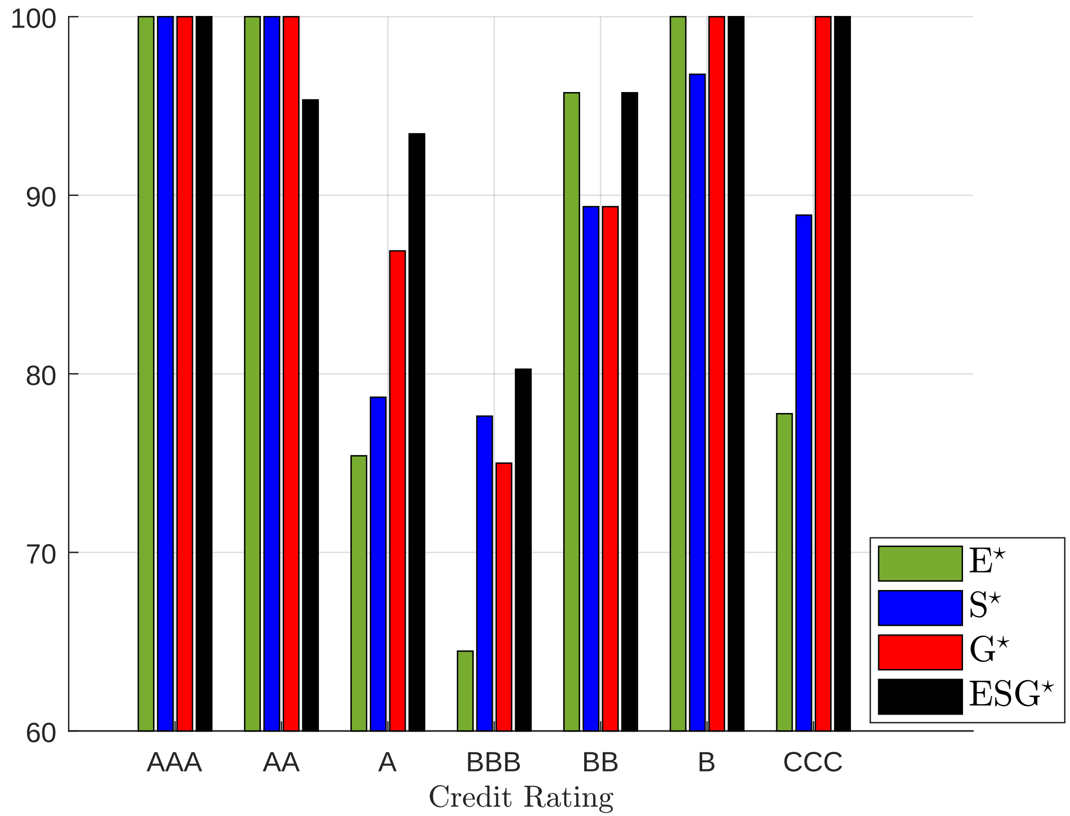
	***	$\mathfrak{R}^2$	Accuracy	Sensitivity	Specificity	AIC
E*	4	48.02%	84.97%	86.90%	83.23%	230.04
S*	7	65.60%	87.90%	88.80%	86.90%	160.83
G*	4	67.70%	89.54%	91.72%	87.58%	150.65
ESG*	7	79.02%	92.50%	93.80%	91.30%	104.80

⇒ Final model: Education, Demographics, Human rights, Government effectiveness, Business environment and R&D

Explaining credit ratings with ESG metrics

Prediction accuracy of credit ratings

Figure 46: Prediction accuracy (in %) of credit ratings



	Rating	Probabilty range
	AAA	83% – 100%
Upper-grade	AA	67% – 82%
	A	50% – 66%
	BBB	39% – 49%
Lower-grade	BB	29% – 38%
	B	11% – 28%
	C	0% – 10%

ESG and sovereign risk

Summary of the results

What is directly priced by the bond market?		What is indirectly priced by credit rating agencies?
E $\succ$ G $\succ$ S Significant market-based ESG indicators	$\neq$	G $\succ$ S $\succ$ E Relevant CRA-based ESG indicators
• High-income countries Transition risk $\succ$ Physical risk • Middle-income countries Physical risk $\succ$ Transition risk		E metrics are second-order variables: • Environmental stantards • Water management • Biodiversity • Climate change
S matters for middle-income countries, especially for Gender inequality, Working conditions and Migration		Education, Demographic and Human rights are prominent indicators for the S pillar
National security, Infrastructure and mobility and International relationships are the relevant G metrics		Government effectiveness, Business environment and R&D dominate the G pillar
Fundamental analysis: $\mathfrak{R}_c^2 \approx 70\%$ Extra-financial analysis: $\Delta\mathfrak{R}_c^2 \approx 13.5\%$		Accuracy $> 95\%$ AAA, AA, B, CCC $\succ$ A $\succ$ BB $\succ$ BBB

ESG risk premium

References

1. Bolton, P., and Kacperczyk, M. (2021), Do Investors Care about Carbon Risk?, *Journal of Financial Economics*, `www.ssrn.com/abstract=3594189`.
2. Pedersen, L.H., Fitzgibbons, S., and Pomorski, L. (2021), Responsible Investing: The ESG-Efficient Frontier, *Journal of Financial Economics*, `www.ssrn.com/abstract=3466417`
3. Pástor, L., Stambaugh, R.F., and Taylor, L.A. (2021), Sustainable Investing in Equilibrium, *Journal of Financial Economics*, `www.ssrn.com/abstract=3498354`

ESG risk premium

Asset pricing at the equilibrium

Bolton and Kacperczyk (2021)

"We study whether carbon emissions affect the cross-section of US stock returns. We find that stocks of firms with higher total carbon dioxide emissions (and changes in emissions) earn higher returns, controlling for size, book-to-market, and other return predictors. We cannot explain this carbon premium through differences in unexpected profitability or other known risk factors. We also find that institutional investors implement exclusionary screening based on direct emission intensity (the ratio of total emissions to sales) in a few salient industries. Overall, our results are consistent with an interpretation that investors are already demanding compensation for their exposure to carbon emission risk."

ESG risk premium

Asset pricing at the equilibrium

Pedersen *et al.* (2021)

"A security with a higher ESG score has

a. *A higher demand from ESG investors, which lowers the expected return;*
b. *Different expected future profits, which can increase the expected return if the market underreacts to this predictability of fundamentals; and*
c. *Stronger flows from investors, which can increase the price in the short term."*

ESG risk premium

Asset pricing at the equilibrium

Pástor *et al.* (2021)

"We model investing that considers environmental, social, and governance (ESG) criteria. In equilibrium, green assets have low expected returns because investors enjoy holding them and because green assets hedge climate risk. Green assets nevertheless outperform when positive shocks hit the ESG factor, which captures shifts in customers' tastes for green products and investors' tastes for green holdings. The ESG factor and the market portfolio price assets in a two-factor model. The ESG investment industry is largest when investors ESG preferences differ most. Sustainable investing produces positive social impact by making firms greener and by shifting real investment toward green firms."

ESG risk premium

Asset pricing at the equilibrium

Van der Berg (2021)

"I show that the performance of ESG investments is strongly driven by price-pressure arising from flows towards sustainable funds, causing high realized returns that do not reflect high expected returns. The coefficient linking ESG flows and realized returns is the product of two factors: The deviation of green funds' portfolios from the market portfolio and a flow multiplier matrix that is the inverse of the market's demand elasticity of substitution between stocks. Empirically, withdrawing 1 dollar from the market portfolio and investing it in the representative ESG fund increases the aggregate value of high ESG-taste stocks by 2–2.5 dollars. Under the absence of flow-driven price pressure, the aggregate ESG industry would have strongly underperformed the market from 2016 to 2021. Furthermore, the positive alpha of a long-short ESG taste portfolio becomes significantly negative."

Difference between short term and long term

- In the short term, green and best-in-class ESG assets can outperform brown and worst-in-class ESG assets
  - Investment flows
  - Materiality of the risk
  - ESG bubble
- In the long run, brown and worst-in-class ESG assets must outperform green and best-in-class ESG assets
  - Skewness risk (e.g., carbon tax, regulation, business disruption)
  - Supply/demand equilibrium

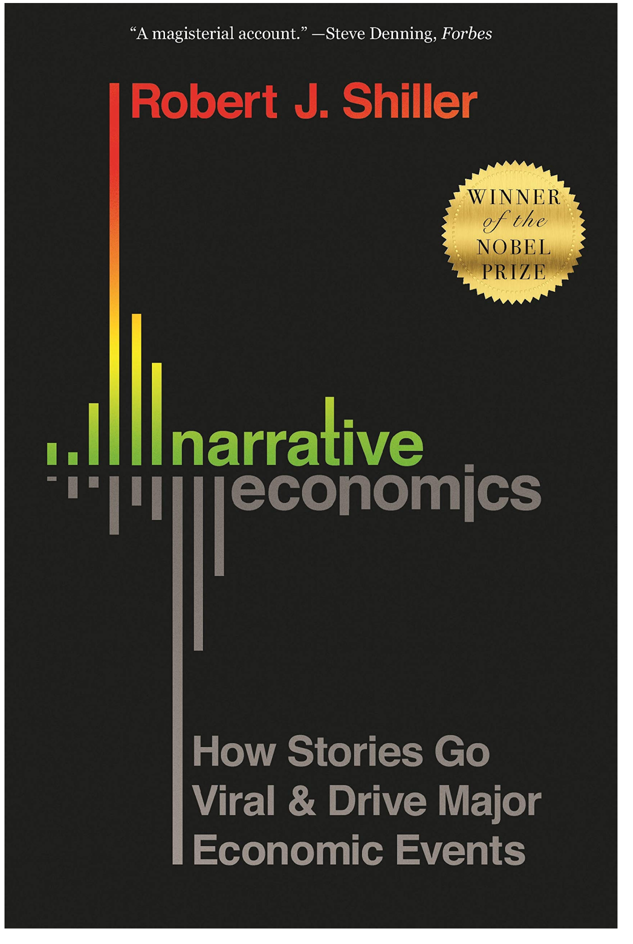
$\Rightarrow$ 2014-2020 was an exceptional period for ESG investing in terms of performance (because of investment flows)

Difference between short term and long term

- The big issue is the following:
  Are investors able to assess the carbon and ESG risks and their associated skewness risks (too optimistic)?
- What is the magnitude of the risk premium? $\Rightarrow$ too large?
- The difference between the return and the risk premium highly depends on the expectations of brown invertors and the reaction of policy markers and regulators

Narratives

Figure 47: Narrative Economics: How Stories Go Viral & Drive Major Economic Events (Robert J. Schiller)



The 'new normal' of ESG investing

- 2000's: ESG investing was motivated by values and ethics
- 2010's: ESG investing was motivated by risk management and performance
- 2020's: Back to the values and ethics?

$\Rightarrow$ The rise and the fall of best-in-class selection

Impact investing and engagement $\succ$ ESG scoring and rating systems

Difficult to assess the performance of ESG investing in this context!!!

Course 2021-2022 in ESG and Climate Risks
Lecture 3. Other ESG Topics

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*University of Paris-Saclay

February 2022

[7] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

SRI Investment funds

- Investment vehicles
  - Mutual funds
  - ETFs
  - Mandates & dedicated funds
- Investment strategies
  - Thematic strategies (e.g. water, social, wind energy, climate, plastic, etc.)
  - ESG-tilted strategies (e.g. exclusion, negative screening, best-in-class, enhanced ESG score, controlled tracking error, etc.)
  - Climate strategies (e.g. low carbon, $2^\circ\mathrm{C}$ alignment, activity exclusions[8], etc.)
  - Sustainability-linked securities (e.g. green bonds, social bonds, etc.)

Both α and β management

[8] e.g. coal exploration, oil exploration, electricity generation with a high GHG intensity

SRI Investment funds

Some examples

Mutual funds

- Amundi Climate Transition
- Amundi ARI European Credit SRI
- AXA World Funds – Euro Bonds SRI
- CPR Invest Social Impact
- Fidelity U.S. Sustainability Index
- Fidelity Sustainable Water & Waste
- Natixis ESG Dynamic Fund
- Vanguard FTSE Social Index
- Etc.

ETFs

- Amundi Index MSCI Europe SRI UCITS ETF
- Amundi MSCI Emerging ESG Leaders UCITS ETF
- Amundi EURO ISTOXX Climate Paris Aligned PAB UCITS ETF
- Lyxor New Energy UCITS ETF
- Lyxor World Water UCITS ETF
- SPDR S&P 500 ESG
- First Trust Global Wind Energy ETF
- Invesco S&P 500 ESG UCITS ETF
- Etc.

Climate change indexes

Some examples

- MSCI Climate Change Indexes — www.msci.com/climate-change-indexes
- FTSE Global Climate Index Series — www.ftserussell.com/products/indices/global-climate
- FTSE Climate Risk-Adjusted Government Bond Index Series — www.ftserussell.com/products/indices/climate-wgbi
- S&P Climate Indices — https://www.spglobal.com/spdji/en/index-family/esg/esg-climate/
- STOXX Climate Benchmark Indices — qontigo.com/solutions/climate-indices

SRI Investment funds

Regulation

The big issue for an investor is:

How to avoid Greenwashing (& ESG washing)?

Greenwash (also greenwashing)

- Activities by a company or an organization that are intended to make people think that it is concerned about the environment, even if its real business actually harms the environment
- A common form of greenwash is to publicly claim a commitment to the environment while quietly lobbying to avoid regulation

Source: Oxford English Dictionary (2020), `https://www.oed.com`

In finance, greenwashing is understood as making misleading claims about environmental practices, performance or products

SRI Investment funds

Regulation

- ESG represents **58% of the net new assets** (NNA) in the European ETF market
- ESG fund assets reach \$1 652 bn
  - Europe: \$1 343 bn (or 81.3%)
  - US: \$236.4 bn (or 14.3%)
  - Asia: \$43.1 bn (or 2.6%)
- Net flows into sustainable mutual funds and ETFs in Q4 2020: \$370 bn (or **+29% of assets**)
- Net flows into sustainable mutual funds and ETFs in 2020
  - Europe: \$273 bn, almost double the total for 2019, almost 5 times more than in 2017
  - US: \$51.2 bn, more than double the total for 2019, almost 10 times more than in 2018

Source: Morningstar, Global Sustainable Fund Flows: Q4 2020 in Review (January 2021)

SRI Investment funds

Regulation

European sustainable finance labels

- Novethic label (pioneer label in 2009, suspended in 2016)
- French SRI label — `https://www.lelabelisr.fr`
- FNG label (Germany) — `https://fng-siegel.org`
- Towards Sustainability label (Belgium) — `https://www.towardssustainability.be`
- LuxFLAG label (Luxembourg) — `https://www.luxflag.org`
- Nordic Swan Ecolabel (Nordic countries) — `https://www.nordic-ecolabel.org`
- Umweltzeichen Ecolabel (Austria) — `https://www.umweltzeichen.at/en`
- French Greenfin label — `https://www.ecologie.gouv.fr/label-greenfin`

SRI Investment funds

Regulation

Remark

According to Novethic (2020), 806 funds had a label at the end of December 2019. Nine months later, this number has increased by 392 and the AUM has be multiplied by 3.2!

SRI Investment funds

Regulation

"Today it is difficult for consumers, companies and other market actors to make sense of the many environmental labels and initiatives on the environmental performance of products and companies. There are more than 200 environmental labels active in the EU, and more than 450 active worldwide; there are more than 80 widely used reporting initiatives and methods for carbon emissions only. Some of these methods and initiatives are reliable, some not; they are variable in the issues they cover" (European Commission, 2020).

Source: `https://ec.europa.eu/environment/eussd/index.htm`

SRI Investment funds

Regulation

The High Level Expert Group (HLEG) on Sustainable Finance was created in October 2016 by the European Commission

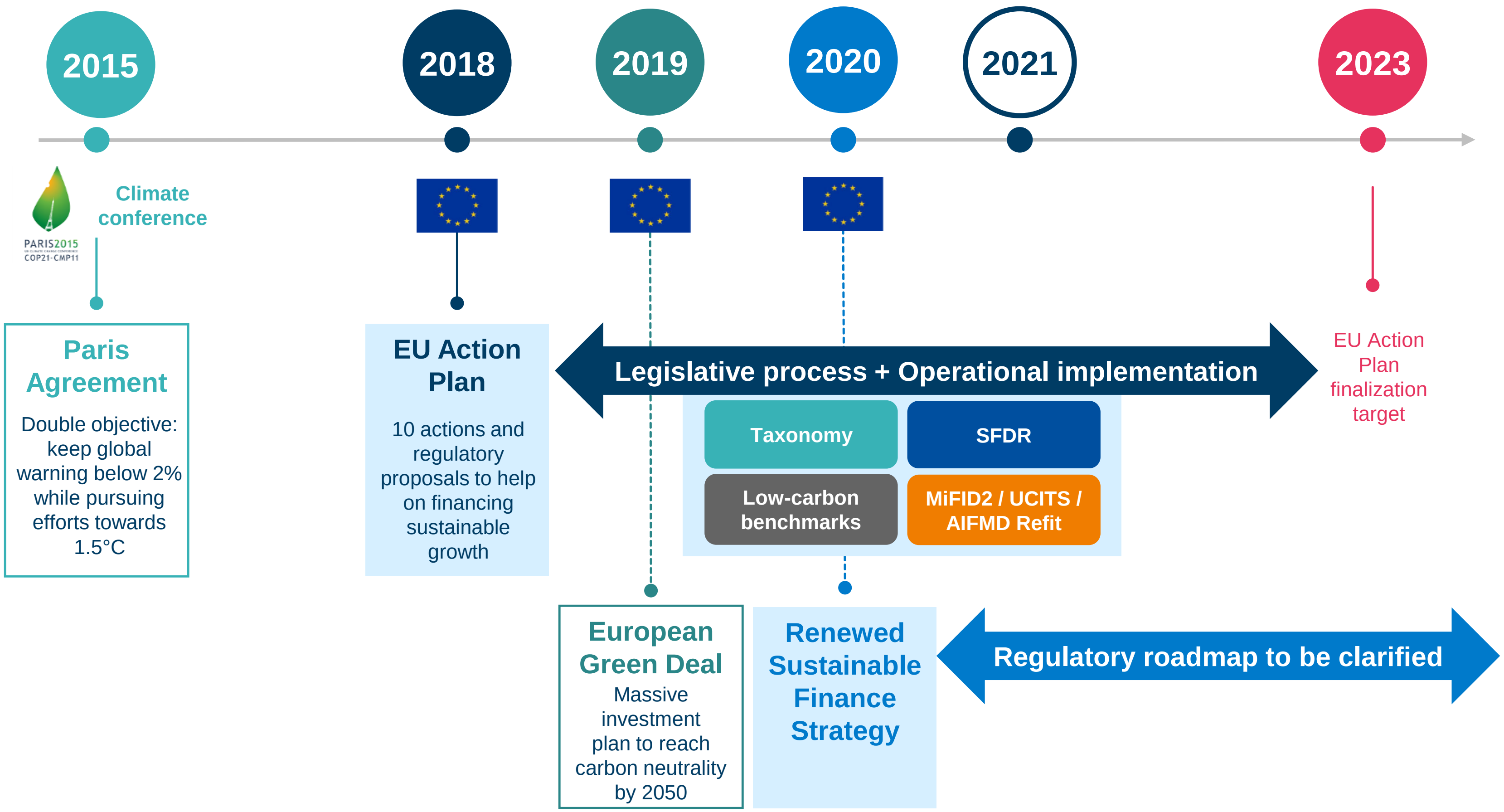
HLEG 2018 report

- Definition of a taxonomy for sustainable assets
- Inclusion of sustainability and ESG Duties of investors
- Disclosure of ESG metrics
- EU label for green investment funds
- EU standard for green bonds
- Sustainability as part of the mandates of European Supervisory Authorities (ESA)

SRI Investment funds

Regulation

Figure 48: The EU Commission regulatory initiatives



Source: Amundi ETF, Indexing & Smart Beta (January 2020)

SRI Investment funds

Regulation

1. Taxonomy
   "*Regulation on the establishment of a framework to facilitate sustainable investment*", 2020/852/EU
2. Disclosure & duties
   "*Sustainable Finance Disclosure Regulation*", 2019/2088/EU (SFDR)
3. Benchmarks
   "*Benchmark Regulation*", 2016/1011/EU (BMR)
   Climate Transition Benchmarks (CTB) & PAB: Paris-Aligned Benchmarks (PAB)
4. Sustainability preferences
   "*Markets in Financial Instruments Directive*", 2014/65/EU (MIFID II)
   "*Insurance Distribution Directive*", 2016/97/EU (IDD)

SRI Investment funds

Regulation

SFDR

- Article 6: Non-ESG funds (standard funds)
- Article 8: ESG funds (funds that promote E or S characteristics)
- Article 9: Sustainable funds (funds that have a sustainable investment objective: impact investing or reduction of carbon emissions)

SRI Investment funds

Regulation

ESMA

- Final report on integrating sustainability risks and factors in the UCITS Directive and the AIFMD (May 2019)
- Final report on integrating sustainability risks and factors in the MIFID II (May 2019)

Climate change indexes

Regulation

New benchmark rules

- Climate transition benchmarks (CTB): high level of decarbonization (-30%), no controversial weapons and tobacco, high positive impact on climate change, etc.
- Paris-aligned benchmarks (PAB): high level of decarbonization (-50%), no controversial weapons and tobacco, no activities in coal, oil and natural gas, global warming below 2°, etc.

- MSCI Climate Paris Aligned Indexes — `www.msci.com/esg/climate-paris-aligned-indexes`
- FTSE TPI Climate Transition Index Series — `www.ftserussell.com/products/indices/tpi-climate-transition`
- STOXX Climate Transition Benchmark (CTB) and STOXX Paris-Aligned Benchmark (PAB) Indices — `qontigo.com/solutions/climate-indices`

Green bonds

Definition

Green bonds (or green loans/green debt instruments) are debt instruments where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible green projects, and which is aligned with the four core components of the Green Bond Principles (GBP) or the Green Loan Principles.

Source: CBI (2019), `https://www.climatebonds.net`

$\Rightarrow$ Green bonds are "*regular*" bonds[9] aiming at funding projects with positive environmental and/or climate benefits

[9] A regular bond pays regular interest to bondholders

Green bonds

Standardization is strongly required by investors and regulators

- Green Bond Principles[10] (ICMA, 2018)
- Climate Bonds Standard (CBI)
- EU Green Bond Standard[11]
- China's Green Bond Standards[12] (PBOC, 2015)

---

[10] The first version is published in 2014

[11] The European Green Deal Investment Plan of 14 January 2020 announced that the European Commission will establish a GBS based on the report of the Technical Expert Group on Sustainable Finance (TEG)

[12] See CBI (2020), *China Green Bond Market 2019 Research Report*, `https://www.climatebonds.net/resources/reports/china-green-bond-market-2019-research-report`

Green bonds

Green Bonds Principles

Green Bonds Principles (GBP)

The 4 core components of the GBP are:

1. Use of proceeds
    1. Pollution prevention and control
    2. Biodiversity conservation
    3. Climate change adaptation
2. Process for project evaluation and selection
3. Management of proceeds
4. Reporting

https://www.icmagroup.org/sustainable-finance/the-principles-guidelines-and-handbooks

Green bonds

Green Bonds Principles

The use of proceeds includes:

- Renewable energy
- Energy efficiency
- Pollution prevention (e.g. GHG control, soil remediation, waste recycling)
- Sustainable management of living natural resources (e.g. sustainable agriculture, sustainable forestry, restoration of natural landscapes)
- Terrestrial and aquatic biodiversity conservation (e.g. protection of coastal, marine and watershed environments)
- Clean transportation
- Sustainable water management
- Climate change adaptation
- Eco-efficient products
- Green buildings

Green bonds
Green Bonds Principles

With respect to the **process for project evaluation and selection** (component 2), the issuer of a green bond should clearly communicate:

- the environmental sustainability objectives
- the eligible projects
- the related eligibility criteria

The **management of proceeds** (component 3) includes:

- The tracking of the "*balance sheet*" and the allocation of funds[13]
- An external review (not mandatory but highly recommended)

[13] The proceeds should be credited to a sub-account

Green bonds

Green Bonds Principles

The **reporting** (component 4) must be based on the following pillars:

- Transparency
- Description of the projects, allocated amounts and expected impacts
- Qualitative performance indicators
- Quantitative performance measures (e.g. energy capacity, electricity generation, GHG emissions reduced/avoided, number of people provided with access to clean power, decrease in water use, reduction in the number of cars required)

Types of debt instruments

Asset-linked bond structures

- Regular bond
- Revenue bond
- Project bond
- Green loans

Asset-backed bond structures

- Securitized bond
- Project bond
- ABS/MBS/CLO/CDO
- Covered bond

The green bond market

- Solar bond by the City of San Francisco in 2001
- Equity-linked climate awareness bond by the European Investment Bank (EIB) in 2007
- First green bond issued by the World Bank (in collaboration with Skandinaviska Enskilda Banken) in November 2008

The green bond market

Green bond issuers

- Sovereigns (agencies, municipals, governments)
- Multilateral development banks (MDB)
- Energy and utility companies
- Banks
- Other corporates

Green bond investors

- Pension funds
- Sovereign wealth funds
- Insurance companies
- Asset managers
- Retail investors (e.g. employee savings plans)

Strong imbalance between supply and demand

The green bond market

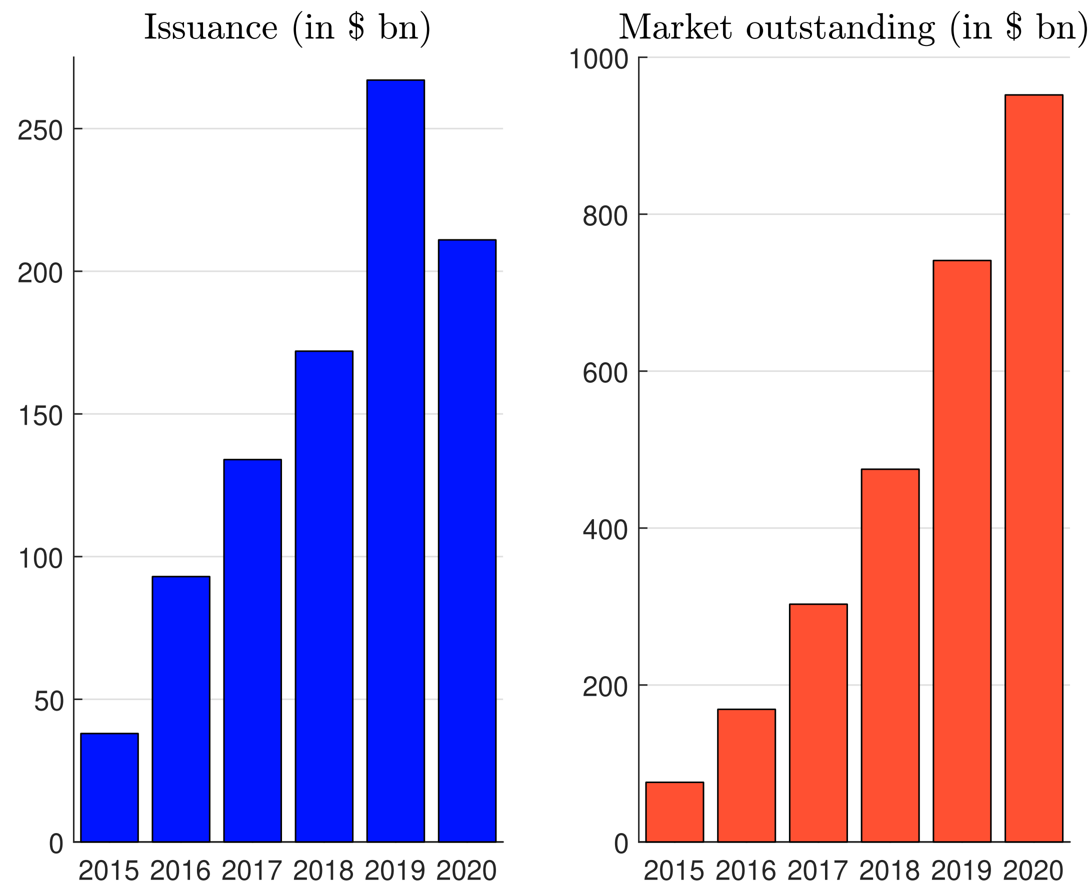


Figure 49: The green bond market

Source: CBI (2020), `https://www.climatebonds.net/market`

The green bond market

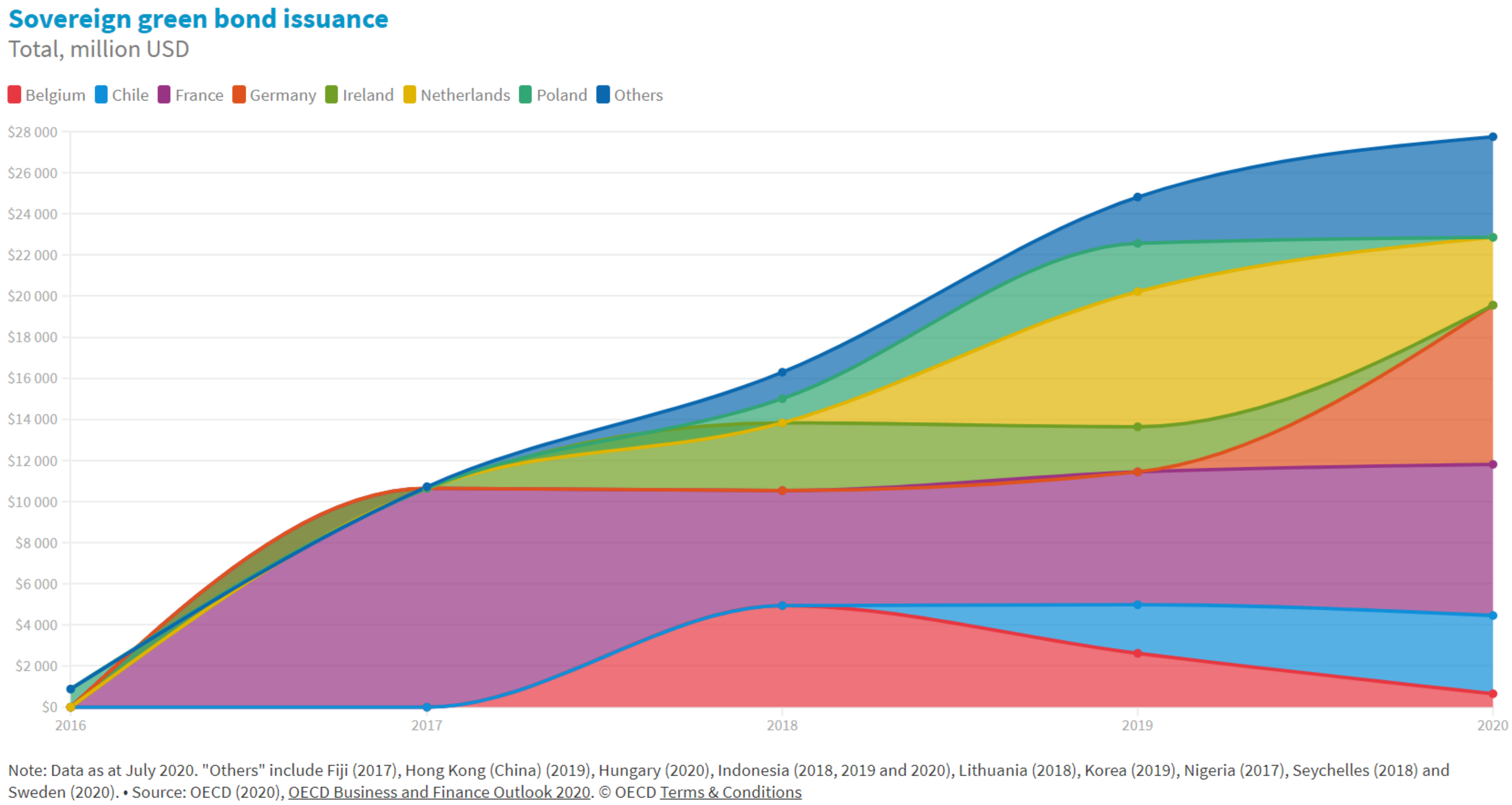


Figure 50: Growing momentum for sovereign green bonds (OECD, Sep. 2020)

Investing in green bonds

Active management

Example of green bond funds:

- Amundi Planet Emerging Green One (EGO), in collaboration with IFC (World Bank)
- Amundi ARI Impact Green Bonds
- AXA WF Global Green Bonds
- BNP Paribas Green Bond
- Mirova Global Green Bond Fund
- Etc.

Investing in green bonds

Passive management

List of green bond indices:

- Bloomberg Barclays MSCI Global Green Bond Index
- S&P Green Bond Index
- Solactive Green Bond Index
- ChinaBond China Climate-Aligned Bond Index:
- ICE BofA Green Index

$\Rightarrow$ ETF and index funds (e.g. Lyxor Green Bond UCITS ETF, iShares Green Bond Index Fund)

The green bond premium

Definition

The green bond premium (or greenium) is the difference in pricing between green bonds and regular bonds

The green bond premium

The greenium debate is a hot topic

You can read the article of the Wall Street Journal written by Matt Wirz[14]:

Why Going Green Saves Bond Borrowers Money

[14] The article is available on the following webpage: https://www.wsj.com/articles/why-going-green-saves-bond-borrowers-money-11608201002

The green bond premium

Table 32: Overview of GB pricing

Study	Market	#GBs	Universe	Period	Method	Greenium
Bachelet *et al.*(2019)	Secondary	89	Global	2013 - 2017	OLS model	2.1/5.9
Bour (2019)	Secondary	95	Global	2014 - 2018	Fixed effects model	−23.2
Ehlers and Packer (2017)	Primary	21	EUR & USD	2014 - 2017	Yield comparison	−18
Fatica *et al.* (2019)	Primary	1 397	Global	2007 - 2018	OLS model	
Hachenberg and Sciereck (2018)	Secondary	63	Global	August 2016	Panel data regression	NS
Hyun *et al* (2020)	Secondary	60	Global	2010 - 2017	Fixed effects GLS model	NS
Karpf and Mandel (2018)	Secondary	1 880	US Municipals	2010 - 2016	Oaxaca-Blinder decomposition	+7.8
Larcker and Watts (2019)	Secondary	640	US Municipals	2013 - 2018	Matching & Yield comparison	NS
Lau *et al.* (2020)	Secondary	267	Global	2013 - 2017	Two-way Fixed effects model	−1.2
Nanayakkara and Colombage (2019)	Secondary	43	Global	2016 - 2017	Panel data with hybrid model	−62.7
Ostlund (2015)	Secondary	28	Global	2011 - 2015	Yield comparison	NS
Preclaw and Bakshi (2015)	Secondary	Index	Global	2014 - 2015	OLS model	−16.7
Schmitt (2017)	Secondary	160	Global	2015 - 2017	Fixed effects model	−3.2
Zerbib (2019)	Secondary	110	Global	2013 - 2017	Fixed effects model	−1.8
Baker *et al.* (2018)	Secondary	2 083 19	US Municipals US Corporates	2010 - 2016 2014 - 2016	OLS model	−7.6/−5.5
Gianfrate and Peri (2019)	Primary Secondary	121 70/118	EUR	2013 - 2017 3 dates in 2017	Propensity score matching	−18 −11/−5
Kapraun and Scheins (2019)	Primary Secondary	1 513 769	Global	2009 - 2018	Fixed effects model	−18 +10
Partridge and Medda (2018)	Primary Secondary	521	US Municipals	2013 - 2018	Yield curve analysis	−4 NS

Source: Ben Slimane *et al.* (2020)

The green bond premium

- From the issuer's point of view, a green bond issuance is more expensive than a conventional issuance due to the need for external review, regular reporting and impact assessments
- From the investor's point of view, there is no fundamental difference between a green bond and a conventional bond, meaning that one should consider a negative green bond premium as a market anomaly

The green bond premium

Ben Slimane *et al.* (2020) test two approaches:

1. Top-down approach
   - Compare a green bond index portfolio to a conventional bond index portfolio
   - Same characteristics in terms of currency, sector, credit quality and maturity
2. Bottom-up approach
   - Compares the green bond of an issuer with a synthetic conventional bond of the same issuer
   - Same characteristics in terms of currency, seniority and duration.

The green bond premium

Main result (Ben Slimane *et al.*, 2020)

The greenium is negative between -5 and -2 bps on average

Other results:

- Differences between sectors, currencies, maturities, regions and ratings
- Transatlantic divided between US and Europe
- The volatility of green bond portfolios are lower than the volatility of conventional bond portfolios $\Rightarrow$ identical Sharpe ratio since the last four years
- Time-varying property of the greenium

The green bond premium

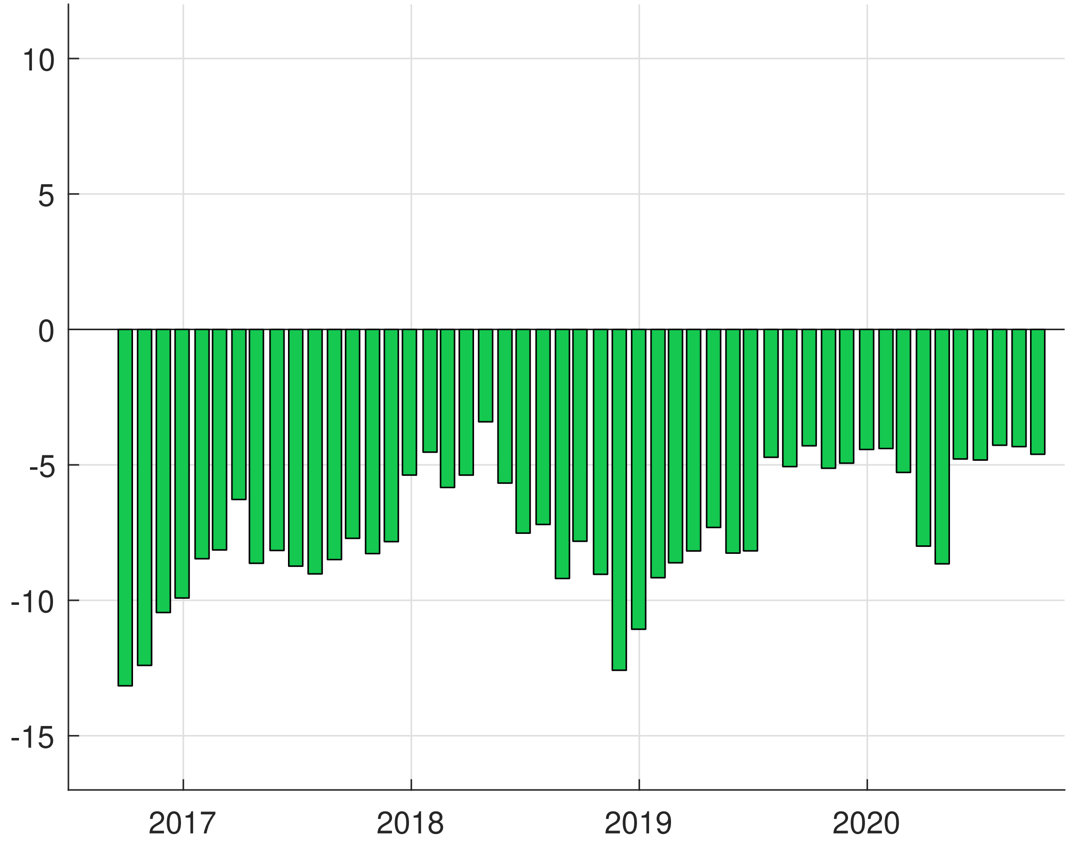


Figure 51: Evolution of the EUR greenium

Source: Ben Slimane *et al.* (2020)

The green bond premium

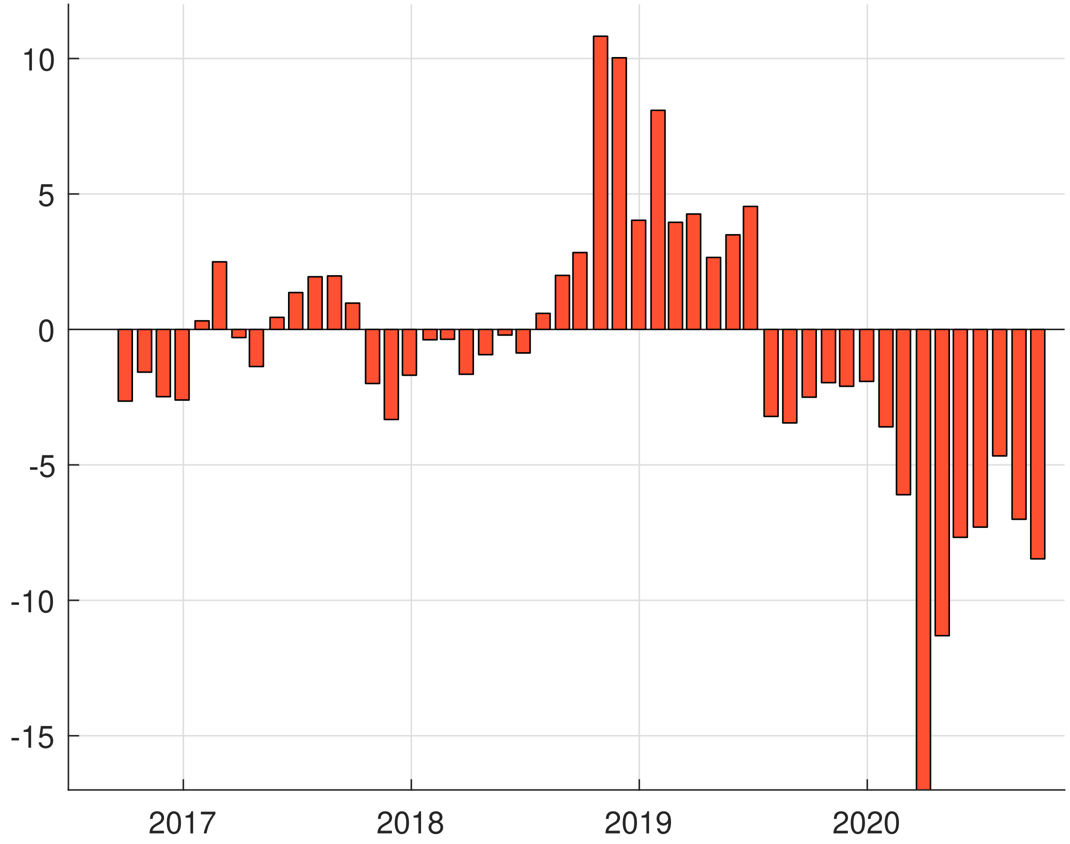


Figure 52: Evolution of the USD greenium

Source: Ben Slimane *et al.* (2020)

The green bond premium

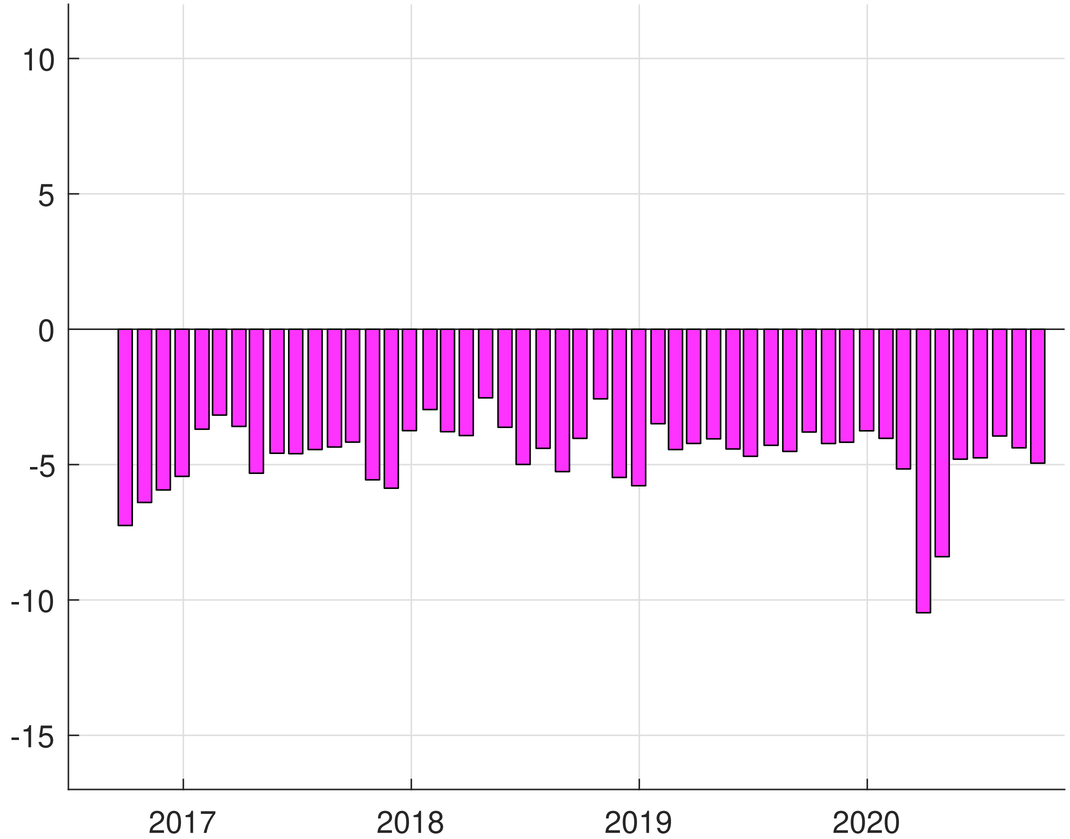


Figure 53: Evolution of the green bond premium (all currencies)

Source: Ben Slimane *et al.* (2020)

The green bond premium

Green financing $\Leftrightarrow$ green investing

1. Bond issuers have a competitive advantage to finance their environmental projects using green bonds instead of conventional bonds
2. Another premium? the "green bond issuer premium"

Social bonds

Definition

Social Bonds are any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance in part or in full new and/or existing eligible Social Projects and which are aligned with the four core components of the Social Bonds Principles (SBP).

Source: ICMA (2020), `https://www.icmagroup.org/sustainable-finance`

Social bonds
Social Bonds Principles

Social Bonds Principles (SBP)

The 4 core components of the SBP are:

1. Use of proceeds
   1. Eligible social project categories
   2. Target populations
2. Process for project evaluation and selection
3. Management of proceeds
4. Reporting

https://www.icmagroup.org/sustainable-finance/the-principles-guidelines-and-handbooks

Social bonds

Social Bonds Principles

The **eligible social projects categories** (component 1) are:

- Affordable basic infrastructure (e.g. clean drinking water, sanitation, clean energy)
- Access to essential services (e.g. health, education)
- Affordable housing (e.g. sustainable cities)
- Employment generation (e.g. pandemic crisis)
- Food security and sustainable food systems (e.g. nutritious and sufficient food, resilient agriculture)
- Socioeconomic advancement and empowerment (e.g. income inequality, gender inequality)
- Etc.

Social bonds
Social Bonds Principles

The **target populations** (component 1) are:

- Living below the poverty line
- Excluded and/or marginalised populations/communities
- People with disabilities
- Migrants and /or displaced persons
- Undereducated
- Unemployed
- Women and/or sexual and gender minorities
- Aging populations and vulnerable youth
- Etc.

Social bonds

Social Bonds Principles

With respect to the **process for project evaluation and selection** (component 2), the issuer of a social bond should clearly communicate:

- the social objectives
- the eligible projects
- the related eligibility criteria

The **management of proceeds** (component 3) includes:

- The tracking of the "*balance sheet*" and the allocation of funds[15]
- An external review (not mandatory but highly recommended)

[15] The proceeds should be credited to a sub-account

Social bonds

Social Bonds Principles

The **reporting** (component 4) must be based on the following pillars:

- Transparency
- Description of the projects, allocated amounts and expected impacts
- Qualitative performance indicators
- Quantitative performance measures (e.g. number of beneficiaries)

Social bonds

Examples

You can download the *Green, Social and Sustainability bonds database* at the following webpage:

`https://www.icmagroup.org/sustainable-finance/green-social-and-sustainability-bonds-database`

You can download the market information template of the social project "*Women's Livelihood Bond 2 (WLB 2) — Singapore*" at the following address:

`https://www.icmagroup.org/Emails/icma-vcards/WLB2_Market%20Information%20Template.pdf`

The social bond market

- The tremendous growth of the social bond market

  "Of the $\$1,280$ bn in cumulative sustainable fixed-income issuance, social bonds account for around 14% of the total, amounting to $180bn [...] This overall expansion trend has intensified during the pandemic. In fact, the growth of the social bond market in 2020, i.e. +374% with respect to 2019 levels, dwarf both the green and sustainability bonds markets' expansion, respectively +37% and +100%" (Laugel and Vic-Philippe, 2020)

- The pandemic has increased the popularity of social bonds
- Investors focus more on the S pillar of ESG

Other sustainability-related products

- Sustainability bonds (= green + social)
- Sustainable loans
- Green notes
- Green ABCP notes
- Financing renewables
- Green infrastructure funds
- ESG private equity funds
- Etc.

Other sustainability-related products

Sustainability-linked bond (SLB)

- Two principles:
  - $=$ a sustainability bond (green/social)
  - $+$ a step up coupon if the KPI is not satisfied

  $\Rightarrow$ forward-looking performance-based instrument
- The financial characteristics of the bond depends on whether the issuer achieves predefined ESG objectives
- Those objectives are:
  1. measured through predefined Key Performance Indicators (KPI)
  2. assessed against predefined Sustainability Performance Targets (SPT)

Other sustainability-related products

ENEL General Purpose SDG Linked Bond

- SDG: 7 (affordable and clean energy), 13 (climate action), 9 (industry, innovation and infrastructure) and 11 (sustainable cities and communties)
- SDG 7 target: renewables installed capacity as of December 31, 2021 $\geq$ 55% (confirmed by external verifier[a])
- One time coupon step up if SDG 7 is not achieved[b] (+ 25 bps)

[a] The external auditor is EY
[b] As of 30 June 2019, the KPI was equal to 45.9%

Other sustainability-related products

H&M sustainability-linked bond

- 18 February 2021
- €500 mn
- Maturity of 8.5 years
- The annual coupon rate is 25 bps
- The objectives to achieve by 2025 are:
  - KPI_1 Increase the share of recycled materials used to 30% (SPT_1)
  - KPI_2 Reduce emissions from the Group's own operations (scopes 1+2) by 20% (SPT_2)
  - KPI_3 Reduce scope 3 emissions from fabric production, garment manufacturing, raw materials and upstream transport by 10% (SPT_3)
- The global KPI is equal to $40\% \times \text{KPI}_1 + 20\% \times \text{KPI}_2 + 40\% \times \text{KPI}_3$
- The step-up of the coupons can consequently be 0%, 20%, 40%, 60%, 80% or 100% of the total step-up rate

The bond generated was 7.6 times oversubscribed!

Definition

Principle

- Financial risks $\Rightarrow$ financial performance (return, volatility, Sharpe ratio, etc.)
- Extra-financial risks $\Rightarrow$ financial performance (return, volatility, Sharpe ratio, etc.)
- **Extra-financial risks $\Rightarrow$ extra-financial performance** (ESG KPIs)

What is the final motivation of the ESG investor?

Financial performance or/and extra-financial performance?

Definition

Definition

The key elements of impact investing are:

1. Intentionality
   The intention of an investor to generate a positive and measurable social and environmental impact
2. Additionality
   Fulfilling a positive impact beyond the provision of private capital
3. **Measurement**
   Being able to account for in a transparent way on the financial, social and environmental performance of investments

Source: Eurosif (2019)

The investor must be able to measure its impact from a quantitative point of view

GIIN

Figure 54: Global Impact Investing Network (GIIN)

https://thegiin.org

The example of social impact bonds

Social impact bond (SIB) = **pay-for-success bond** ($\approx$ call option)

The Peterborough SIB

- On 18 March 2010, the UK Secretary of State for Justice announced a six-year SIB pilot scheme that will see around 3 000 short term prisoners from Peterborough prison, serving less than 12 months, receiving intensive interventions both in prison and in the community
- Funding from investors will be initially used to pay for the services
- If reoffending is not reduced by at least 7.5%, the investors will receive no recompense

The example of sustainability-linked bonds

Sustainability-linked[16] (SLB) = **pay-for-failure bond** ($\approx$ cap option)

Risk taker

SIB: investor viewpoint $\neq$ SLB: issuer viewpoint

[16] See the examples of ENEL and H&M previouly

Measurement tools

Impact assessment and metrics

- Avoided CO2 emissions in tons per $M invested
- Amount of clean water produced by the project
- Number of children who are less obese
- Land management
- Affordable housing
- Job creation
- Construction of student housing

Sustainable development goals (SDG)

The sustainable development goals are a collection of 17 interlinked global goals designed to be a "*blueprint to achieve a better and more sustainable future for all*"

https://sdgs.un.org

Sustainable development goals (SDG)

Figure 55: The map of sustainable development goals

Sustainable development goals (SDG)

Figure 56: Mapping the SDGs across E, S and G

Sustainable development goals (SDG)

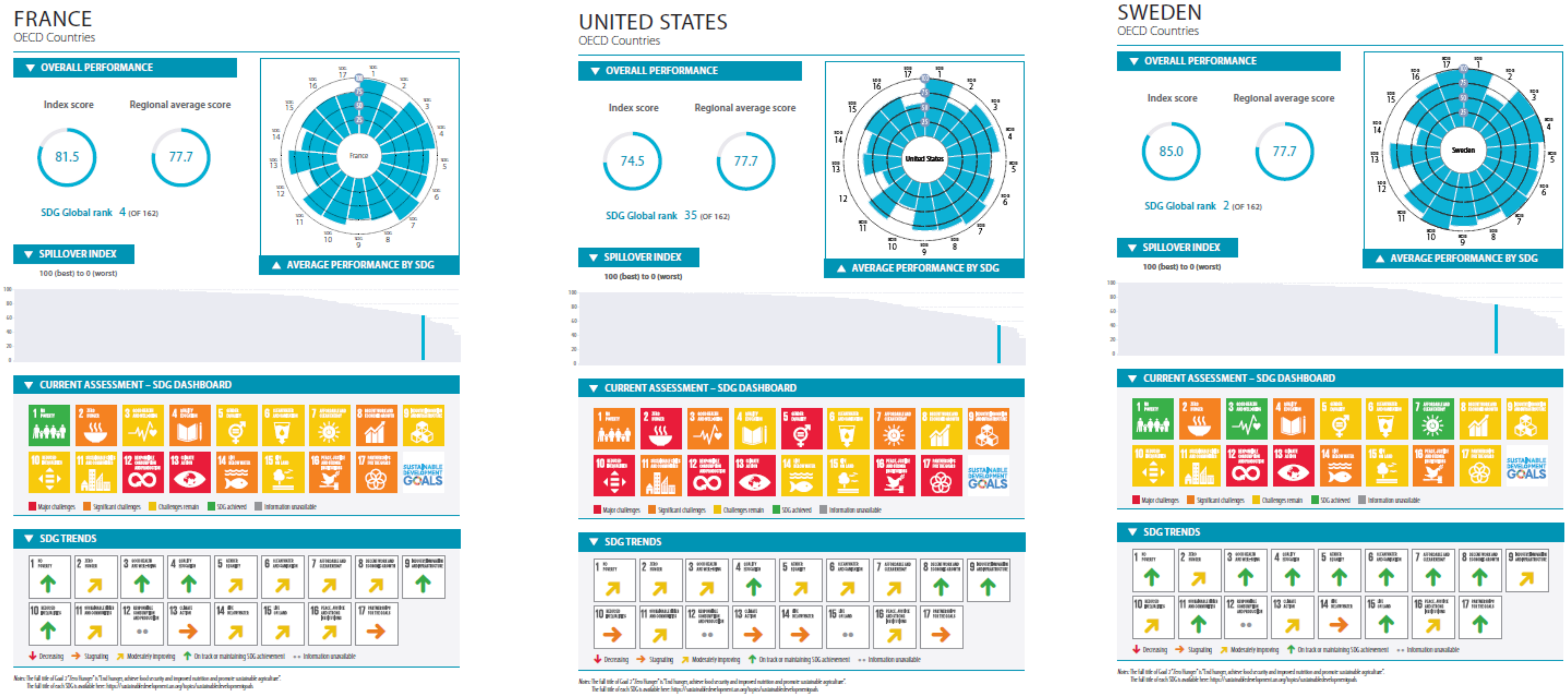


Figure 57: Examples of sovereign SDG reports

Source: Sustainable Development Report 2019, `https://dashboards.sdgindex.org`

The challenge of reporting

- Impact reporting and investment standards (IRIS) proposed by GIIN
- EU taxonomy on sustainable finance
- Non-financial reporting directive 2014/95/EU (NFRD)
- Carbon accounting

The challenge of reporting

Table 33: Impact reporting of the CPR Invest — Social Impact fund

	Social indicator		Coverage ratio	
	Global Index	CPR Fund	Global Index	CPR Fund
CEO pay ratio	333	114	82%	84%
% of women in the board direction	18%	19%	79%	75%
Hours of training	33 hours	39 hours	33%	45%
Trade union rate	36%	45%	25%	36%

Source: CPR Asset Management (2021)

The challenge of reporting

- Amundi ARI – Impact Green Bonds (Annual impact record 2020)
  - GHG avoided emissions per €1 mn invested per year : 586.5 tCO_2e
  - GHG avoided emissions rebased per €1 mn invested per year 882.7 tCO_2e
- CPR Invest – Climate Action
  - -69% of tCO_2e wrt MSCI ACWI
- CPR Invest – Food For Generations
  - **Water consumption**: 6 765 m3/meur for the fund vs 13 258 for the benchmark and 18 869 for the universe
  - **Waste recycling ratio**: 71.14% for the fund vs 66.45% for the benchmark and 67.22% for the universe

Source: Amundi (2021) and CPR Asset Management (2021)

The challenge of reporting

Table 34: Impact investing reporting of the Amundi Finance & Solidarité fund

	2020	Since inception (2012)
People housed	2 364	10 336
Job created/preserved	9 439	43 655
Care recipients	83 240	250 314
Trained people	18 702	59 686
Preserved agricultural farmland (hectare)	438	987
Waste recycling (ton)	82 590	219 287
Microcredit beneficiaries	60 171	276 514

Source: Amundi (2021)

The challenge of reporting

Figure 58: Companies' portfolio contribution of the Finance & Solidarité fund

Source: Amundi (2021)

Shareholder activism

Shareholder activism can take various forms

1. Exit (sell shares, take an offsetting bet)
2. Vote (form coalition/express dissent/call back lent shares)
3. Engage behind the scene with management and the board
4. Voice displeasure publicly (in the media)
5. Propose resolutions (shareholder proposals)
6. Initiate a takeover (acquire a sizable equity share)

Source: Bekjarovski and Brière (2018)

ESG engagement policies

- On-going engagement
  - Meet companies in order to better understand sectorial ESG challenges
  - Encourage companies to adopt best ESG practices
  - Challenge companies on ESG risks
- Engagement for influence
  - Make recommendations
  - Measure companies ESG progress
- AGM[17] engagement
  - Exercise on voting rights
  - Discuss with companies any resolution items that the investor may vote against

[17] Annual General Meeting

Shareaction 2020 Report

Figure 59: Shareaction 2020 Report: Voting Matters

Source: `https://shareaction.org/research-resources/voting-matters-2020/`

Statistics

Key findings

- One in six asset managers did not use their voting rights at over 10% of the resolutions they could have voted on
- European asset managers continue to outperform US asset managers
- European asset managers do not tend to file shareholder resolutions on climate change and social issues in their own jurisdictions
- 70 additional resolutions would have passed, if one or more of the Big Three had changed their vote

Statistics

Key findings (climate)

- A number of Climate Action 100+ (CA100+) members fail to vote for climate action
- Banks are under pressure to act on climate change

Statistics

Key findings (social)

- Despite the rhetoric on Covid-19 increasing the focus on S, there is little evidence of it affecting voting decisions
- Support for diversity resolutions is higher than for those on human rights and pay gaps
- Investors showed less support for resolutions requesting companies to disclose both gender and race pay gaps, than for gender pay gap only

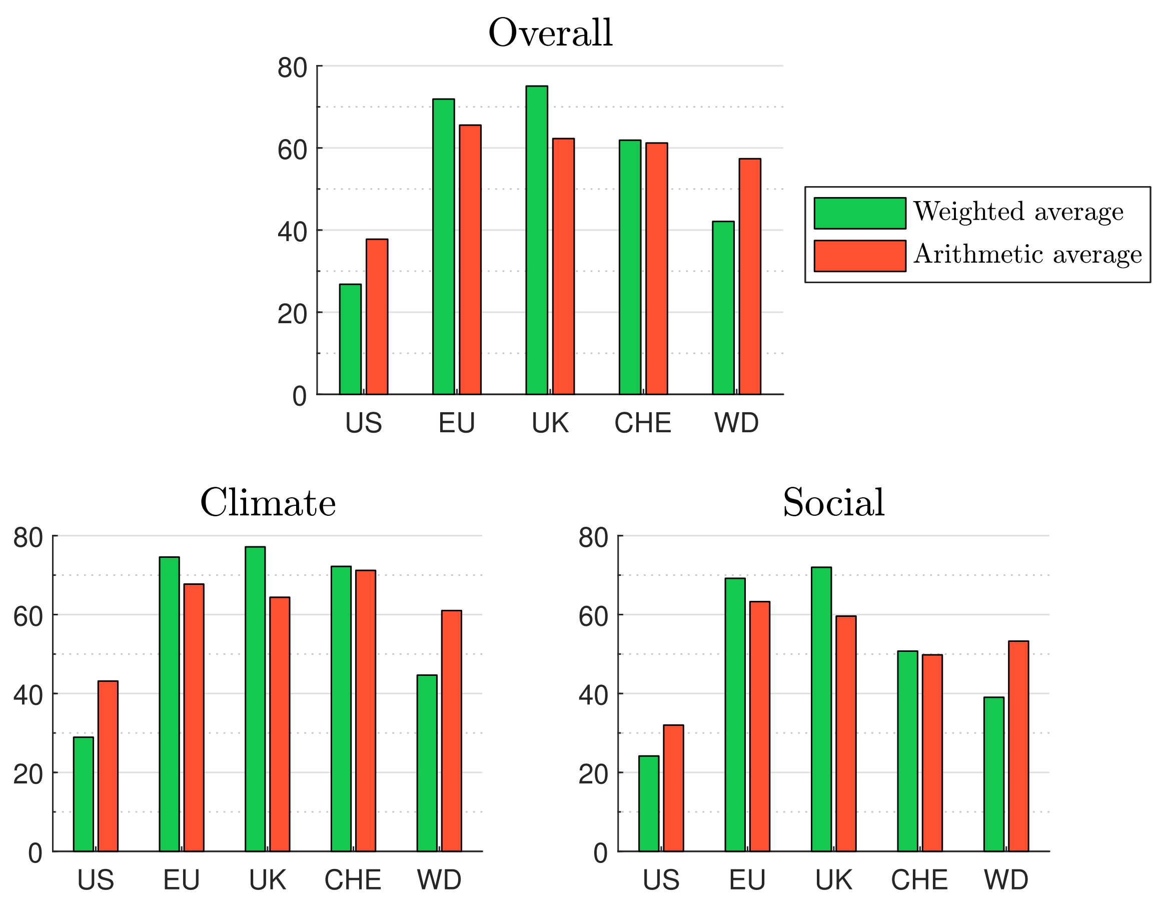
Statistics

Table 35: Ranking of the largest asset managers wrt voting ratios (2020)

Name	Country	AUM	Rank	Overall	Climate	Social
BlackRock	US	6 704	**19**	12%	11%	12%
Vanguard	US	5 625	**18**	14%	15%	12%
Fidelity	US	2 852	16	31%	20%	44%
State Street	US	2 776	15	35%	40%	29%
Capital Group	US	1 833	**20**	8%	12%	4%
JPMorgan IM	US	1 805	13	43%	51%	34%
Amundi	France	1 653	**2**	89%	91%	88%
GSAM	US	1 500	12	45%	48%	43%
Legal & General IM	UK	1 412	**1**	96%	96%	95%
Invesco	US	1 093	14	37%	52%	19%
T. Rowe Price	US	1 075	17	22%	27%	17%
Wellington	US	1 029	11	51%	62%	39%
Nuveen AM	US	948	10	63%	71%	56%
Northern Trust AM	US	906	7	70%	79%	59%
UBS AM	Switzerland	806	4	79%	91%	67%
AXA IM	France	801	6	71%	85%	55%
DWS	Germany	767	9	66%	66%	65%
BNP Paribas AM	France	594	5	72%	65%	80%
Aberdeen	UK	574	8	66%	78%	52%
Allianz GI	Germany	563	**3**	81%	89%	73%

Statistics

Figure 60: Voting ratios (in %) per country (2020)



Source: ShareAction (2020) & author's calculation

An example

Amundi's 2020 voting season

Key facts

- 4 241 general meetings
- 71% general meetings at which Amundi voted against at least one resolution
- 49 968 resolution votes
- 20% resolution votes against management:
  1. Structure of the board (47%)
  2. Capital transaction (20%)
  3. Remunerations (16%)
  4. Shareholder resolutions (12%)
  5. Other (5%)

Source: Amundi's stewardship report 2020

An example

Amundi's 2020 voting season

Shareholder resolutions

- **E** Amundi voted in favor of 86% of climate-related shareholder resolutions
- **S** Amundi voted in favor of 79% of social-related shareholder resolutions (social, health and human rights)
- **G** Amundi supported 88% of compensation-related shareholder resolutions

Engagement

- 489 pre-AGM meetings, 2 378 issues raised with companies
- Amundi engaged with 472 companies on energy transition and climate change and 447 companies on the protection of direct and indirect employees and human rights

Source: Amundi's stewardship report 2020

Shareaction 2021 Report

Figure 61: Shareaction 2021 Report: Voting Matters

Source: `https://shareaction.org/reports/voting-matters-2021-are-asset-managers-using-their-proxy-votes-for-action-on-environmental-and-social-issues`

Shareaction 2021 Report

Summary

The world's largest asset managers continue to block efforts to make progress on environmental and social issues.

- *[...] voting performance of the industry overall has remained stagnant, with a mere four percentage point increase in 'for' votes.*
- *The very largest asset managers' voting records provide particular cause for concern. [...] The six largest asset managers also vote more conservatively than the recommendations of their proxy advisors.*
- *Many asset managers are not exercising their voting rights, with seven assessed managers voting on fewer than 60 per cent of resolutions. Five of these are members of Climate Action 100+ [...]*

(Shareaction 2021 Report, page 5)

Statistics

Table 36: Ranking of the largest asset managers wrt voting ratios (2021)

Name	Country	AUM	Rank	Overall	Climate	Social
BlackRock	US	8 671	12	40%	53%	34%
Vanguard	US	7 253	**19**	26%	38%	20%
Fidelity	US	3 783	17	29%	23%	33%
State Street	US	3 465	15	32%	42%	27%
Capital Group	US	2 382	**18**	28%	26%	31%
JP Morgan AM	US	2 381	13	37%	50%	31%
Amundi	France	2 114	**2**	93%	97%	90%
GSAM	US	1 954	10	47%	57%	40%
Legal & General IM	UK	1 750	4	77%	87%	73%
Franklin Templeton	US	1 499	**20**	25%	25%	27%
T. Rowe Price	US	1 470	16	31%	44%	25%
Morgan Stanley IM	US	1 458	8	55%	59%	53%
Invesco	US/UK	1 349	13	37%	51%	28%
Wellington	US	1 291	11	44%	60%	37%
Northern Trust AM	US	1 165	6	60%	68%	57%
Nuveen	US	1 151	7	56%	76%	48%
UBS AM	Switzerland	1 087	5	75%	72%	75%
AXA IM	France	1 049	8	55%	72%	45%
DWS Group	Germany	969	**3**	85%	92%	80%
BNP Paribas AM	France	756	**1**	98%	96%	99%

Statistics

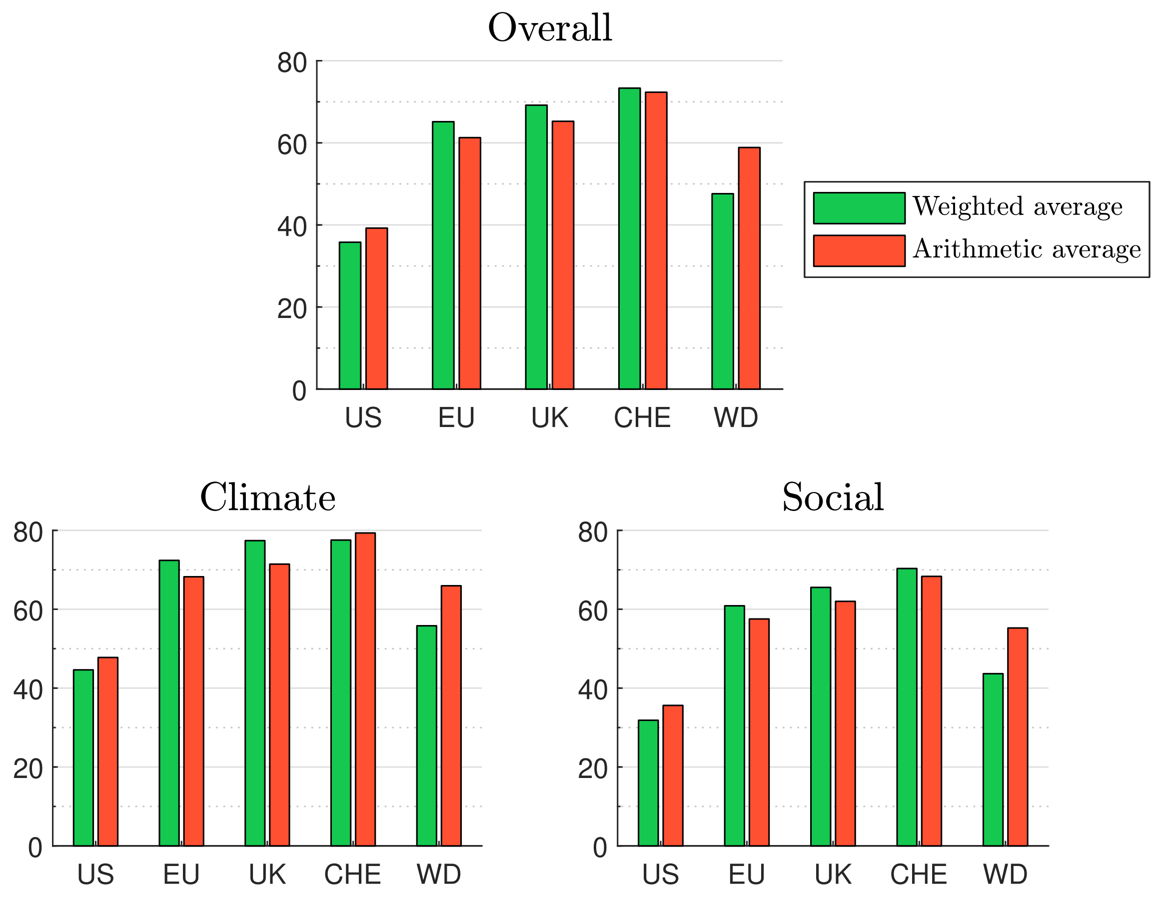
Table 37: Asset managers who saw the largest increase in votes ‘for’ between 2020 and 2021

Asset manager	Average percentage ‘for’ in 2020	Average percentage ‘for’ in 2021	Change in percentage points
Credit Suisse Asset Management	16%	77%	61
Nordea Asset Management	30%	91%	61
Lyxor Asset Management	1%	42%	41
Achmea Investment Management	58%	96%	38
BlackRock	12%	40%	28
BNP Paribas Asset Management	72%	98%	26
Capital Group	8%	28%	20

Source: ShareAction (2021)

Statistics

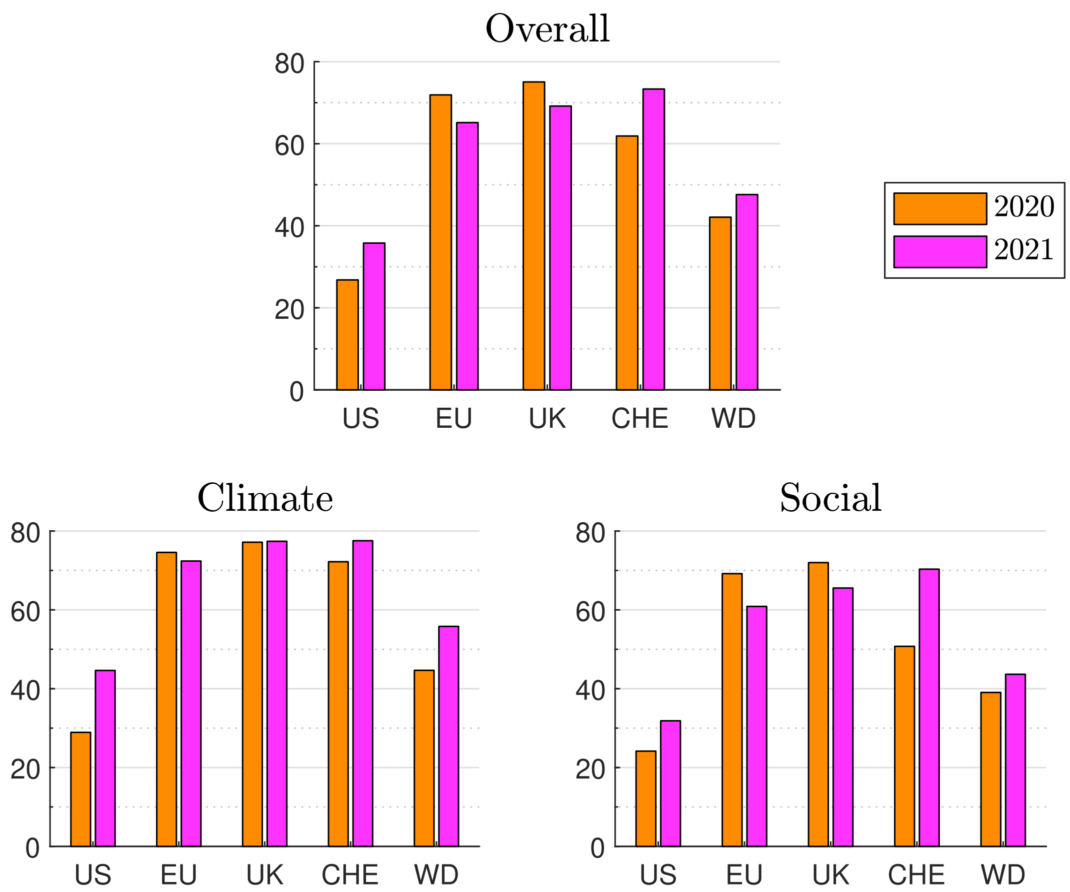
Figure 62: Voting ratios (in %) per country (2021)



Source: ShareAction (2021) & author's calculation

Statistics

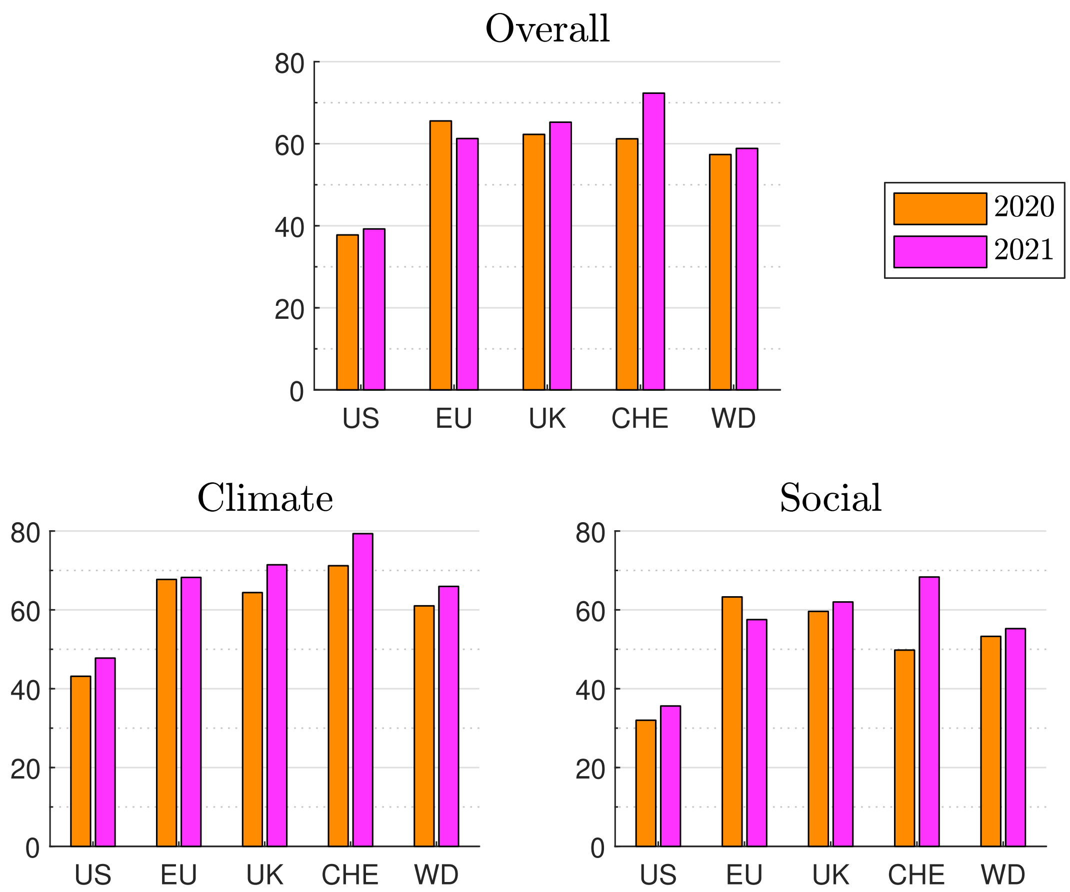
Figure 63: Comparison of 2020 and 2021 voting ratios (in %) per country (weighted average)



Source: ShareAction (2020, 2021) & author's calculation

Statistics

Figure 64: Comparison of 2020 and 2021 voting ratios (in %) per country (arithmetic average)



Source: ShareAction (2020, 2021) & author's calculation

Accounting

Course 2021-2022 in ESG and Climate Risks
Lecture 4. Climate Risk

Thierry Roncalli*

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*University of Paris-Saclay

February 2022

[18] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Prologue

"There is no Plan B, because there is no Planet B"

Ban Ki-moon, UN Secretary-General, September 2014

Is it a question of climate-related issues?

In fact, it is more an economic growth issue

"The Golden Rule of Accumulation: A Fable for Growthmen"

Edmund Phelps, *American Economic Review*, 1961
Nobel Prize in Economics, 2006

Climate risks and financial losses

Climate risks transmission channels to financial stability

- The **physical risks** that arise from the increased frequency and severity of climate and weather related events that damage property and disrupt trade
- The **liability risks** stemming from parties who have suffered loss from the effects of climate change seeking compensation from those they hold responsible
- The **transition risks** that can arise through a sudden and disorderly adjustment to a low carbon economy

Speech by Mark Carney at the International Climate Risk Conference for Supervisors, Amsterdam, April 6, 2018

Physical and transition risks $\Leftrightarrow$ E

Liability risks $\Leftrightarrow$ S (and G ?)

Climate risks and financial risks

Risks are transversal to financial risks

- **Carbon risk** (reputational and regulation risks) $\Rightarrow$ economic, market and credit risks
- **Climate risk** (extreme weather events, natural disasters) $\Rightarrow$ economic, operational, credit and market risks

Carbon/climate risks are part of risk management

Some definitions

Climate risk(s)

Climate risks include transition risk and physical risks:

- Transition risk is defined as the financial risk associated with the transition to a low-carbon economy. It includes policy changes, reputational impacts, and shifts in market preferences, norms and technology
- Physical risk is defined as the financial losses due to extreme weather events and climate disasters like flooding, sea level rise, wildfires, droughts and storms

Some definitions

Global warming ($\approx$ climate change)

Global warming is the long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning

NASA Global Climate Change — `https://climate.nasa.gov`

Some definitions

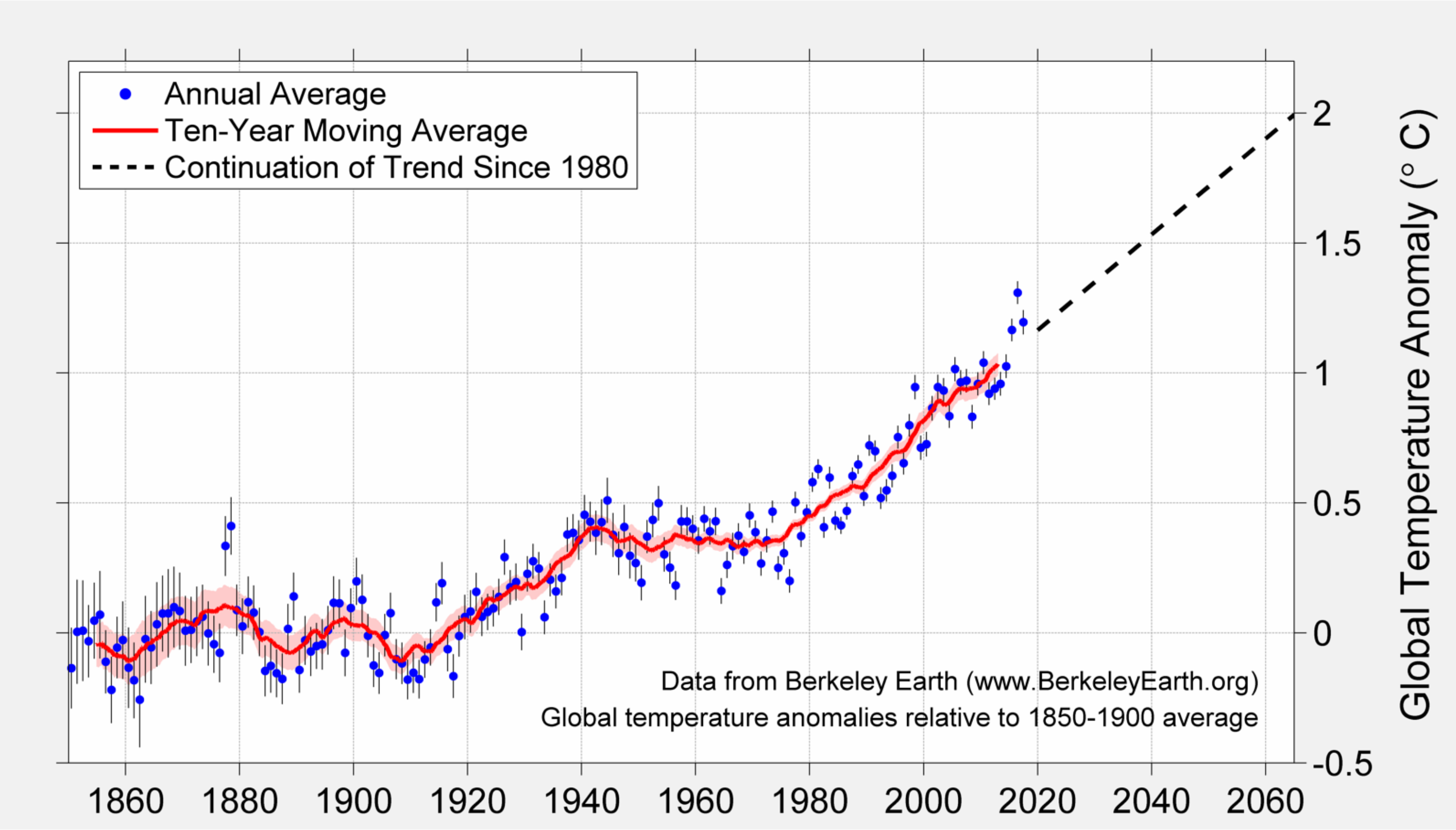


Figure 65: Global temperature anomaly

Source: Berkeley Earth (2018), `http://berkeleyearth.org`

Some definitions

Carbon risk

Carbon risks correspond to the potential financial losses due to greenhouse gas (or GHG) emissions, mainly CO_2 emissions (in a strengthening regulatory context)

Some definitions

GHG

Greenhouse gases absorb and emit radiation energy, causing the greenhouse effect[a]:

1. Water vapour (H_2O)
2. Carbon dioxide (CO_2)
3. Methane (CH_4)
4. Nitrous oxide (N_2O)
5. Ozone (O_3)

[a] Without greenhouse effect, the average temperature of Earth's surface would be about $-18^\circ\mathrm{C}$. With greenhouse effect, the current temperature of Earth's surface is about $+15^\circ\mathrm{C}$.

Some definitions

Table 38: Pros and cons of greenhouse gases

GHG	Pros	Cons	Global warming
Water vapour	Life		
Carbon dioxide	Photosynthesis	Pollution	✓
Methane	Energy	Explosive[19]	✓
Nitrous oxide	Dentist ☺		✓
Ozone	UV rays		

[19] And dangerous for human life

Some definitions

Carbon equivalent

Carbon dioxide equivalent (or CO_2e) is a term for describing different GHG in a common unit

- A quantity of GHG can be expressed as CO_2e by multiplying the amount of the GHG by its global warming potential (GWP)
- 1 kg of carbone dioxide corresponds to 1 kg of CO_2
- 1 kg of methane corresponds to 25 kg of CO_2
- 1 kg of nitrous oxide corresponds to 310 kg of CO_2

In what follows, we use CO_2 in place of CO_2e

CO_2 emissions

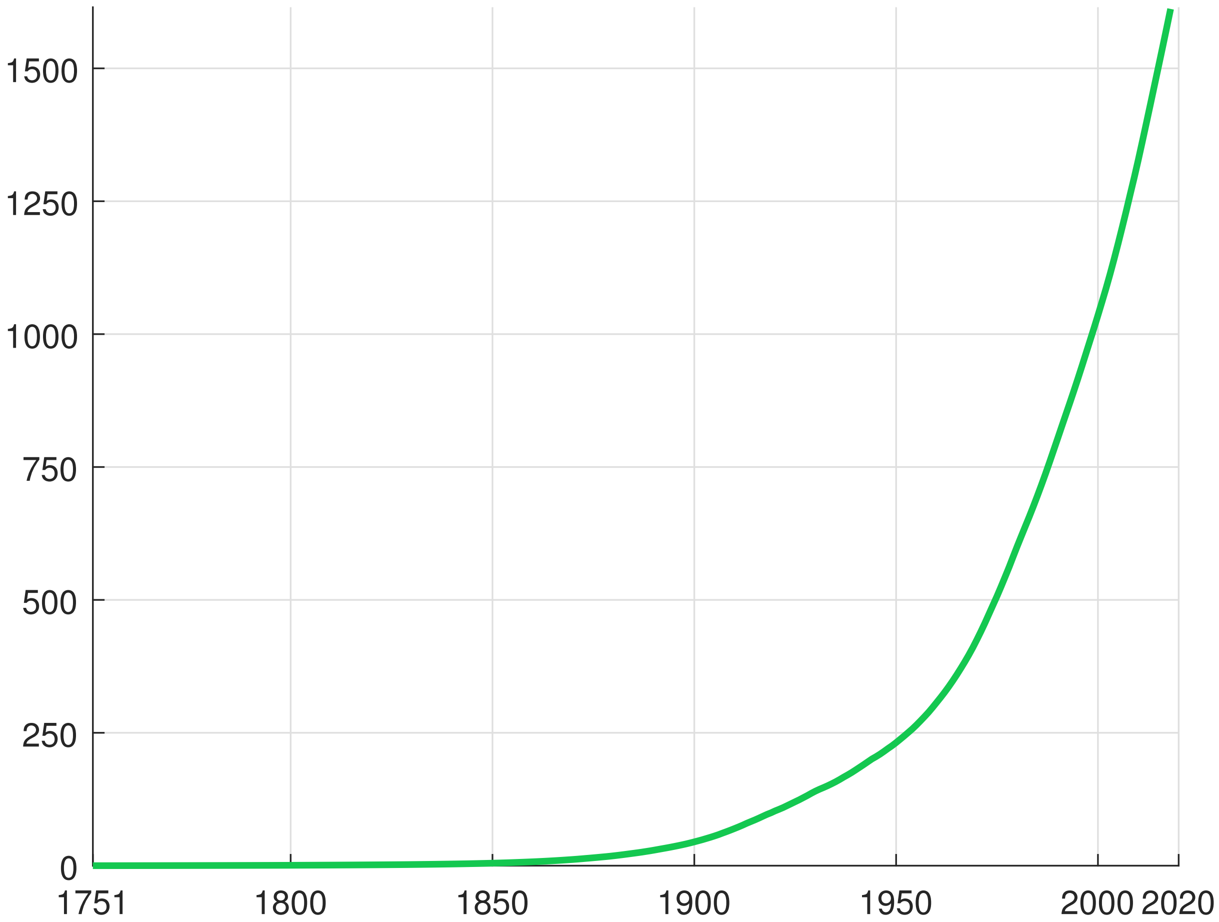


Figure 66: Cumulative CO_2 emissions (in $GtCO_2e$)

Source: Data on CO_2 and GHG Emissions by Our World in Data (https://github.com/owid/co2-data)

CO_2 emissions

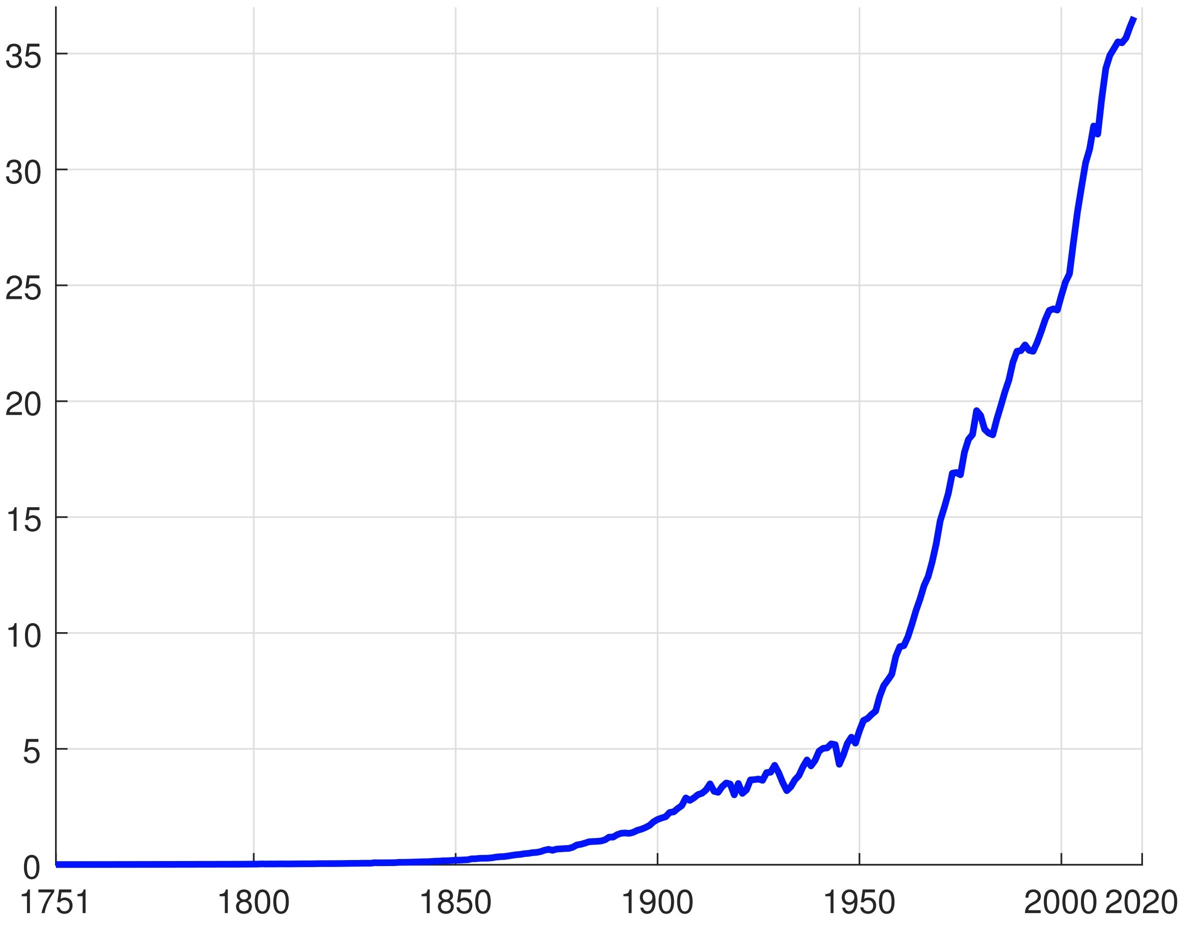


Figure 67: Annual CO_2 emissions (in $GtCO_2e$)

Source: Data on CO_2 and GHG Emissions by Our World in Data (`https://github.com/owid/co2-data`)

CO_2 emissions

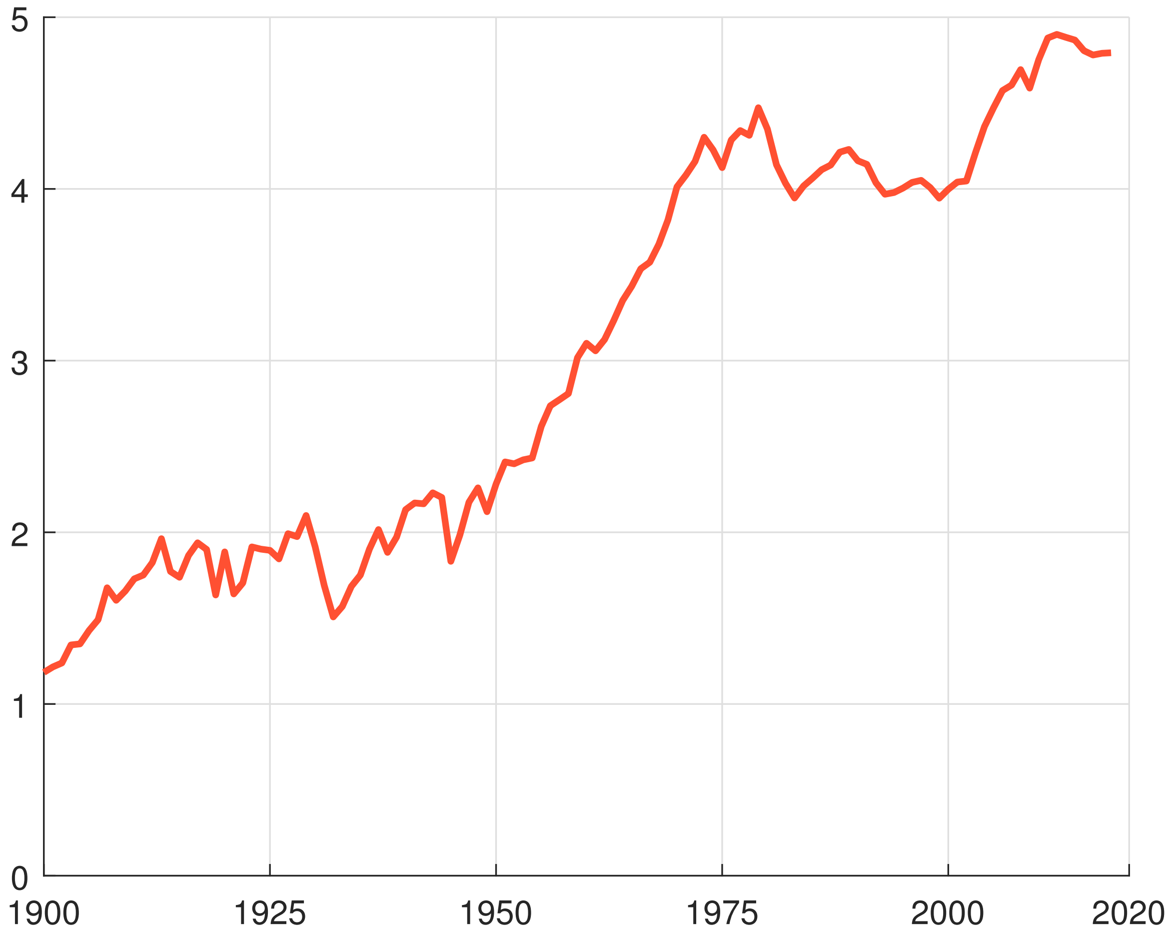


Figure 68: CO_2 emissions per capita (in tons per capita)

Source: Data on CO_2 and GHG Emissions by Our World in Data (`https://github.com/owid/co2-data`)

CO_2 emissions

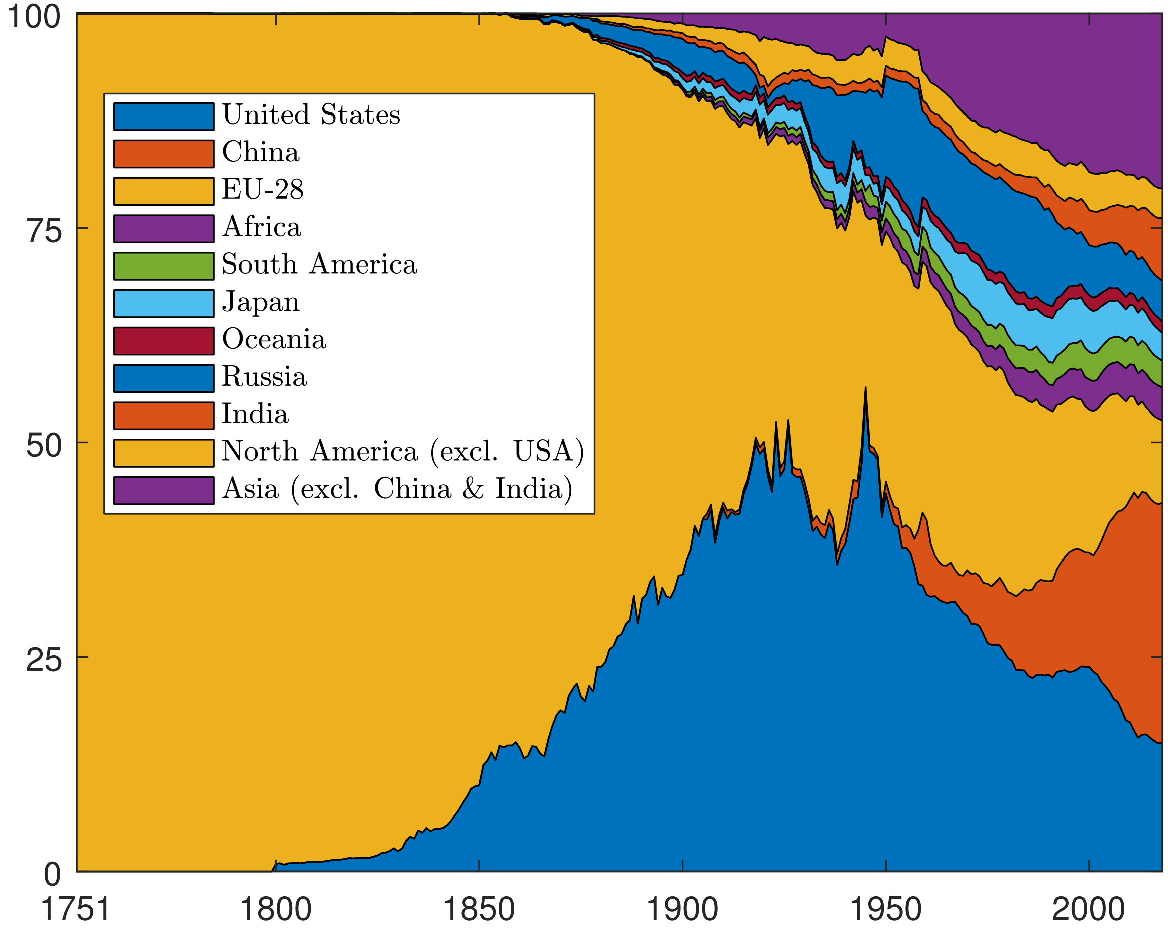
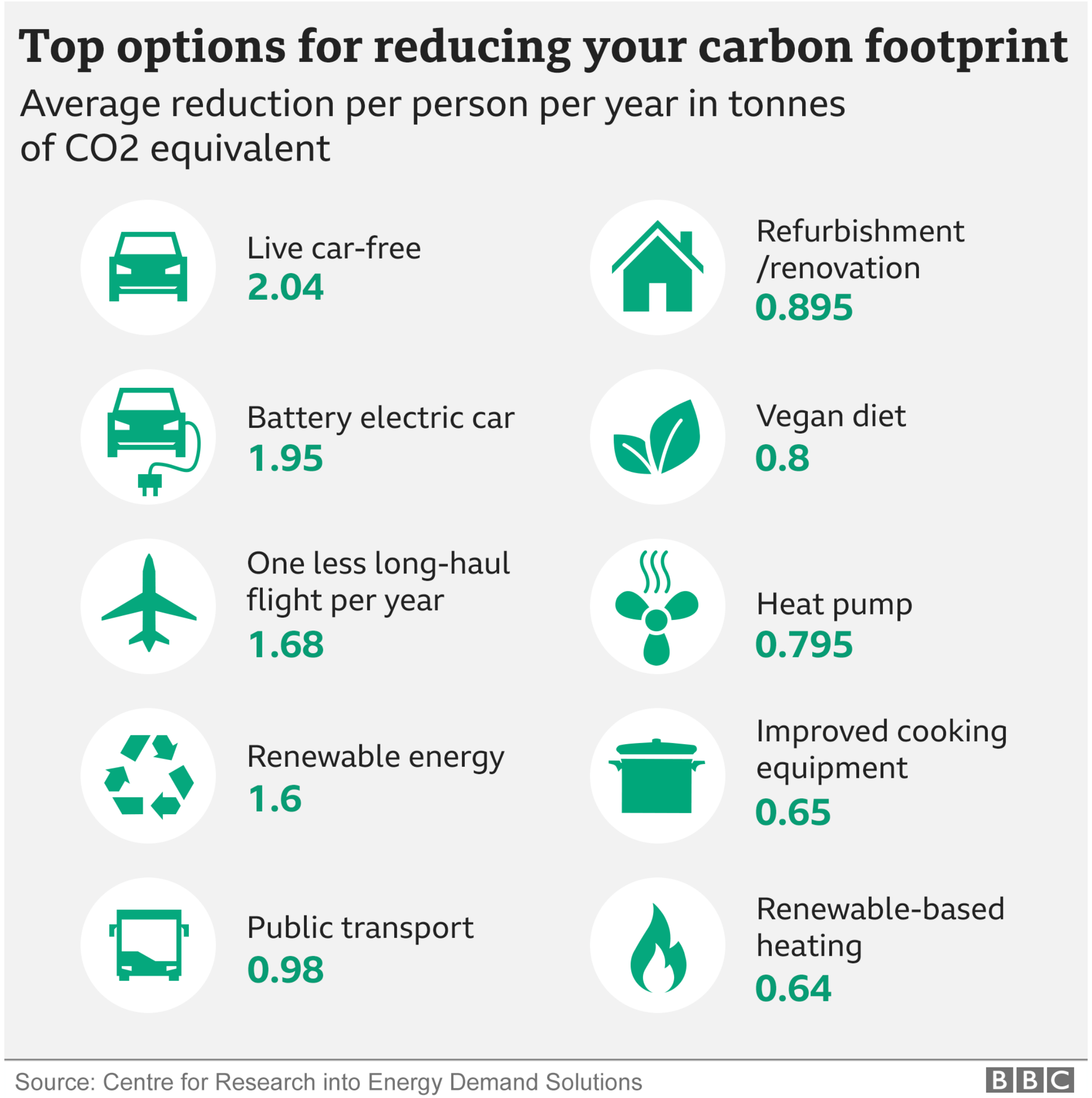


Figure 69: Share of CO_2 emissions (in %)

Source: Data on CO_2 and GHG Emissions by Our World in Data (`https://github.com/owid/co2-data`)

CO_2 emissions



IPCC

- The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change
- The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options
- Website: `https://www.ipcc.ch`

Remark

IPCC is known as "*Groupe d'experts intergouvernemental sur l'évolution du climat*" (GIEC) in French

$\Rightarrow$ Other international bodies: International Energy Agency (IEA), etc.

Scientific evidence of global warming: a rocky road

- 1824: Joseph Fourier published the scientific article "*Remarques générales sur les températures du globe terrestre et des espaces planétaires*" $\Rightarrow$ the greenhouse effect
- 1863: John Tyndall published the books "*Heat Considered as a Mode of Motion*" in 1863 and "*Contributions to Molecular Physics in the Domain of Radiant Heat*" in 1872
- 1896: Svante Arrhenius published the scientific article "*On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground*" $\Rightarrow$ if the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression
- 1958: Charles David Keeling started collecting carbon dioxide samples at the Mauna Loa Observatory (Hawai) $\Rightarrow$ Keeling curve
- 2021: Klaus Hasselmann and Syukuro Manabe won the Nobel Prize in Physics for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming

Scientific evidence of global warming: a rocky road

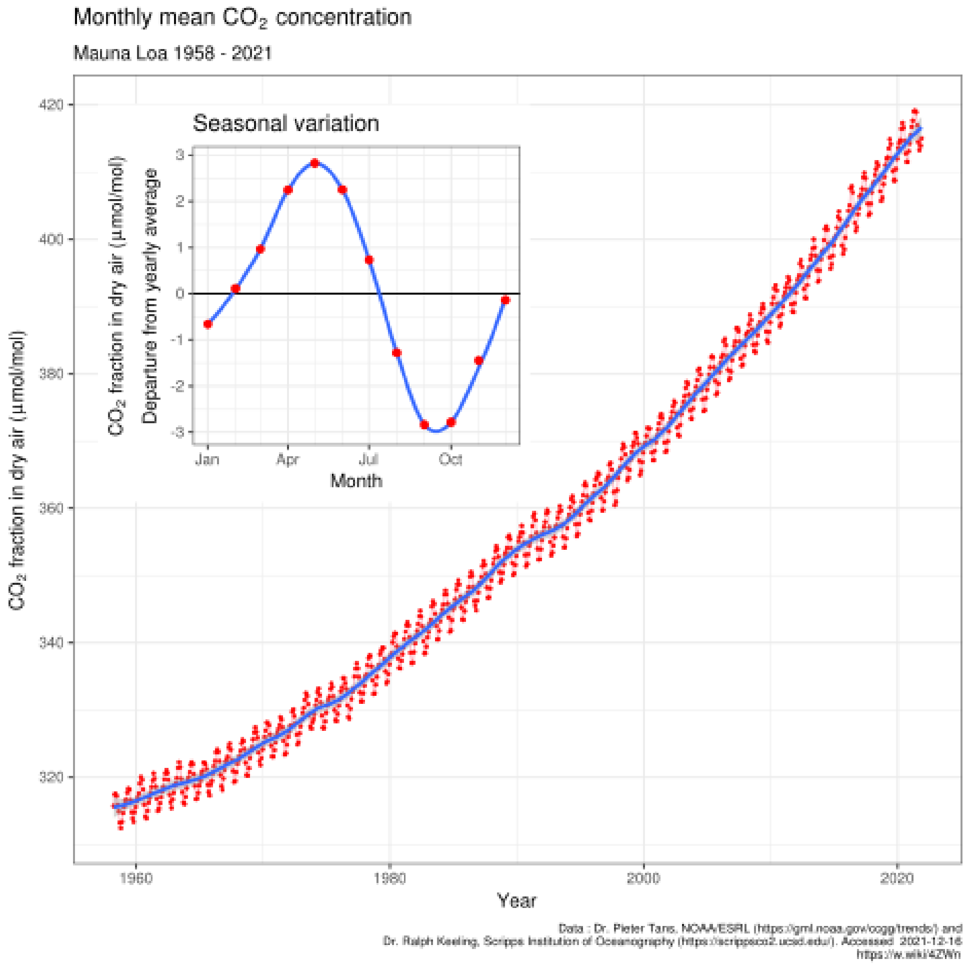


Figure 70: Keeling curve

Source: `https://en.wikipedia.org/wiki/Keeling_Curve`.

IPCC

Past

- Global sea level rose by 19 cm over the period 1901-2010
- Global glacier volume loss is equivalent to 400 bn tons per year since 30 years

Future

- Global sea level could increase by 82 cm by 2100
- Global glacier volume could decrease by 85% by 2100

IPCC, Climate Change Synthesis Report (2014)

IPCC

IPCC working groups

- The IPCC Working Group I (WGI) examines the physical science underpinning past, present, and future climate change
- The IPCC Working Group II (WGII) assesses the impacts, adaptation and vulnerabilities related to climate change
- The IPCC Working Group III (WGIII) focuses on climate change mitigation, assessing methods for reducing greenhouse gas emissions, and removing greenhouse gases from the atmosphere

IPCC

Some famous reports

- IPCC Fifth Assessment Report (AR5): Climate Change 2014 — `www.ipcc.ch/report/ar5`
- Global Warming of 1.5°C — `www.ipcc.ch/sr15`
- IPCC Sixth Assessment Report (AR6): Climate Change 2022 — `www.ipcc.ch/report/sixth-assessment-report-cycle`

IPCC scenarios

- Website: `https://www.ipcc.ch/data`
- The IPCC AR5 scenarios database comprises **31** models and in total **1 184** scenarios
- 4 reference scenarios: **representative concentration pathways** (RCP)
- Each RCP represents one possible evolution profile of GHG concentrations
  - RCP 2.6: CO_2 emissions start declining by 2020 and go to zero by 2100
  - RCP 4.5: CO_2 emissions peak around 2040, then decline
  - RCP 6.0: CO_2 emissions peak around 2080, then decline
  - RCP 8.5: CO_2 emissions continue to rise throughout the 21st century
- For each RCP, socio-economic development scenarios and various adaptation and mitigation strategies are associated
- They are called the **shared socioeconomic pathways** (SSP)

IPCC scenarios

RCP	Model	Contact
RCP 2.6	IMAGE	Detlef van Vuuren (detlef.vanvuuren@pbl.nl)
RCP 4.5	MiniCAM	Katherine Calvin (katherine.calvin@pnnl.gov)
RCP 6.0	AIM	Toshihiko Masui (masui@nies.go.jp)
RCP 8.5	MESSAGE	Keywan Riahi (riahi@iiasa.ac.at)

Table 39: Associated model for each RCP

IPCC scenarios

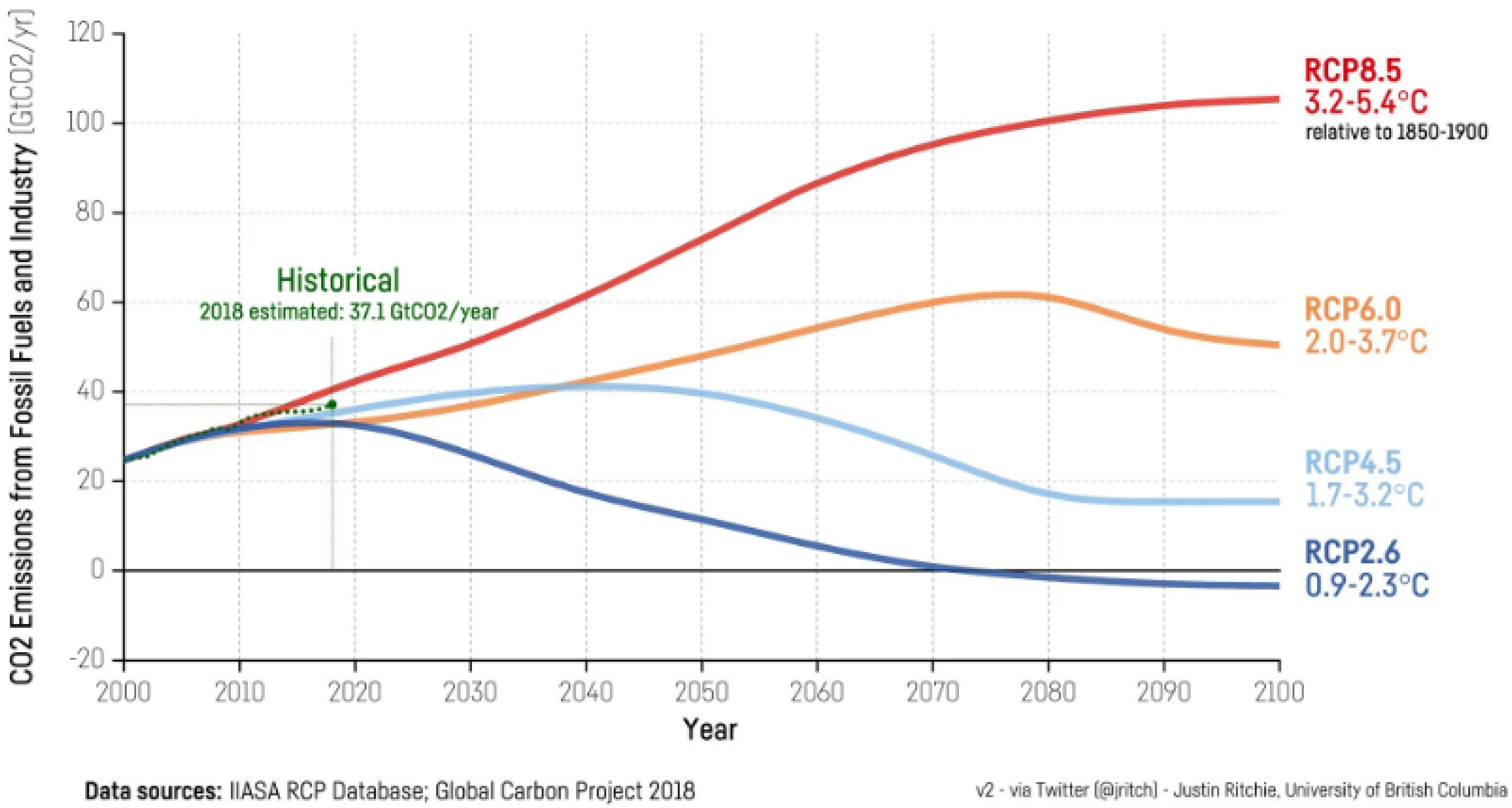


Figure 71: IPCC RCP scenarios: CO_2 emissions from fossil fuels and industry

Carbon neutrality

Carbon neutrality (or net zero) means that any CO2 released into the atmosphere from human activity is balanced by an equivalent amount being removed

Apple Commits to Become Carbon Neutral to by 2030 (https://www.bbc.com/news/technology-53485560)

Carbon dioxide removal

Carbon dioxide removal (CDR)

1. Nature-based solutions
   - Afforestation (creating new forests)
   - Reforestation (multiplying trees in old forests)
   - Restoration of peat bogs
   - Restoration of coastal and marine habitats
2. Enhanced natural processes
   - Land management and no-till agriculture, which avoids carbon release through soil disturbance
   - Better wildfire management
   - Ocean fertilisation to increase its capacity to absorb CO_2 (enhanced weathering)
3. Technology solutions
   - Bioenergy with carbon capture and storage (BECCS)
   - Direct air capture (DAC)
   - Carbon mineralization

Carbon dioxide removal

The example of peatlands

- Peatlands are the largest natural terrestrial carbon store
- The term "*peatland*" refers to peat soil and wetland habitats
- They cover only 3% of the Earth's surface
- They store 600 $GtCO_2e$
  - $\approx$ 45% of all soil carbon
  - $\approx$ 67% of all atmosphere carbon
- A depth of one meter corresponds to 1 000 years of carbon storage
- Natural peatlands store 0.37 $GtCO_2e$ per year

Two issues:

1. Stopping the destruction
2. Restoring and rebuilding

Carbon offsetting

Carbon offsetting $\neq$ carbon emissions reduction

Definition

"Carbon offsetting consists for an entity in compensating its own carbon emissions by providing for emissions reductions outside its business boundaries [...] It allows an entity to claim carbon reductions from projects financed either directly or indirectly through carbon credits" (Créhalet, 2021).

Carbon offsetting

Carbon offsetting mechanisms:

Suppliers of carbon offsets

$\Downarrow$

Carbon credits

$\Downarrow$

Purchasers of carbon offsets

$\Rightarrow$ Many issues: carbon credit issuance, double counting, leakage, certification, etc.

Examples with **REDD+** projects:

- **R**educing **E**missions from **D**eforestation and **F**orest **D**egradation
- What will happen if the forest has burned down?
- Issues of land management (afforestation in one area can lead to a deforestation in another area)

The shared socioeconomic pathways

- **SSP1**: Low challenges for both mitigation and adaptation, rapid development: **Sustainability** (Taking the Green Road)
- **SSP2**: Moderate challenges for mitigation and adaptation: **Middle of the Road**
- **SSP3**: High challenges for both mitigation and adaptation — Concern about competitiveness, security and regional conflict pushing countries to focus on regional issues: **Regional Rivalry** (a Rocky Road)
- **SSP4**: Low challenges for mitigation high for adaptation — Unequal investment in human capital, concentration of power in a small business elite: **Inequality** (A Divided Road)
- **SSP5**: High challenge for mitigation low for adaptation: **Fossil-fueled Development** (Taking the Highway)

Figure 72: The shared socioeconomic pathways

Source: O'Neill *et al.* (2016)

The shared socioeconomic pathways

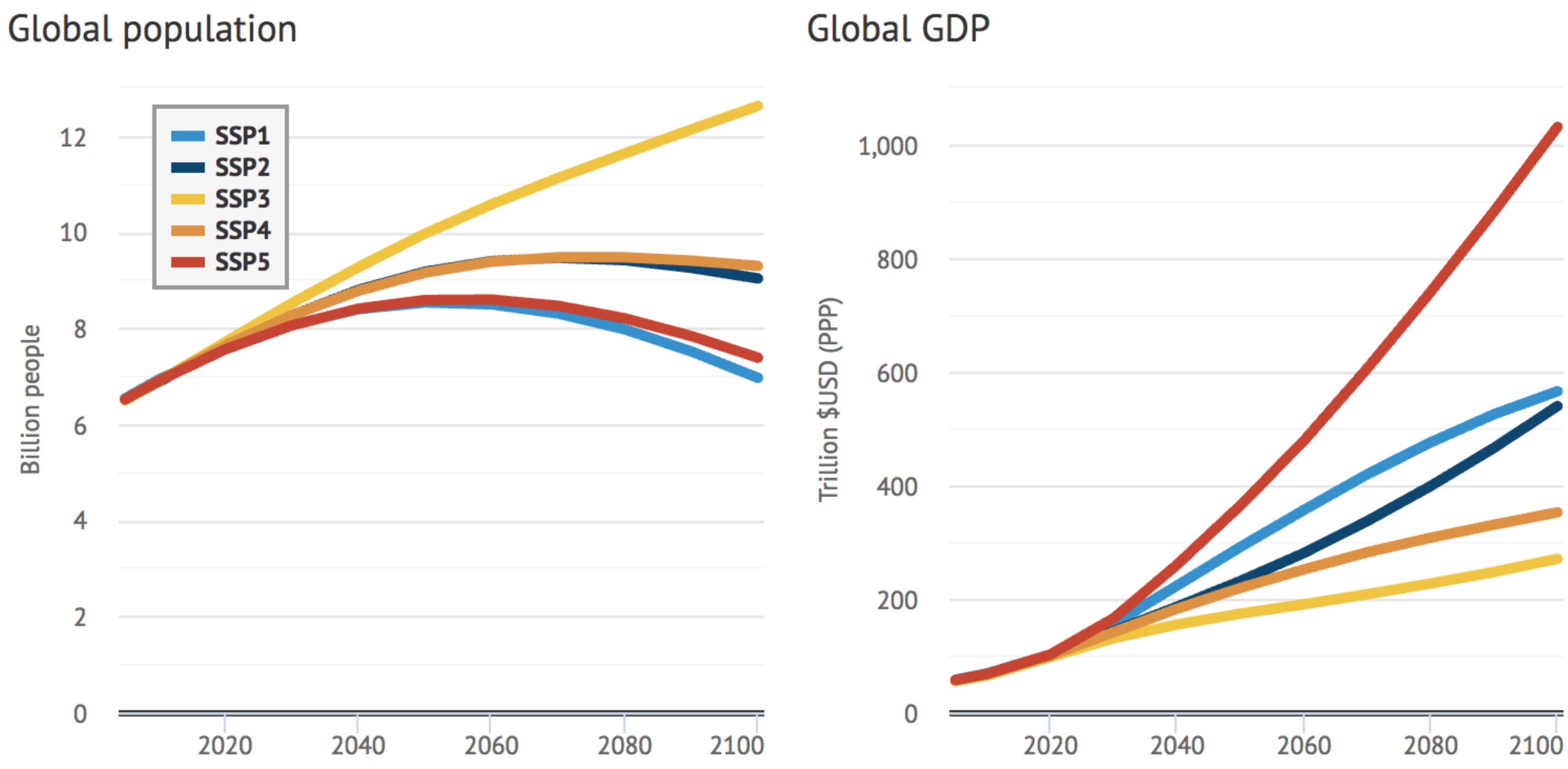


Figure 73: Projections of population and economic growth across SSP

Source: `https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change`

The shared socioeconomic pathways

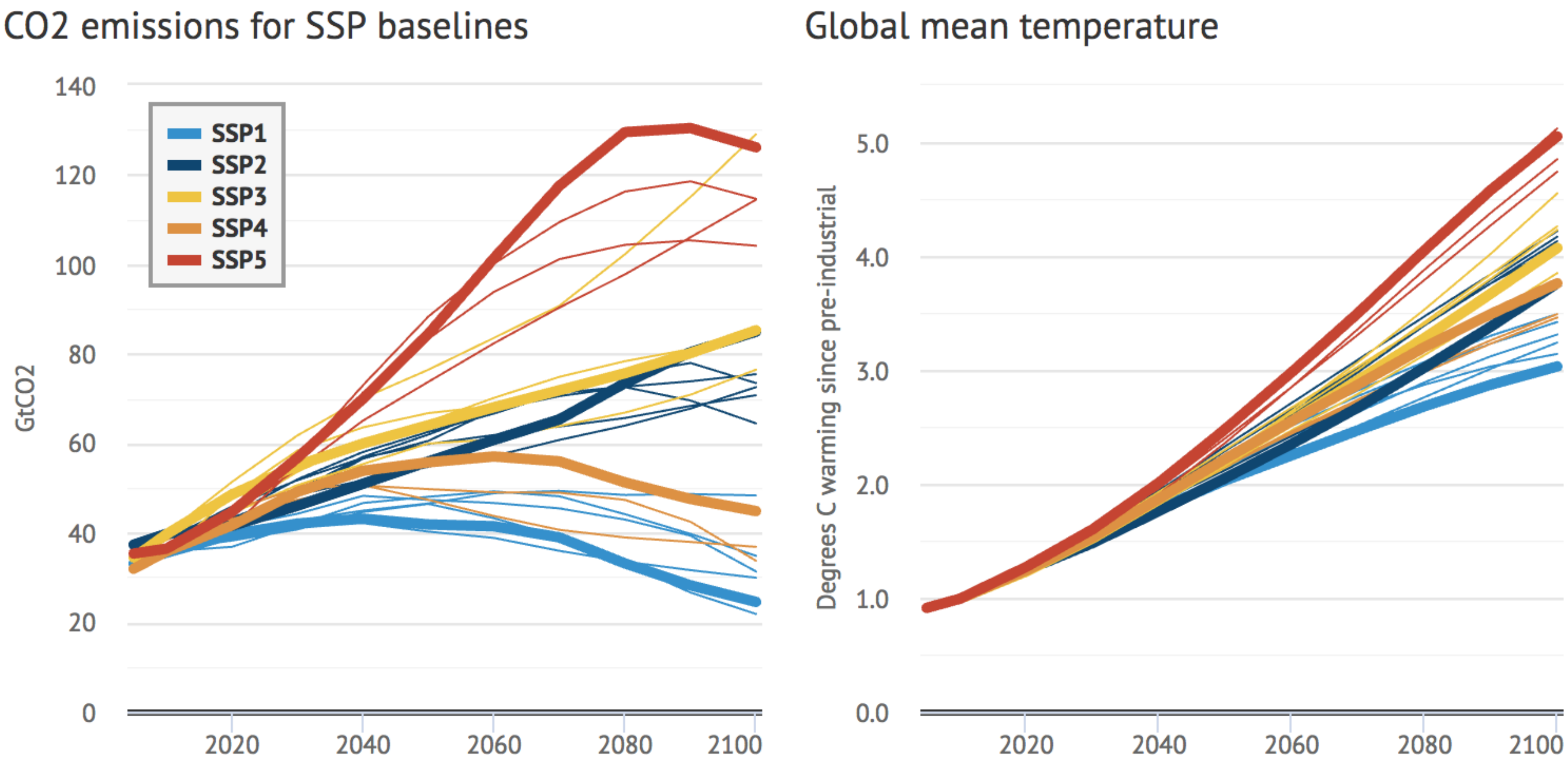


Figure 74: Projections of CO_2 emissions and temperatures across SSP

Source: `https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change`

Climate risk and missing factors

The example of permafrost

- The permafrost contains 1 700 billion tons of carbon, almost double the amount of carbon that is currently in the atmosphere.
- Arctic permafrost holds roughly 15 million gallons of mercury – at least twice the amount contained in the oceans, atmosphere and all other land combined.
- A global temperature rise of 1.5°C above current levels would be enough to start the thawing of permafrost in Siberia.
- The global warming will become out-of-control after this tipping point.
- The thawing of the permafrost also threatens to unlock disease-causing viruses long trapped in the ice.

$\Rightarrow$ The survival of Humanity becomes uncertain if the tipping point is reached

Regulation of climate risk

- UN, international bodies & coalitions
- Countries
- Cities
- Industry self-regulation
- Non-governmental organizations (NGO)
- Financial regulators

Hard regulation $\neq$ **soft regulation**

Regulation of climate risk

UN

United Nations Climate Change Conference

- Conference of the Parties (COP)
- Dealing with climate change
- COP 1: Berlin (1995)
- COP 3: Kyoto (1997) $\Rightarrow$ Kyoto Protocol (CMP)
- COP 21: Paris (2015) $\Rightarrow$ Paris Agreement (CMA)
- COP 26: Glasgow (November 2021)

Regulation of climate risk

UN

The **Kyoto Protocol** is an international treaty that commits state parties to reduce GHG emissions, based on the scientific consensus that:

1. **Global warming is occurring**
2. It is likely that **human-made CO_2 emissions have caused it**

Regulation of climate risk
UN

The **Paris Agreement** is an international treaty with the following goals:

1. Keep a global temperature rise this century well below $2^{\circ}\mathrm{C}$ above the pre-industrial levels
2. Pursue efforts to limit the temperature increase to $1.5^{\circ}\mathrm{C}$
3. Increase the ability of countries to deal with the impacts of climate change
4. Make finance flows consistent with low GHG emissions and climate-resilient pathways

$\Rightarrow$ Nationally determined contributions (NDC)

Regulation of climate risk

UN

Table 40: CO_2 emissions by country

Rank	Country	CO_2 emissions Total (in GT)	Share	CO_2 emissions Per capita (in MT)
1	China	10.06	28%	7.2
2	USA	5.41	15%	15.5
3	India	2.65	7%	1.8
4	Russia	1.71	5%	12.0
5	Japan	1.16	3%	8.9
6	Germany	0.75	2%	8.8
7	Iran	0.72	2%	8.3
8	South Korea	0.72	2%	12.1
9	Saudi Arabia	0.72	2%	17.4
10	Indonesia	0.72	2%	2.2
11	Canada	0.56	2%	15.1
15	Turkey	0.42	1%	4.7
17	United Kingdom	0.37	1%	5.8
19	France	0.33	1%	4.6
20	Italy	0.33	1%	5.3

Source: Earth System Science Data, `https://earth-system-science-data.net`

World Bank Open Data, `https://data.worldbank.org/topic/climate-change`

Regulation of climate risk

UN

Paris Agreement: where we are?

- 194 states have signed the Agreement
- They represent about 80% of GHG emissions
- USA, Iran and Turkey have not signed the Agreement

Regulation of climate risk

UN

Figure 75: Paris Agreement assessments of aviation and shipping

Source: Climate Action Tracker (CAT), https://climateactiontracker.org

Regulation of climate risk

Coalitions

- **The Coalition of Finance Ministers for Climate Action**

  `www.financeministersforclimate.org`

  - Commitment to implement fully the Paris Agreement
  - Santiago Action Plan
  - Helsinki principles (1. align, 2. share, 3. promote, 4. mainstream, 5. mobilize, 6. engage)

Regulation of climate risk
Coalitions

- **One Planet Summit**

  `www.oneplanetsummit.fr`

- **One Planet Sovereign Wealth Funds (OPSWF)**
  - Funding members: Abu Dhabi Investment Authority (ADIA), Kuwait Investment Authority (KIA), NZ Superannuation Fund (NZSF), Public Invesment Fund (PIF), Qatar Investment Authority (QIA), NBIM
  - New members: Bpifrance, CDP Equity, COFIDES, FONSIS, ISIF, KIC, Mubadala IC, NIIF, NIC NBK
- **One Planet Asset Managers**
  - Funding members: Amundi AM, BlackRock, BNP PAM, GSAM, HSBC Global AM, Natixis IM, Northern Trust AM, SSGA
  - New members: AXA IM, Invesco, Legal & General IM, Morgan Stanley IM, PIMCO UBS AM
- **One Planet Private Equity Funds**
  - Members: Ardian, Carlyle Group, Global Infrastructure Partners, Macquarie Infrastructure and Real Assets (MIRA), SoftBank IA

Regulation of climate risk

Countries

The example of France

- August 2015: French Energy Transition for Green Growth Law (or Energy Transition Law)
- Roadmap to mitigate climate change and diversify the energy mix

Other examples: Germany (2021 Renewable Energy Act), UK (2013 Energy Act), The Netherlands (2019 Climate Change Mitigation Act), etc.

Regulation of climate risk

Countries

Article 173 of the French Energy Transition Law

- The annual report of listed companies must include:
  - Financial risks related to the effects of climate change
  - The measures adopted by the company to reduce them
  - The consequences of climate change on the company's activities
- New requirements for investors:
  - Disclosure of climate (and ESG) criteria into investment decision making process
  - Disclosure of the contribution to the energy transition and the global warming limitation international objective
  - Reporting on climate change-related risks (including both physical risks and transition risks), and GHG emissions of assets
- Banks and credit providers shall conduct climate stress testing

Regulation of climate risk

Carbon pricing

- Polluter pays principle
  - A carbon price is a cost applied to carbon pollution to encourage polluters to reduce the amount of GHG they emit into the atmosphere
  - Negative externality

- Two instruments of carbon pricing
  1. **Carbon tax**
  2. **Cap-and-trade** (CAT) or **emissions trading scheme** (ETS)

- Some examples
  1. EU emissions trading system (2005) — `https://ec.europa.eu/clima/policies/ets_en`
  2. New Zealand ETS (2008)
  3. Chinese national carbon trading scheme (2017)

Regulation of climate risk
Carbon pricing

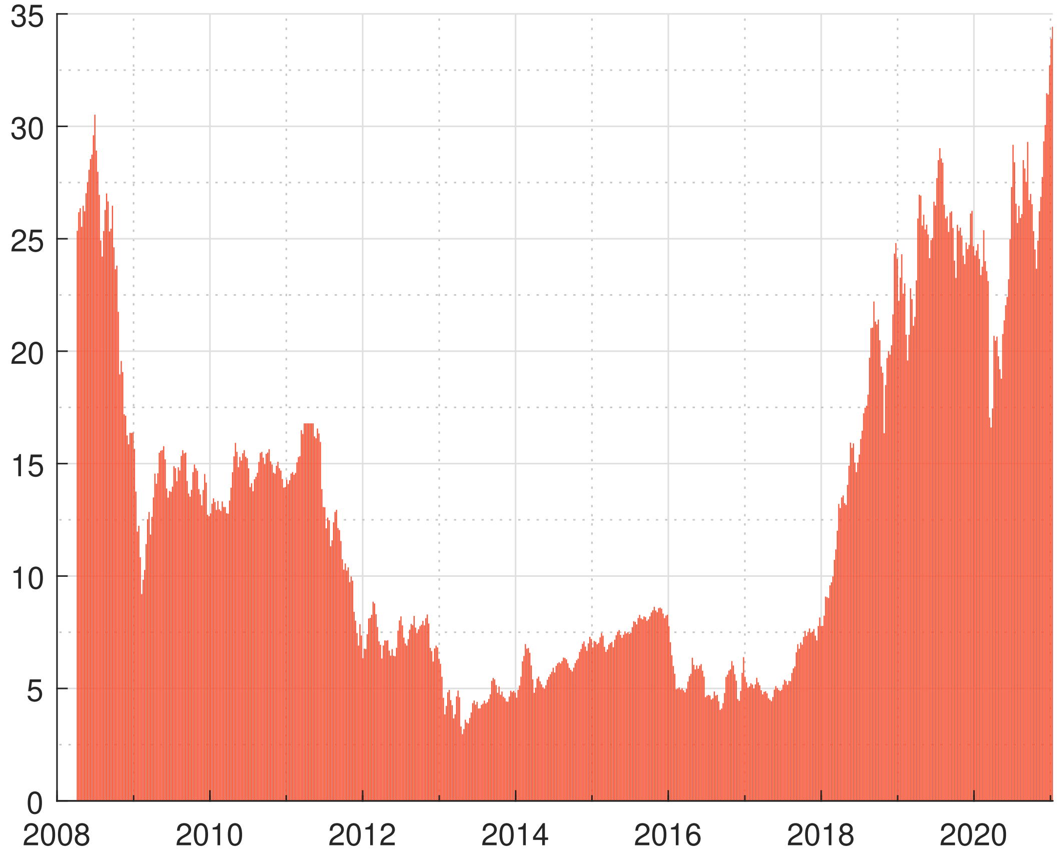


Figure 76: EU ETS carbon price* (in €/tCO_2)

(*)The carbon price reaches 34.43 euros a tonne on Monday 11, 2021

Regulation of climate risk

Carbon pricing

Table 41: Carbon tax (in $\$/tCO_2$)

Country	2018	2019	2020	Country	2018	2019	2020
Sweden	139.11	126.78	133.26	Latvia	5.58	5.06	10.49
Liechtenstein	100.90	96.46	105.69	South Africa			7.38
Switzerland	100.90	96.46	104.65	France	55.30	50.11	6.98
Finland	76.87	69.66	72.24	Argentina		6.24	5.94
Norway	64.29	59.22	57.14	Chile	5.00	5.00	5.00
Ireland	24.80	22.47	30.30	Colombia	5.67	5.17	4.45
Iceland	35.71	31.34	30.01	Singapore		3.69	3.66
Denmark	28.82	26.39	27.70	Mexico	3.01	2.99	2.79
Portugal	8.49	14.31	27.52	Japan	2.74	2.60	2.76
United Kingdom	25.46	23.59	23.23	Estonia	2.48	2.25	2.33
Slovenia	21.45	19.44	20.16	Ukraine	0.02	0.37	0.35
Spain	24.80	16.85	17.48	Poland	0.09	0.08	0.08

Source: World Bank Carbon Pricing Dashboard, `https://carbonpricingdashboard.worldbank.org`

Regulation of climate risk

Stranded assets

- Stranded Assets are assets that have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities
- For example, a $2^{\circ}\mathrm{C}$ alignment implies to keep a large proportion of existing fossil fuel reserves in the ground (30% of oil reserves, 50% of gas reserves and 80% of coal)
- Risk factors: Regulations, carbon prices, change in demand, social pressure, etc.
- Example of the covid-19 crisis $\Rightarrow$ air travel

Regulation of climate risk

Financial regulation

- Financial Stability Board (FSB)
- European Central Bank (ECB)
- The French Prudential Supervision and Resolution Authority (ACPR)
- The Prudential Regulation Authority (PRA)
- Network for Greening the Financial System (NGFS)
- Etc.

Regulation of climate risk

Financial regulation

Bolton, P., Despres, M., Pereira Da Silva, L.A., Samama, F. and Svartzman, R. (2020), *The Green Swan — Central Banking and Financial Stability in the Age of Climate Change*, BIS Publication, `https://www.bis.org/publ/othp31.htm`

Regulation of climate risk

Financial regulation

Task Force on Climate-related Financial Disclosures (TCFD)

- Established by the FSB in 2015 to develop a set of voluntary, consistent disclosure recommendations for use by companies in providing information to investors, lenders and insurance underwriters about their climate-related financial risks
- Website: `www.fsb-tcfd.org`
- Chairman: Michael R. Bloomberg (founder of Bloomberg L.P.)
- 31 members
- June 2017: Publication of the "*Recommendations of the Task Force on Climate-related Financial Disclosures*"
- October 2020: Publication of the 2020 "*Status Report: Task Force on Climate-related Financial Disclosures*"

Regulation of climate risk

Financial regulation

Recommendation	ID	Recommended Disclosure
Governance	1	Board oversight
	2	Management's role
Strategy	3	Risks and opportunities
	4	Impact on organization
	5	Resilience of strategy
Risk management	6	Risk ID and assessment processes
	7	Risk management processes
	8	Integration into overall risk management
Metrics and targets	9	Climate-related metrics
	10	Scope 1, 2, 3 GHG emissions
	11	Climate-related targets

Table 42: The 11 recommended disclosures (TCFD, 2017)

Regulation of climate risk

Financial regulation

Some key findings of the 2020 Status Report (TCFD, 2020):

- Disclosure of climate-related financial information has increased since 2017, but continuing progress is needed
- Average level of disclosure across the Task Force's 11 recommended disclosures was 40% for energy companies and 30% for materials and buildings companies
- Asset manager and asset owner reporting to their clients and beneficiaries, respectively, is likely insufficient

Climate stress testing

- ACPR (2020): Climate Risk Analysis and Supervision[20]
- Bank of England (2021): Climate Biennial Exploratory Scenario (June 2021)

Top-down approach $\neq$ bottom-up approach

Stress of risk-weighted asset: Bouchet and Le Guenedal (2020).

[20] https://acpr.banque-france.fr/en/scenarios-and-main-assumptions-acpr-pilot-climate-exercise

Climate capital requirements

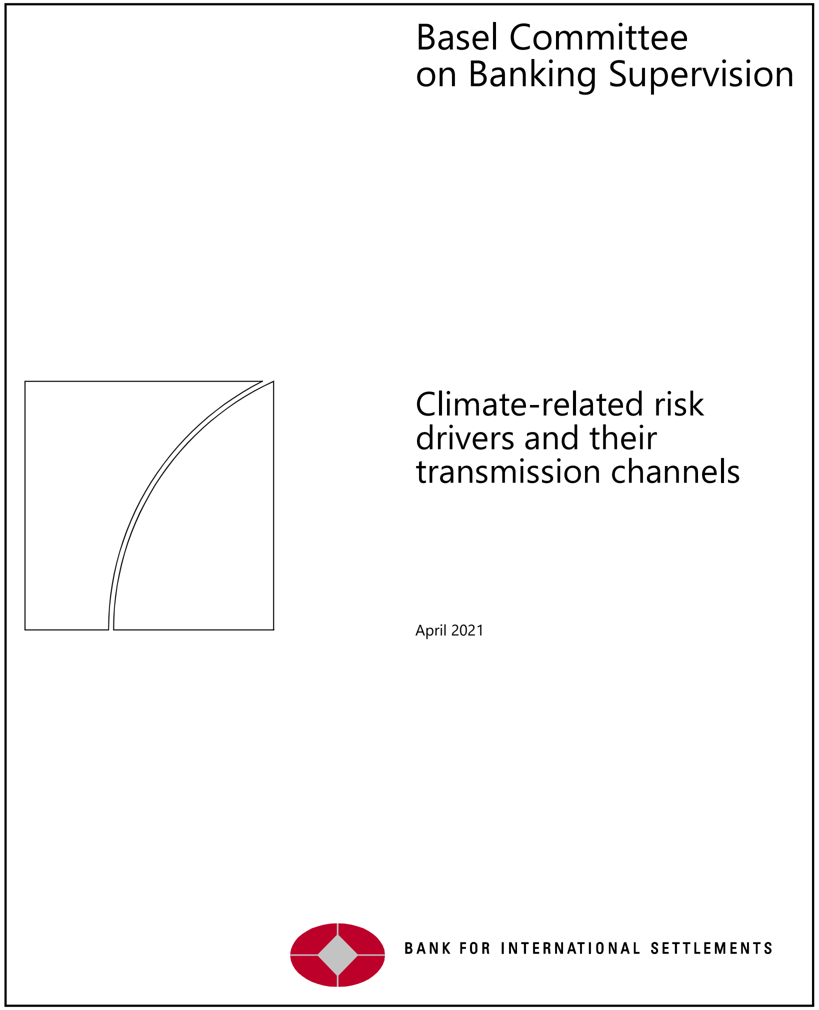
Green supporting factor

- Risk weights may depend on the green/brown nature of the credit
- Green loans
- Green supporting factor $\neq$ Brown penalising factor

Similar idea: Green Quantitative Easing (GQE)

Climate capital requirements

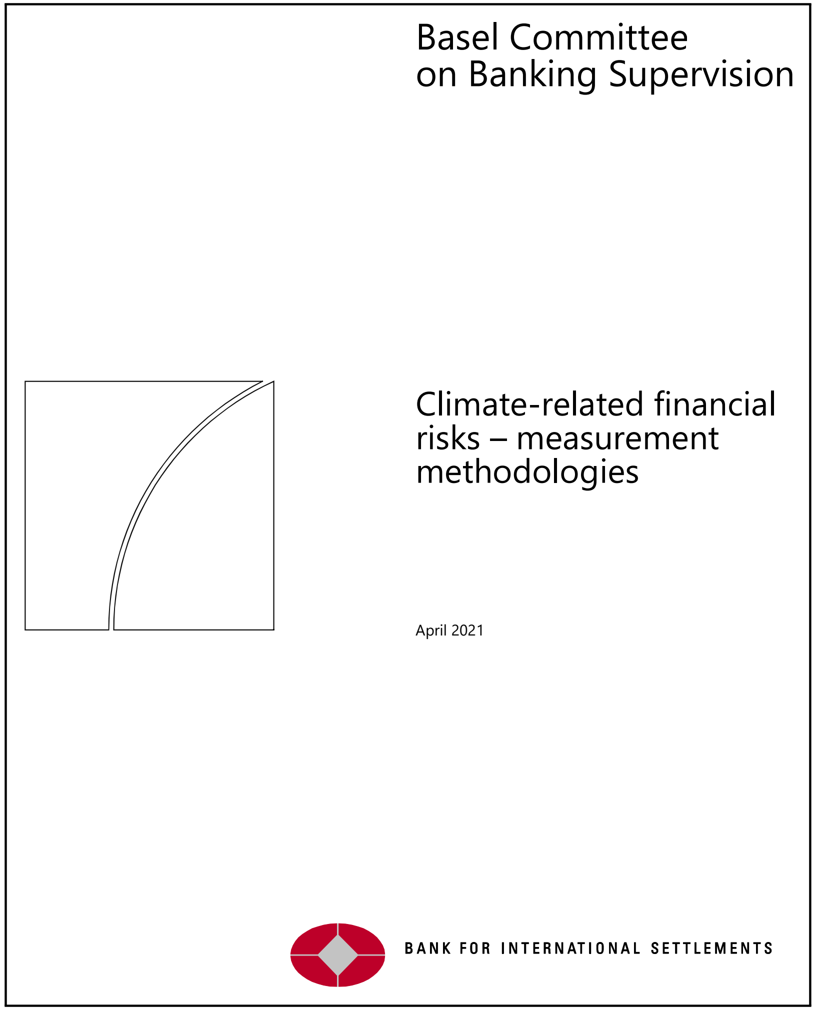
Figure 77: In April 2021, Basel Committee publishes two reports on climate risk


Basel Committee
on Banking Supervision

Climate-related risk
drivers and their
transmission channels

April 2021

BANK FOR INTERNATIONAL SETTLEMENTS


Basel Committee
on Banking Supervision

Climate-related financial
risks – measurement
methodologies

April 2021

BANK FOR INTERNATIONAL SETTLEMENTS

Climate risk modeling

Remark

In what follows, we use the survey and the simulations of Le Guenedal (2019)

Climate risk modeling
The Solow growth model

The model

- Production function:

$$Y(t) = F(K(t), A(t) L(t))$$

  where $K(t)$ is the capital, $L(t)$ is the labor and $A(t)$ is the knowledge factor

- Law of motion for the capital per unit of effective labor $k(t) = K(t) / (A(t) L(t))$:

$$\frac{\mathrm{d}k(t)}{\mathrm{d}t} = s f(k(t)) - (g_L + g_A + \delta_K) k(t)$$

  where s is the saving rate, δ_K is the depreciation rate of capital and g_A and g_L are the productivity and labor growth rates

Climate risk modeling
The golden rule

Golden rule with the Cobb-Douglas production and Hicks neutrality

The equilibrium to respect the '*fairness*' between generations is:

$$k^{\star} = \left(\frac{s}{g_L + g_A + \delta_K} \right)^{\dfrac{1}{1-\alpha}}$$

"*Each generation in a boundless golden age of natural growth will prefer the same investment ratio, which is to say the same natural growth path*" (Phelps, 1961, page 640).

"*By a golden age I shall mean a dynamic equilibrium in which output and capital grow exponentially at the same rate so that the capital-output ratio is stationary over time*" (Phelps, 1961, page 639).

Climate risk modeling

Golden rule and climate risk

What is economic growth and what is the balanced growth path?

- There is a saving rate that maximizes consumption over time and between generations ("**the fair rate to preserve future generations**")
- Economic growth corresponds to the exponential growth of capital and output to answer the needs of the growing population
- Introducing human and natural capitals add constraints and therefore **reduce growth**!

$$\text{Economic growth} \Rightarrow \begin{cases} \text{productivity} \nearrow \text{ and labor} \nearrow \\ \text{maximization of } \textbf{consumption-based utility} \text{ function} \end{cases}$$

Climate risk modeling

Extension to natural capital

What are the effects of environmental constraints on growth?

Introducing a decreasing natural capital (Romer, 2006)

The balanced growth path $g_Y^\star$ is equal to:

$$g_Y^\star = g_L + g_A - \frac{g_L + g_A + \delta_{N_c}}{1-\alpha}\vartheta$$

where δ_{N_c} is the depreciation rate of natural capital and ϑ is the elasticity of output with respect to (normalized) natural capital $N_c(t)$

"*The static-equilibrium type of economic theory which is now so well developed is plainly inadequate for an industry in which the indefinite maintenance of a steady rate of production is a physical impossibility, and which is therefore bound to decline*" (Hotteling, 1931, page 138-139)

Accounting for environment... changes the definition of economic growth

Climate risk modeling

Inter-temporal utility functions

Preferences modeling (Ramsey model)

- ρ is the discount rate (time preference)
- $c(t)$ is the consumption per capita and u is the CRRA utility function:

$$u(c(t)) = \begin{cases} \dfrac{1}{1-\theta} c(t)^{1-\theta} & \text{if } \theta > 0, \quad \theta \neq 1 \\ \ln c(t) & \text{if } \theta = 1 \end{cases}$$

  where θ is the risk aversion parameter
- Maximization of the welfare function:

$$\int_t^\infty e^{-\rho t} u(c(t)) \, \mathrm{d}t$$

Climate risk modeling

The discounting issue

Does the golden rule of saving rates hold in a Keynesian approach with discounted maximization of consumption?

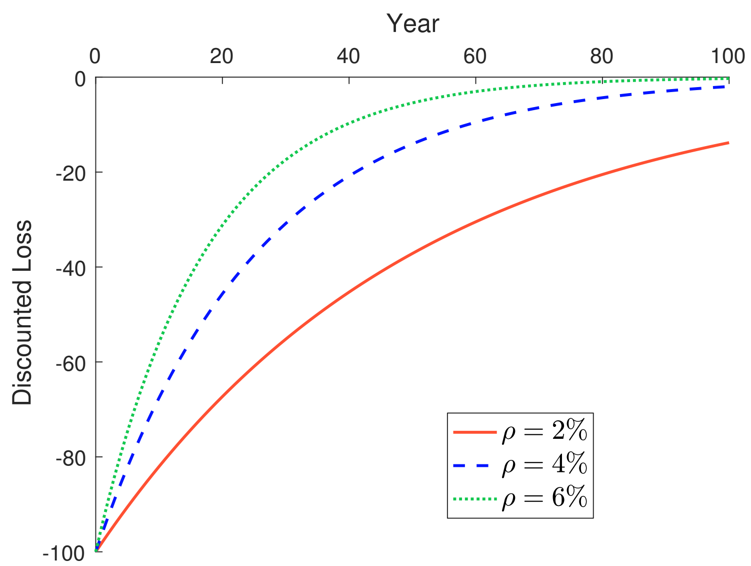


Figure 78: Discounted value of $100 loss

- *"There is still time to avoid the worst impacts of climate change, if we take strong action now"* (Stern, 2007)
- *"I got it wrong on climate change – it's far, far worse"* (Stern, 2013)

The value of a loss in 100 years almost disappears... while it is only the next generation!

Climate risk modeling

Does consumption maximization make sense?

How many planets do we need?

To achieve the current levels of consumption for the world population, we need:

- US: 5 planets
- France: 3 planets
- India: 0.6 planet

Source: Global Footprint Network, `http://www.footprintcalculator.org`

Climate risk modeling

Fairness between generations

Keynes

"In the long run, we are all dead"

John Maynard Keynes[a], *A Tract on Monetary Reform*, 1923.

[a] *"Men will not always die quietly"*, *The Economic Consequences of the Peace*, 1919.

Carney

"The Tragedy of the Horizon"

Mark Carney, Chairman of the Financial Stability Board, 2015

⇒ Back to the Golden Rule and the Fable for Growthmen...

Integrated assessment model (IAM)

Definition

Main categories

- **Optimization models**
  The inputs of these models are parameters and assumptions about the structure of the relationships between variables. The outputs provided by optimization process are scenarios depending on a set of constraints
- **Evaluation models**
  Based on exogenous scenarios, the outputs provide results from partial equilibriums between variables

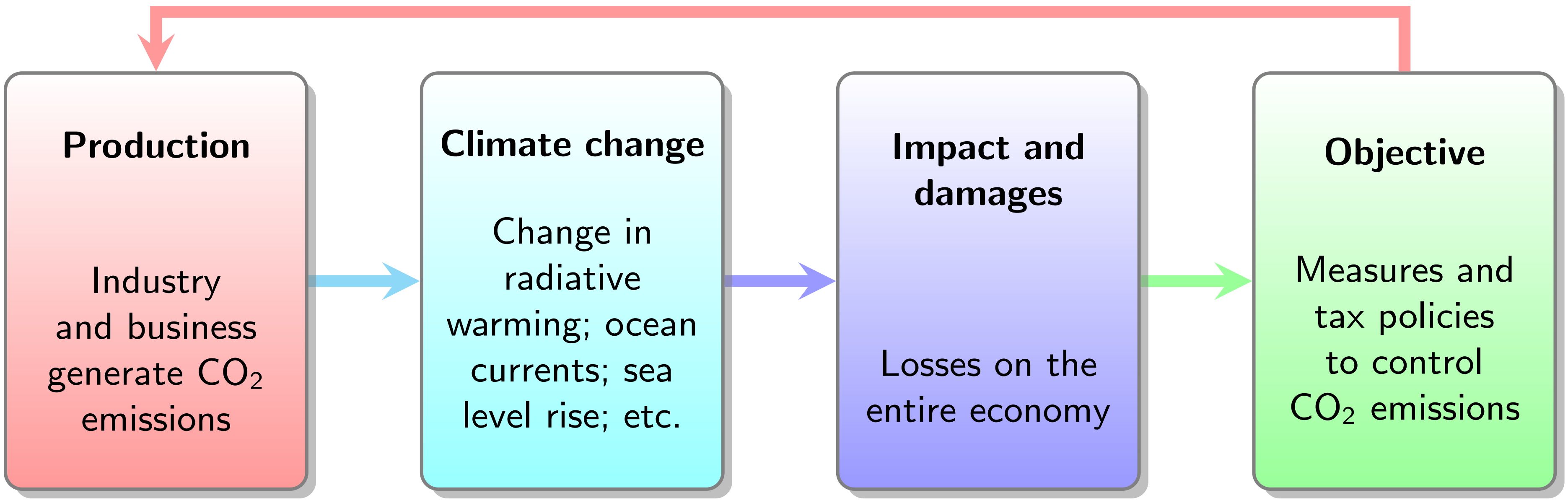
Three main components of IAMs

1. Economic growth relationships
2. Dynamics of climate emissions
3. Objective function

Integrated assessment model (IAM)

Modeling framework

Figure 79: Economic models of climate risk



Integrated assessment model (IAM)

Modeling framework

1. Economic module
    1. Production function $\Longrightarrow$ GDP
    2. Impact of the climate risk on GDP (damage losses, mitigation and adaptation costs)
    3. The climate loss function depends on the temperature
2. Climate module
    1. Dynamics of GHG emissions
    2. Modeling of Atmospheric and lower ocean temperatures
3. Optimal control problem
    1. Maximization of the utility function
    2. We can test many variants

Integrated assessment model (IAM)

Modeling framework

The most famous IAM is the **Dynamic Integrated model of Climate and the Economy** (or DICE) developed by Nordhaus[21] (1993)

The RICE model (Regional Integrated Climate-Economy model) is a variant of the DICE model

[21] 2018 Nobel Laureate

Integrated assessment model (IAM)

Production and output

- The **gross output** is equal to:

$$Y(t) = A_{\mathrm{TFP}}(t)\, K(t)^{\alpha}\, L(t)^{1-\alpha}$$

where:

$$\begin{cases} A_{\mathrm{TFP}}(t) = (1 + g_A(t))\, A_{\mathrm{TFP}}(t-1) \\ K(t) = (1 - \delta_K) K(t-1) + I(t) \\ L(t) = (1 + g_L(t))\, L(t-1) \end{cases}$$

- Climate change impacts the **net output**:

$$Q(t) = \Omega_{\mathrm{Climate}}(t)\, Y(t)$$

- We also have $Q(t) = C(t) + I(t)$ and $C(t) = (1 - s(t))\, Q(t)$

Integrated assessment model (IAM)

The loss (or damage) function

- The loss function is given by:

$$\Omega_{\text{Climate}}(t) = \Omega_D \cdot \Omega_\Lambda = \frac{1}{1 + D(t)} \cdot (1 - \mathit{\Lambda}(t))$$

where $D(t)$ and $\mathit{\Lambda}(t)$ measure climate damages[22] and abatement costs[23]

- Climate damages are assumed to be quadratic:

$$D(t) = a_1 \mathcal{T}_{\text{AT}}(t) + a_2 \mathcal{T}_{\text{AT}}(t)^2$$

where $\mathcal{T}_{AT}(t)$ is the atmospheric temperature, while abatement costs depend on the control rate $\mu(t)$:

$$\Lambda(t) = b_1 \mu(t)^{b_2}$$

[22] The climate damage coefficient $\Omega_D(t) = (1 + D(t))^{-1}$ represents the fraction of GDP loss because of the temperature increase

[23] It includes costs of reduction of greenhouse gases emission, abatement and mitigation costs

Integrated assessment model (IAM)

GHG emissions, concentrations and radiative forcing

- The total emission of green house gases $\mathcal{E}(t)$ is given by:

$$\mathcal{E}(t) = (1 - \mu(t))\,\sigma(t)\,Y(t) + \mathcal{E}_{\mathrm{Land}}(t)$$

  where mitigation policies are translated by the control rate $\mu(t)$, $\mathcal{E}_{\mathrm{Land}}(t)$ represents exogenous land-use emissions and $\sigma(t)$ is the uncontrolled ratio of green house gases emissions to output

- The evolution of the GHG concentration $\mathcal{C} = (\mathcal{C}_{\mathrm{AT}}, \mathcal{C}_{\mathrm{UP}}, \mathcal{C}_{\mathrm{LO}})$ is given by:

$$\mathcal{C}(t) = \Phi_{\mathcal{C},\Delta}\mathcal{C}(t-1) + B_{\mathcal{C},\Delta}\mathcal{E}(t)$$

- The increase of radiative forcing $\mathcal{F}_{\mathrm{RAD}}(t)$ depends on the GHG concentration in the atmosphere:

$$\mathcal{F}_{\mathrm{RAD}}(t) = \eta \ln_2\left(\frac{\mathcal{C}_{\mathrm{AT}}(t)}{\mathcal{C}_{\mathrm{AT}}(1750)}\right) + \mathcal{F}_{\mathrm{EX}}(t)$$

Integrated assessment model (IAM)

Temperatures

Atmospheric and lower ocean temperatures are given by:

$$\begin{aligned} C_{\mathrm{AT}} \frac{\mathrm{d}\mathcal{T}_{\mathrm{AT}}(t)}{\mathrm{d}t} &= \mathcal{F}_{\mathrm{RAD}}(t) - \lambda \mathcal{T}_{\mathrm{AT}}(t) - \gamma(\mathcal{T}_{\mathrm{LO}}(t) - \mathcal{T}_{\mathrm{AT}}(t)) \\ C_{\mathrm{LO}} \frac{\mathrm{d}\mathcal{T}_{\mathrm{LO}}(t)}{\mathrm{d}t} &= \gamma(\mathcal{T}_{\mathrm{LO}}(t) - \mathcal{T}_{\mathrm{AT}}(t)) \end{aligned}$$

where γ is the heat exchange coefficient and λ is the climate feedback parameter.

Integrated assessment model (IAM)

The optimal control problem

Simplified version of the DICE model (Nordhaus, 1993)

$$\{\mu^\star(t), s^\star(t)\} = \arg\max \sum_{t=0}^{T} \frac{u(c(t), L(t))}{(1+\rho)^t}$$

$$\text{s.t.} \quad \begin{cases} Y(t) = A_{\mathrm{TFP}}(t) K(t)^\alpha L(t)^{1-\alpha} \\ A_{\mathrm{TFP}}(t) = (1 + g_A(t)) A_{\mathrm{TFP}}(t-1) \\ K(t) = (1-\delta_K) K(t-1) + I(t) \\ L(t) = (1 + g_L(t)) L(t-1) \\ Q(t) = \Omega_{\mathrm{C}\lim\mathrm{ate}}(t) Y(t) \\ C(t) = (1 - s(t)) Q(t) \\ \mathcal{E}(t) = (1 - \mu(t)) \sigma(t) Y(t) + \mathcal{E}_{\mathrm{Land}}(t) \\ \mathcal{C}(t) = \Phi_{\mathcal{C},\Delta} \mathcal{C}(t-1) + B_{\mathcal{C},\Delta} \mathcal{E}(t) \\ \mathcal{F}_{\mathrm{RAD}}(t) = \eta \log_2 \left(\frac{\mathcal{C}_{\mathrm{AT}}(t)}{\mathcal{C}_{\mathrm{AT}}(1750)} \right) + \mathcal{F}_{\mathrm{EX}}(t) \\ \mathcal{T}(t) = \Phi_{\mathcal{T},\Delta} \mathcal{T}(t-1) + B_{\mathcal{T},\Delta} \mathcal{F}_{\mathrm{RAD}}(t) \end{cases}$$

Integrated assessment model (IAM)

Scenario analysis

The process of building scenarios is the same in every model

1. Choice of the structure
   - Optimization or evaluation?
   - Optimization function?
   - Complexity or simplicity?
2. Calibration
   - Choice for the discount rate (Nordhaus vs Stern)
   - Calibration of energy prices and substitution (etc.)
3. Applications
   - Compare baseline scenario of the different models
   - Compute the 2°C scenario, the optimal welfare scenario, etc.

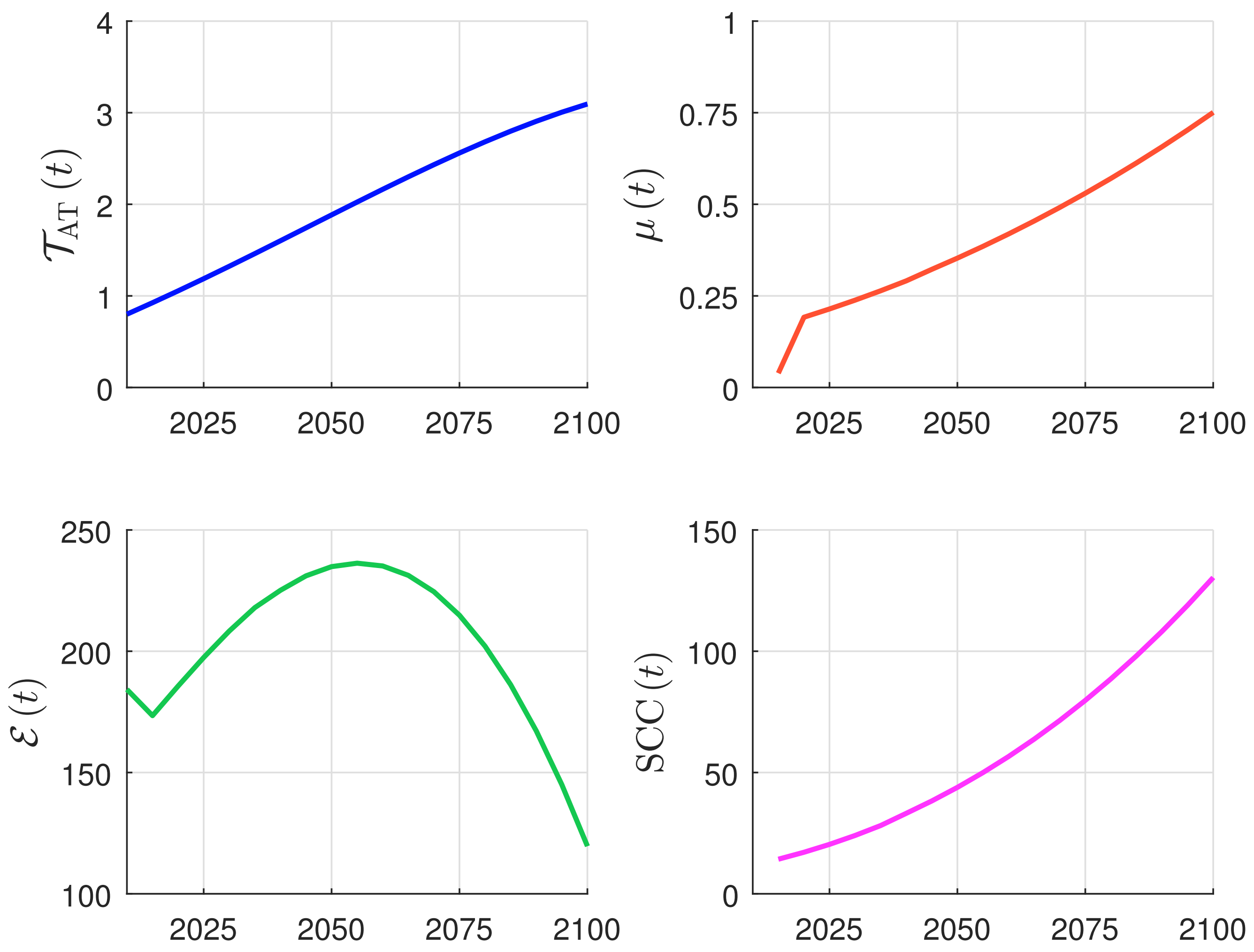
Integrated assessment model (IAM)

Important variables

- $\mathcal{T}_{\mathrm{AT}}(t)$ — Atmospheric temperature
- $\mu(t)$ — Control rate (mitigation policies)
- $\mathcal{E}(t)$ — Total emissions of GHG
- $\mathrm{SCC}(t)$ — Social cost of carbon

Integrated assessment model (IAM)

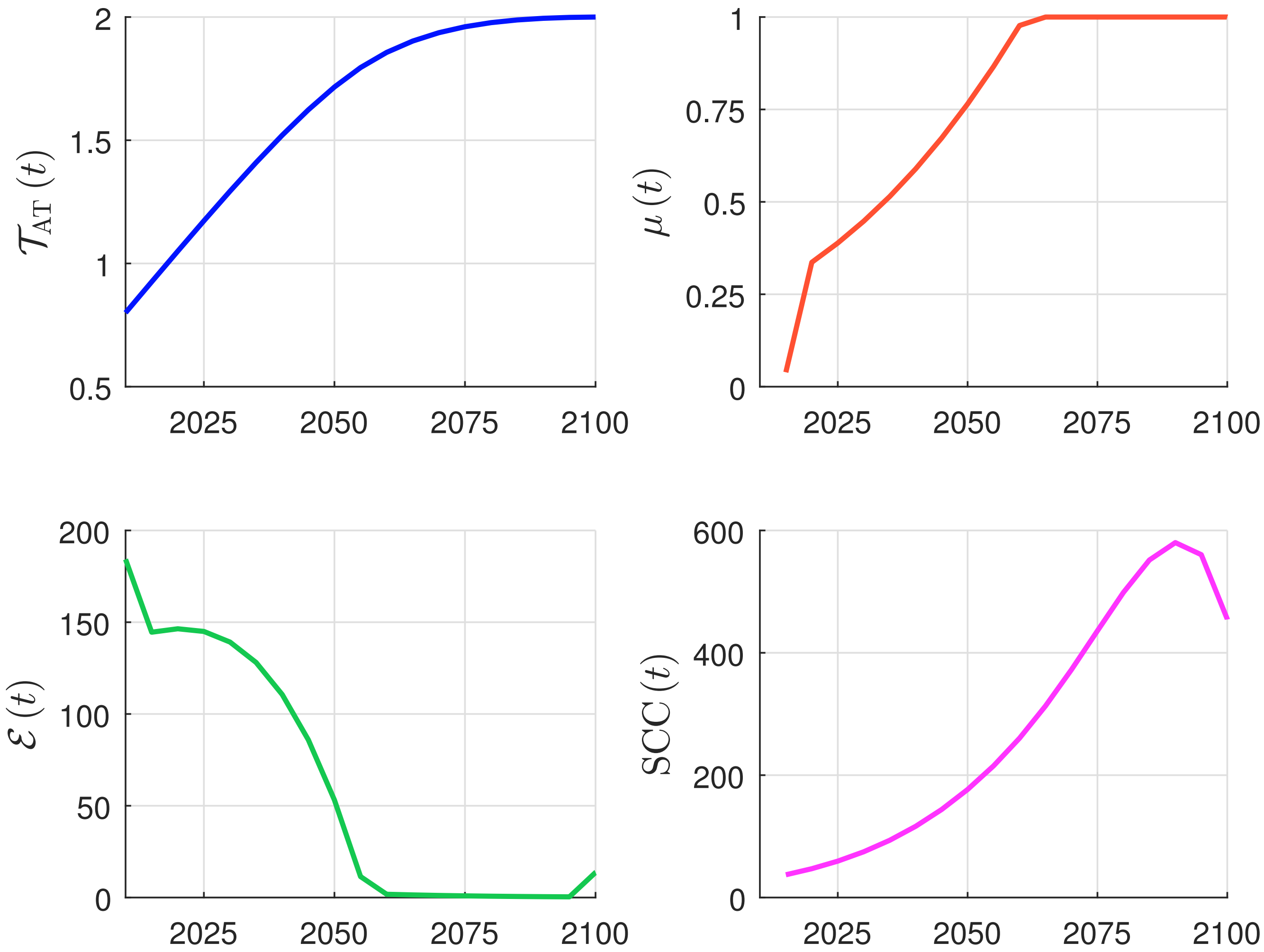
2013 DICE optimal welfare scenario



Source: Le Guenedal (2019)

Integrated assessment model (IAM)

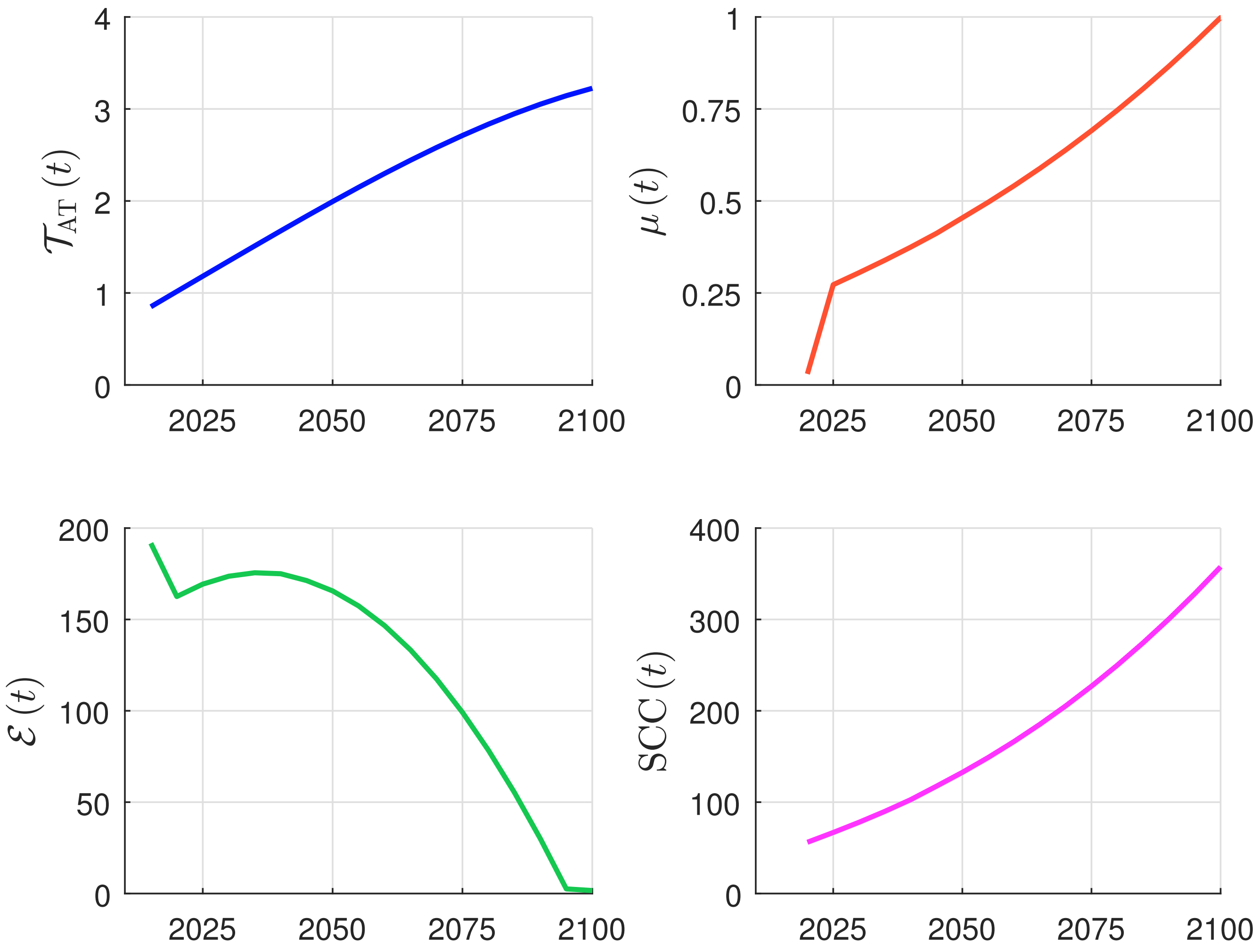
2013 DICE 2°C scenario



Source: Le Guenedal (2019)

Integrated assessment model (IAM)

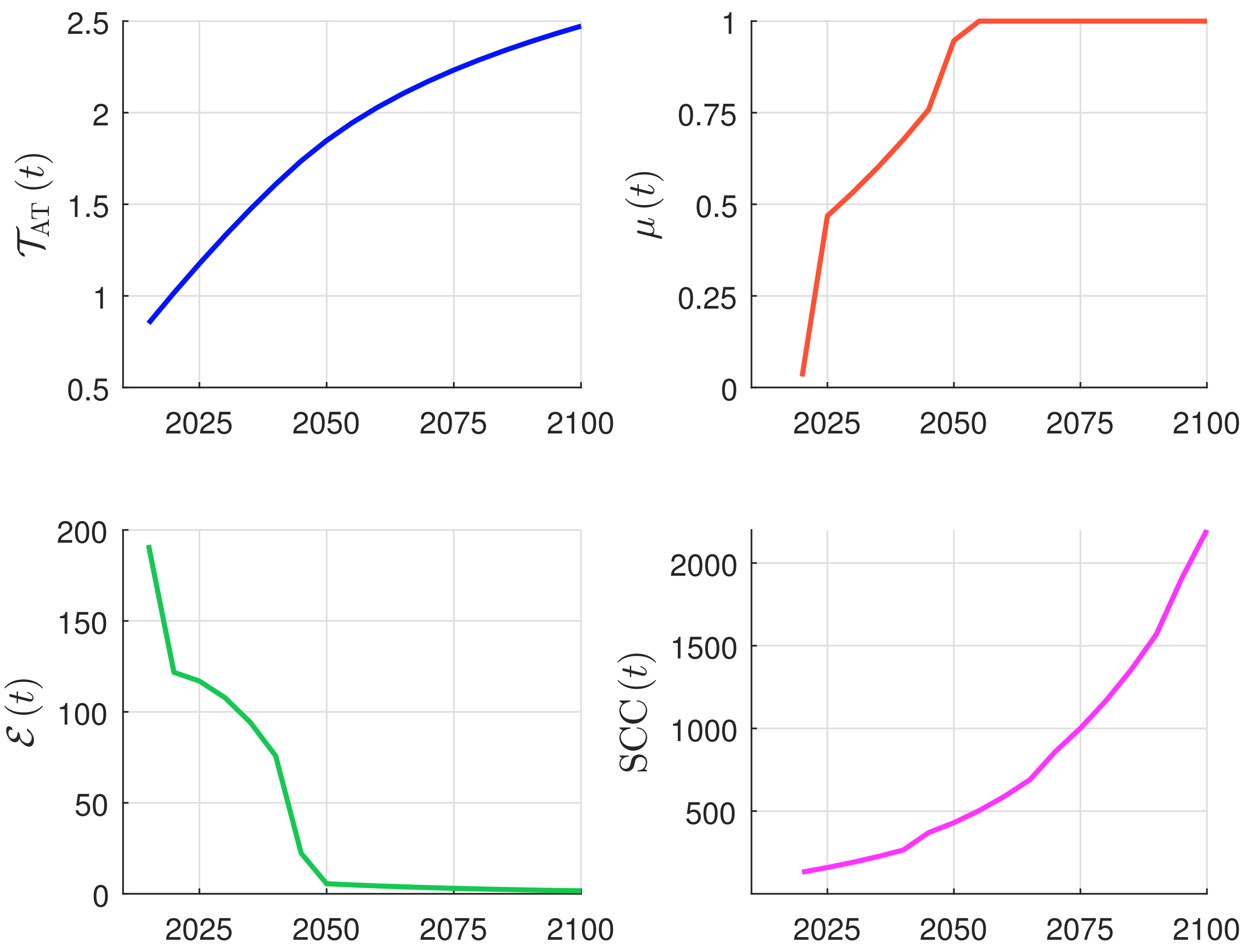
2016 DICE optimal welfare scenario



Source: Le Guenedal (2019)

Integrated assessment model (IAM)

2016 DICE 2°C scenario



Source: Le Guenedal (2019)

Integrated assessment model (IAM)

The tragedy of the horizon

Achieving the 2°C scenario

- In 2013, the DICE model suggested to reduce drastically CO_2 emissions...
- Since 2016, **the 2°C trajectory is no longer feasible!** (minimum ≈ 2.6°C)
- For many models, we now have:

$$\mathbb{P}\left(\Delta T > 2^{\circ} C\right) > 95\%$$

Integrated assessment model (IAM)

Malthusianism and climate risk

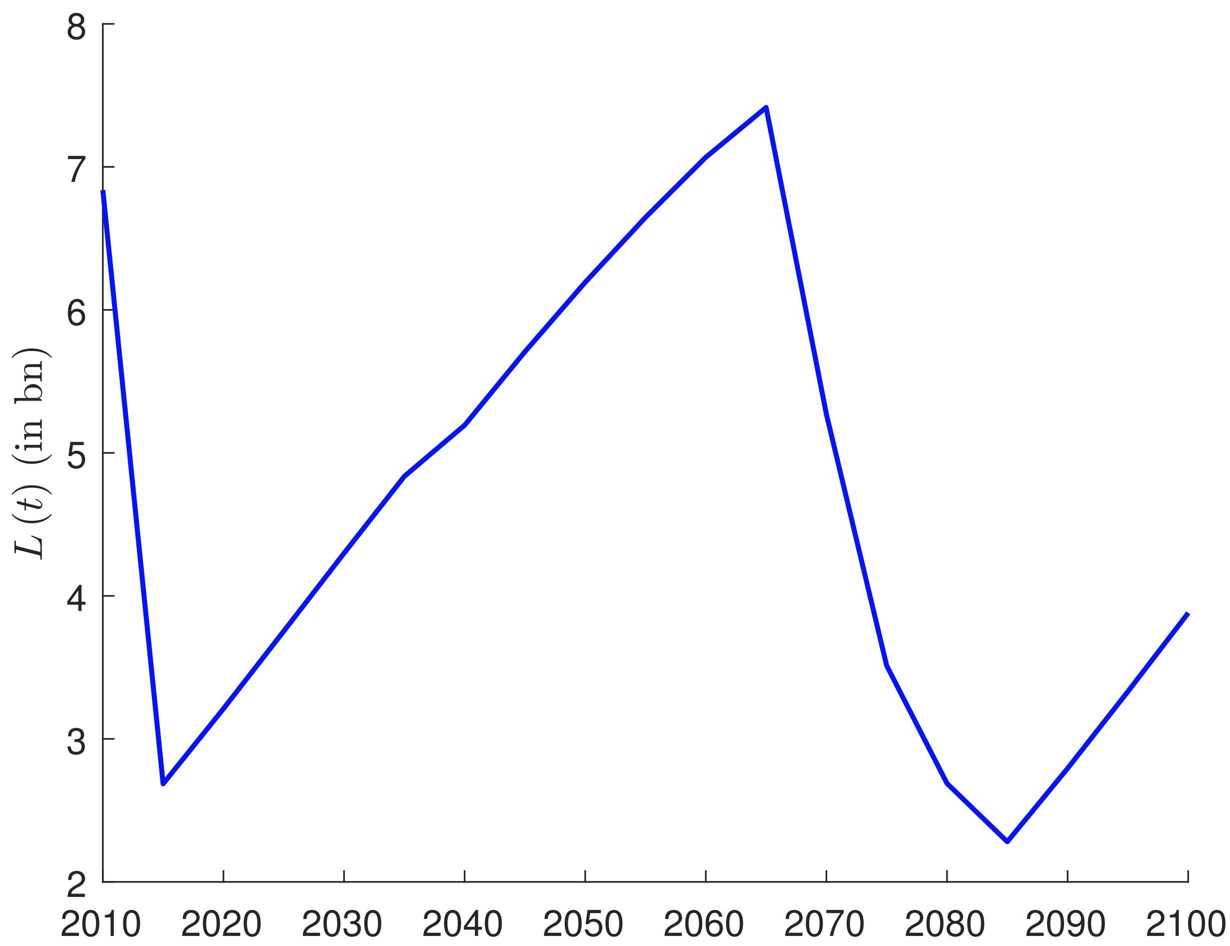


Figure 80: Optimal control on population growth rate (2°C scenario)

Integrated assessment model (IAM)

Social cost of carbon (SCC)

"This concept represents the economic cost caused by an additional ton of carbon dioxide emissions (or more succinctly carbon) or its equivalent. [...] In the language of mathematical programming, the SCC is the shadow price of carbon emissions along a reference path of output, emissions, and climate change" (Nordhaus, 2011).

Mathematical definition

We have:

$$\mathrm{SCC}(t) = \frac{\partial W^{\star} / \partial \mathcal{E}(t)}{\partial W^{\star} / \partial C(t)} = \frac{\partial C(t)}{\partial \mathcal{E}(t)}$$

Integrated assessment model (IAM)

Debate around the social cost of carbon

We have:

- \$266/tCO_2 for Stern (2007)
- \$57/tCO_2 for Golosov *et al.* (2014)
- \$31.2/tCO_2 for Nordhaus (2018) in the case of optimal welfare
- \$229/tCO_2 for Nordhaus (2018) in the case of the 2.5°C scenario
- \$125/tCO_2 for Daniel *et al.* (2018)

Integrated assessment model (IAM)

Limits of IAMs

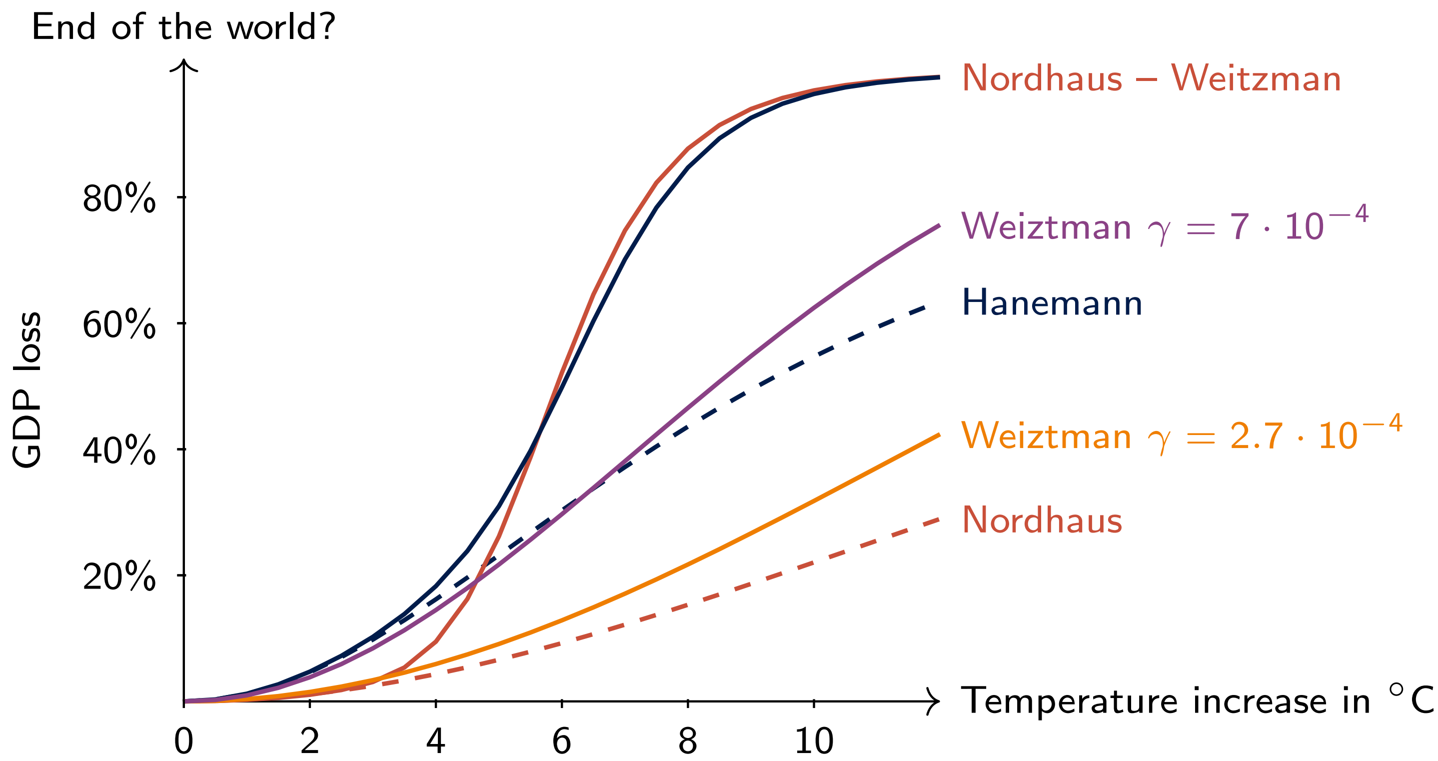


Figure 81: Damage functions

$\Rightarrow$ There is high uncertainty above 2°C and **financial models cannot be based on damage functions**

Integrated assessment model (IAM)

Limits of IAMs

- Financial models do not account for portfolio contribution to the technical change (**adaptation/mitigation**)
- The direct exposure to an **optimal tax** (regulation risk) may be approached by using optimization models of policy makers. However, each model leads to a different carbon price...
- Interconnectedness and systemic risks
- First round losses $\neq$ second round losses
- Stranded assets

Integrated assessment model (IAM)

- AIM ________________ RCP 6.0
- DICE/RICE
- FUND
- GCAM
- IMACLIM (CIRED)
- IMAGE ________________ RCP 2.6
- MESSAGE ________________ RCP 8.5
- MiniCAM ________________ RCP 4.5
- PAGE
- REMIND
- RESPONSE (CIRED)
- WITCH

Climate risk and inequalities

Three types of inequalities

- Spatial (or regional) inequalities
- Social (or intra-generation) inequalities
- Time (or inter-generation) inequalities

$\Rightarrow$ These issues are highly related to liability risks:

> *"[...] liability risks stemming from parties who have suffered loss from the effects of climate change seeking compensation from those they hold responsible" (Mark Carney, 2018)*

- Regional inequalities $\Rightarrow$ lack of cooperation between countries (e.g., Glasgow COP 26)
- Social inequalities $\Rightarrow$ climate action postponing (e.g., carbon tax in France)

Regional inequalities

The **R**egional **I**ntegrated model of **C**limate and the **E**conomy (RICE) model is a sub-regional neoclassical climate economy model (Nordhaus and Yang, 1996)

$\Rightarrow$ Sub-regional problem of welfare:

- Each region of the world has a different utility functions
- The big issue is how the most developed regions can finance the transition to a low-carbon economy of the less developed regions

Both spacial and time (inter-generation) inequalities

Social inequalities

The **N**ested **I**nequalities **C**limate-**E**conomy (NICE) model integrates distributional differences of income (Dennig *et al.*, 2015)

> *"[...] If the distribution of damage is less skewed to high income than the distribution of consumption, then weak or no climate policy will result in sufficiently large damages on the lower economic strata to eventually stop their welfare levels from improving, and instead cause them to decline" (Dennig et al., 2015)*

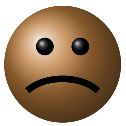
Both social (intra-generation) and time (inter-generation) inequalities

Climate risk measurement

- Climate risk = risk factor for long-term investors, because of its impacts on asset prices
- Managing climate risk in a portfolio first requires to measure it
- We face two dimensions that are highly related: physical risk and transition risk

Physical risk

- More an operational risk than a business risk?
- Measuring physical risk is a difficult task
- Strong impact on real estate & insurance sectors
- Low impact on stock prices?



Transition risk

- A business risk
- Measuring transition risk is a difficult task
- Impact on many sectors (energy, materials, industrials, utilities, etc.)
- High impact on stock prices?

Carbon footprint

- Carbon footprint = generic term used to define the total greenhouse gas (GHG) emissions
- Carbon footprint is measured in carbon dioxide equivalent (CO_2e)
- Carbon emissions cannot be compared fairly if the size of the two companies differs (carbon emissions $\Rightarrow$ carbon intensities)

Carbon emissions

The GHG Protocol corporate standard classifies a company's greenhouse gas emissions in three scopes:

- **Scope 1**: direct GHG emissions from all direct GHG emissions by the company
- **Scope 2**: indirect GHG emissions from the consumption of purchased energy (electricity, heat, steam, etc.)
- **Scope 3**: other indirect GHG emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions:
  - **Scope 3 upstream**: indirect emissions that come from the supply side (extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities not covered in Scope 2, outsourced activities, etc.)
  - **Scope 3 downstream**: indirect emissions associated with the product sold by the entity (use of the product, waste disposal, recycling, etc.)

Carbon emissions

$\mathcal{CE}_1$, $\mathcal{CE}_2$ and $\mathcal{CE}_3$ are expressed in tons of carbon dioxide equivalent or tCO_2e

Remark

Scopes 1 and 2 are mandatory to report, whereas scope 3 is voluntary (and harder to measure and monitor)

Carbon emissions

Data on GHG emissions:

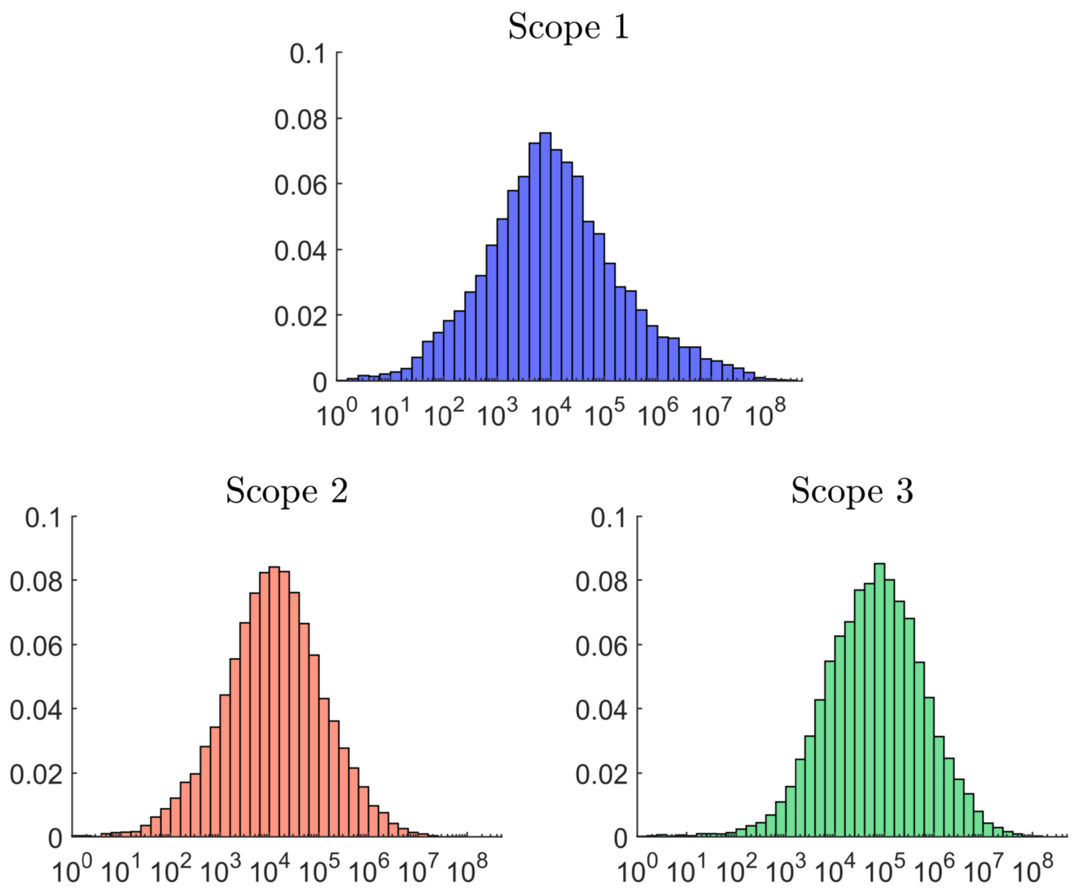
- Countries and regions: World Bank (`data.worldbank.org/topic/climate-change`), Climate Watch Data (`www.climatewatchdata.org/ghg-emissions`), Global Carbon Project (`www.globalcarbonproject.org`), etc.
- Corporates:
  1. CDP (Carbon Disclosure Project) = self-reported values of companies
  2. S&P Trucost data = CDP + estimated values

S&P Trucost data

- For the year 2019, we have about 15 700 corporations
- $\mathcal{CE}_1 = 15.57$ GtCO_2e, $\mathcal{CE}_2 = 2.45$ GtCO_2e and $\mathcal{CE}_3 = 10.17$ GtCO_2e
- $\mathcal{CE}_1 + \mathcal{CE}_2 + \mathcal{CE}_3 = 28.2$ GtCO_2e ($\geq 75\%$ of the 36 GtCO_2e global emissions)

Carbon emissions

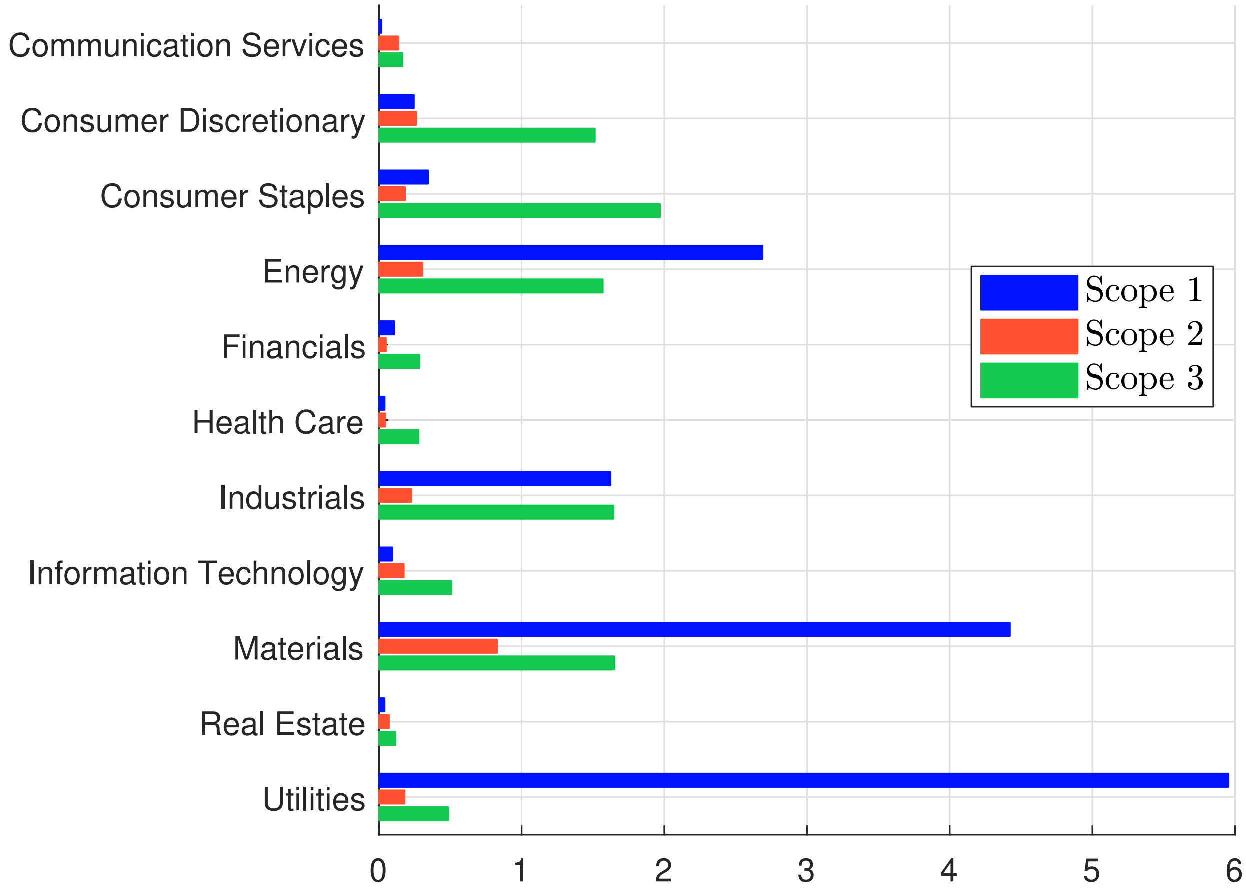
Figure 82: Histogram of carbon emission (log scale, tCO_2e)



Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Carbon emissions

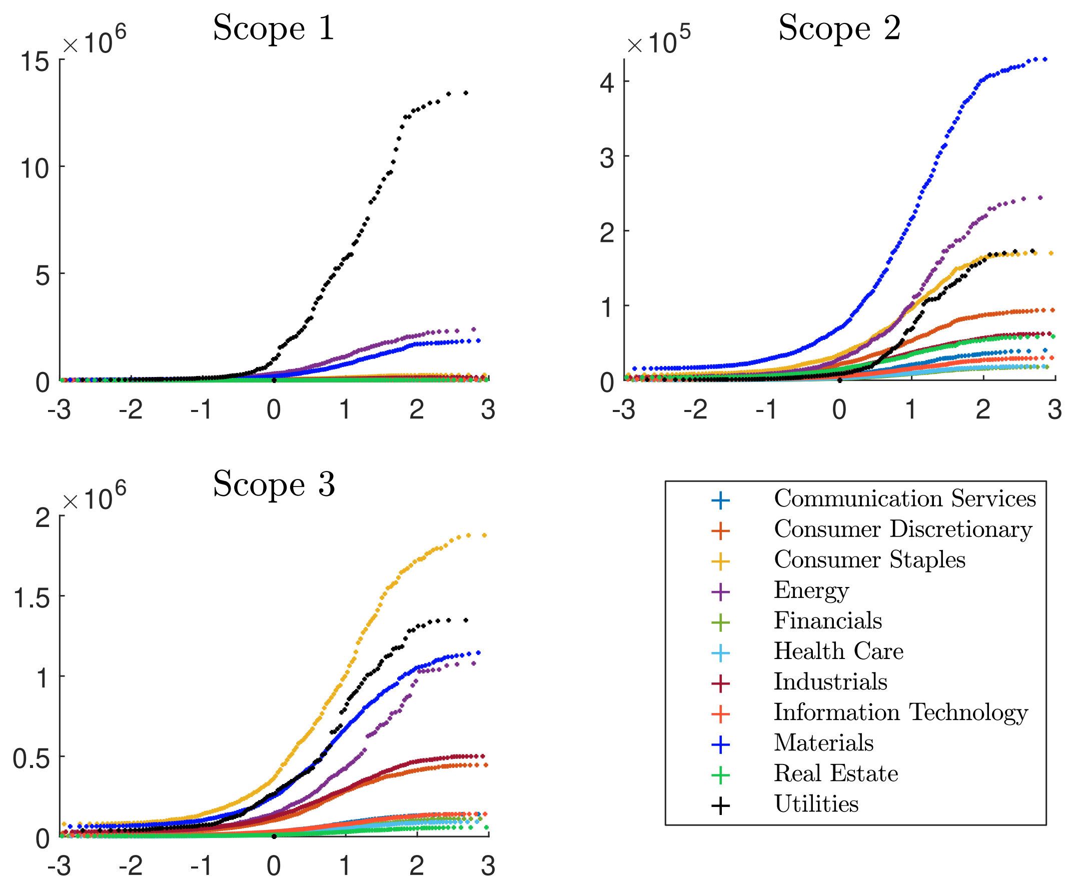
Figure 83: Total absolute scopes per GICS sector in $GtCO_2e$



Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Carbon emissions

Figure 84: QQ-plot of carbon scopes per GICS sector in $MtCO_2e$



Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Carbon emissions

Table 43: Scope 1 + 2 vs. scope 3

Sector	Breakdown (in %)					Multiplier
	$\mathcal{SC}_1$	$\mathcal{SC}_2$	$\mathcal{SC}_3$	$\mathcal{SC}_{1+2}$	$\mathcal{SC}_{1+2+3}$	$\dfrac{\mathcal{SC}_3}{\mathcal{SC}_{1+2}}$
Communication Services	0.11	5.52	1.60	0.84	1.12	1.07
Consumer Discretionary	1.57	10.64	14.88	2.81	7.16	2.99
Consumer Staples	2.21	7.46	19.37	2.92	8.85	3.74
Energy	17.26	12.39	15.42	16.60	16.18	0.52
Financials	0.69	2.00	2.78	0.87	1.55	1.81
Health Care	0.26	1.79	2.71	0.47	1.28	3.29
Industrials	10.42	9.20	16.15	10.25	12.38	0.89
Information Technology	0.60	7.11	4.98	1.48	2.74	1.89
Materials	28.40	33.76	16.21	29.13	24.47	0.31
Real Estate	0.25	2.87	1.12	0.61	0.79	1.04
Utilities	38.23	7.28	4.77	34.02	23.47	0.08

Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Considering or not scope 3 emissions gives two different pictures!

Carbon intensity

Definition

The carbon intensity of company i with respect to scope j is a normalization of the carbon emissions:

$$\mathcal{CI}_{i,j} = \frac{\mathcal{CE}_{i,j}}{Y_i}$$

where:

- $\mathcal{CE}_{i,j}$ is the company's absolute scope j emissions
- Y_i is an output indicator measuring its activity

Carbon intensity

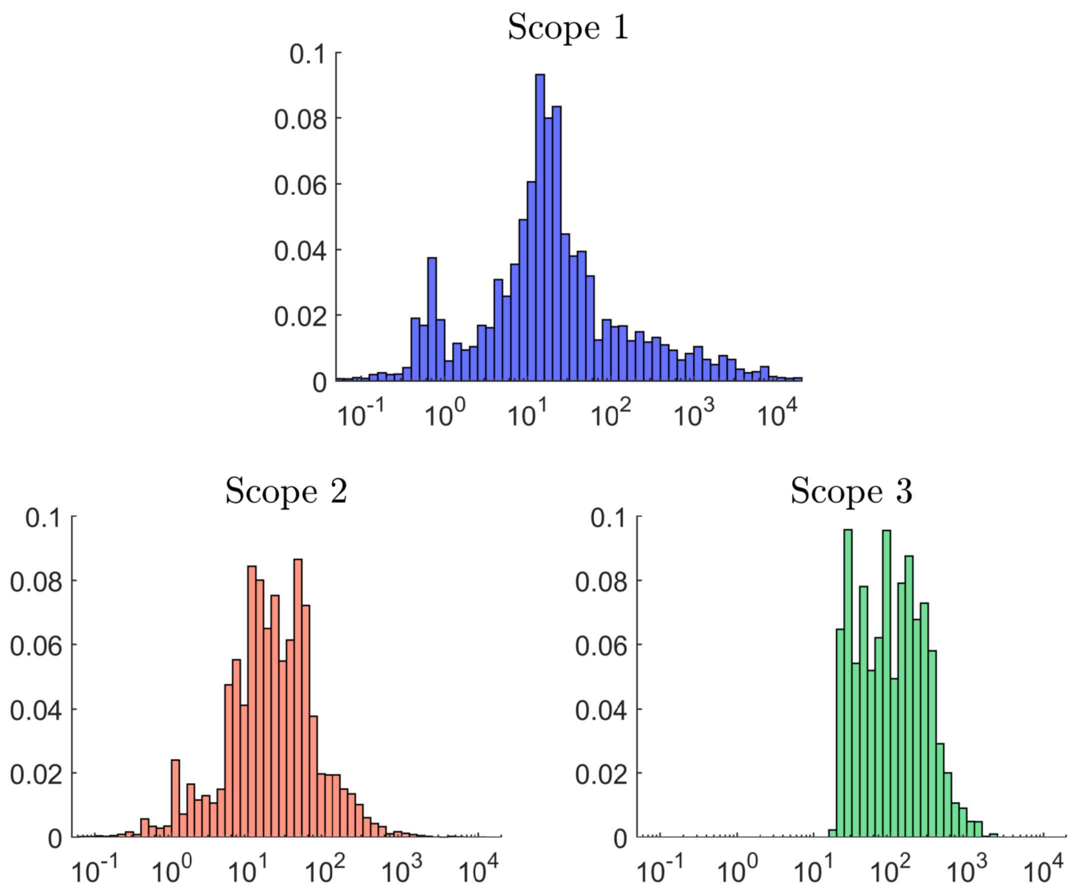
Two main approaches:

1. **Generic** carbon intensity per $
   1. Revenue: $CO_2e/\$$
   2. Enterprise value including cash (EVIC): $CO_2e/\$$
2. **Physical** carbon intensity per production unit
   1. Transport sector (aviation): CO_2e/RPK (revenue passenger kilometers)
   2. Transport sector (shipping): CO_2e/RTK (revenue ton kilometers)
   3. Industry (cement): CO_2e/t cement (ton of cement)
   4. Industry (steel): CO_2e/t steel (ton of steel)
   5. Electricity: CO_2e/MWh (megawatt hour)
   6. Buildings: CO_2e/SQM (square meter)

$\Rightarrow$ In what follows, we use the revenues to normalize carbon emissions

Carbon intensity

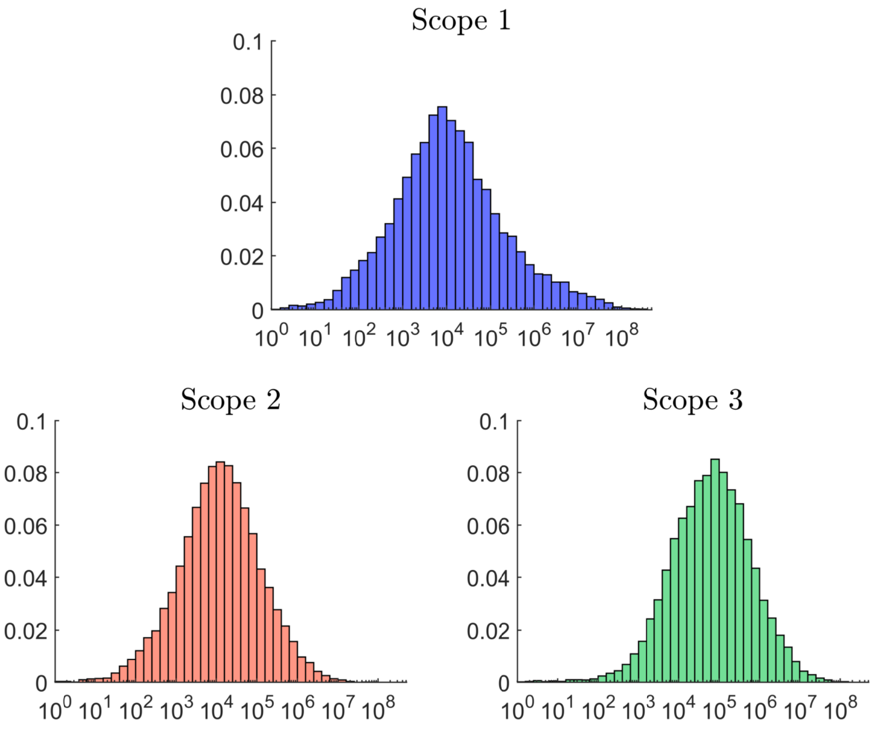
Figure 85: Histogram of carbon intensity (log scale, tCO_2e/\$ mn)



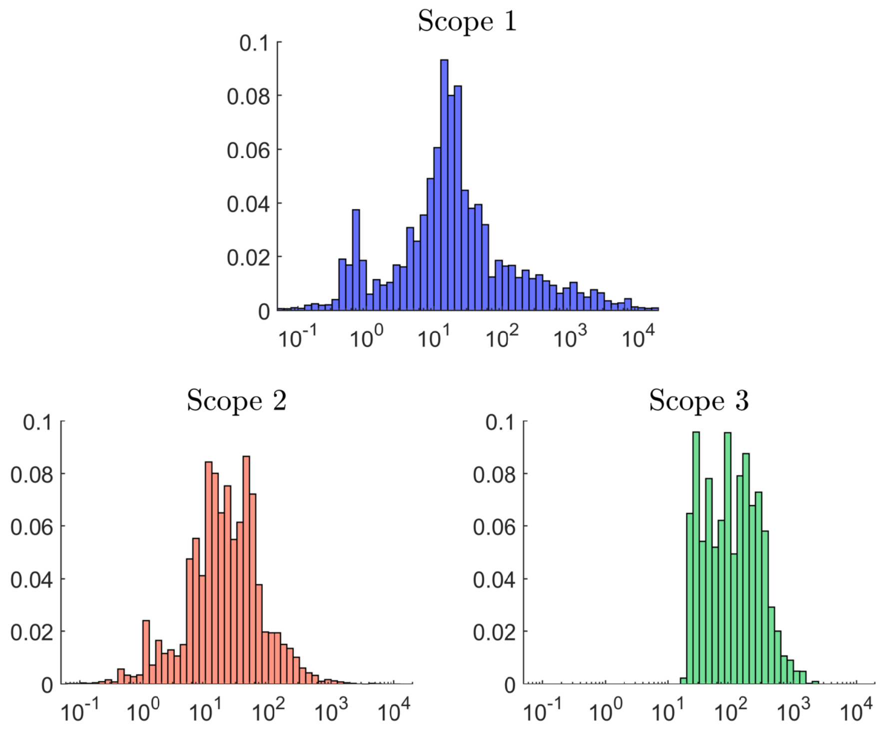
Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Carbon intensity

Carbon emissions



Carbon intensity



Carbon intensity

Table 44: Examples of carbon emissions and intensity

Company	Emission (in tCO_2e)			Revenue	Intensity (in tCO_2e/\$ mn)		
	Scope 1	Scope 2	Scope 3	(in \$ mn)	Scope 1	Scope 2	Scope 3
Alphabet	74 462	5 116 949	7 166 240	161 857	0.460	31.614	44.275
Amazon	5 760 000	5 500 000	20 054 722	280 522	20.533	19.606	71.491
Apple	50 463	862 127	27 618 943	260 174	0.194	3.314	106.156
BP	49 199 999	5 200 000	103 840 194	276 850	177.714	18.783	375.077
Danone	722 122	944 877	28 969 780	28 308	25.509	33.378	1023.365
Enel	69 981,891	5 365 386	8 726 973	86 610	808.016	61.949	100.762
Juventus	6 665	15 739	35 842	709	9.401	22.198	50.553
LVMH	67 613	262 609	11 853 749	60 083	1.125	4.371	197.291
Microsoft	113 414	3 556 553	5 977 488	125 843	0.901	28.262	47.500
Nestle	3 291 303	3 206 495	61 262 078	93 153	35.332	34.422	657.647
Netflix	38 481	145 443	1 900 283	20 156	1.909	7.216	94.277
Total	40 909 135	3 596 127	49 831 487	200 316	204.223	17.952	248.764
Volkswagen	4 494 066	5 973 894	65 335 372	282 817	15.890	21.123	231.016

Source: Trucost reporting year 2019.

Carbon intensity

Table 45: Statistics of carbon emissions and intensity

Scope	Emission (in $10^6 \cdot tCO_2e$)				Intensity (in $10^3 \cdot tCO_2e/\$$ mn)			
	Avg.	Med.	Q (95%)	Max.	Avg.	Med.	Q (95%)	Max.
1	0.992	0.010	2.28	587.1	0.277	0.016	1.14	207.4
2	0.156	0.012	0.53	99.1	0.053	0.021	0.19	11.9
3	0.648	0.067	2.50	137.5	0.170	0.099	0.51	2.0

Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Carbon intensity

Table 46: Rank correlation matrix (in %) of carbon metrics

	$\mathcal{CE}_1$	$\mathcal{CE}_2$	$\mathcal{CE}_3$	$\mathcal{CI}_1$	$\mathcal{CI}_2$	$\mathcal{CI}_3$
$\mathcal{CE}_1$	100.0					
$\mathcal{CE}_2$	78.1	100.0				
$\mathcal{CE}_3$	81.9	81.9	100.0			
$\mathcal{CI}_1$	70.3	32.8	32.0	100.0		
$\mathcal{CI}_2$	38.0	55.3	18.1	54.4	100.0	
$\mathcal{CI}_3$	55.5	36.6	55.6	66.6	44.7	100.0

Source: Trucost reporting year 2019 & Le Guenedal and Roncalli (2022).

Carbon intensity

Additivity property

Carbon intensity is additive when we consider a given issuer:

$$\begin{aligned}\mathcal{CI}_{i,1+2+3} &= \frac{\mathcal{CE}_{i,1} + \mathcal{CE}_{i,2} + \mathcal{CE}_{i,3}}{Y_i} \\ &= \mathcal{CI}_{i,1} + \mathcal{CI}_{i,2} + \mathcal{CI}_{i,3}\end{aligned}$$

Carbon intensity

The additivity property is not satisfied when we consider a set of issuers

- We consider a portfolio x invested in n assets. We have:

$$\mathcal{CE}_j(x) = \sum_{i=1}^{n} \frac{W_i}{\mathcal{MV}_i} \cdot \mathcal{CE}_{i,j} = \sum_{i=1}^{n} \varpi_i \cdot \mathcal{CE}_{i,j}$$

where $\mathcal{MV}_i$ is the market value of the company i, W_i is the dollar value invested in the company i and ϖ_i is the ownership ratio:

$$\varpi_i = \frac{W_i}{\mathcal{MV}_i}$$

- Let x_i be the weight of the company i. We have:

$$W_i = x_i \cdot W$$

where $W = \sum_{i=1}^{n} W_i$ is the dollar value of the portfolio

Carbon intensity

- We also have:

$$\varpi_i = \frac{W_i}{\mathcal{MV}_i} = \frac{x_i \cdot W}{\mathcal{MV}_i}$$

- We deduce that:

$$\mathcal{CE}_j\left(x\right) = W \cdot \left(\sum_{i=1}^{n} x_i \cdot \frac{\mathcal{CE}_{i,j}}{\mathcal{MV}_i} \right) = W \cdot \left(\sum_{i=1}^{n} x_i \cdot \mathcal{CI}_{i,j}^{\mathcal{MV}} \right)$$

where $\mathcal{CI}_{i,j}^{\mathcal{MV}}$ is the carbon intensity, where the normalization factor is the market value of the company:

$$\mathcal{CI}_{i,j}^{\mathcal{MV}} = \frac{\mathcal{CE}_{i,j}}{\mathcal{MV}_i}$$

- $\mathcal{CE}_j\left(x\right)$ is generally expressed generally in tCO2e per 1\$ mn invested ($W = \$10^6$)

Carbon intensity

- The weighted-average carbon intensity (WACI) is equal to:

$$\mathcal{CI}_j(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{CI}_{i,j}$$

$\Rightarrow$ The two equations are mutually satisfied $\Leftrightarrow Y_i \propto \mathcal{MV}_i$

Carbon intensity

- The exact value of the carbon intensity is:

$$\mathcal{CI}_j(x) = \frac{\mathcal{CE}_j(x)}{Y(x)} = \sum_{i=1}^{n} \omega_i \cdot \mathcal{CI}_{i,j}$$

where:

$$Y(x) = W \cdot \left(\sum_{i=1}^{n} x_i \cdot \frac{Y_i}{\mathcal{MV}_i} \right)$$

and:

$$\omega_i = \frac{x_i \cdot \dfrac{Y_i}{\mathcal{MV}_i}}{\sum_{k=1}^{n} x_k \cdot \dfrac{Y_k}{\mathcal{MV}_k}}$$

Carbon intensity

Example

- We assume that $\mathcal{CE}_{1,j} = 5 \times 10^6$, $Y_1 = 2 \times 10^5$, $\mathcal{MV}_1 = 10^7$, $\mathcal{CE}_{2,j} = 5 \times 10^7$, $Y_2 = 4 \times 10^6$ and $\mathcal{MV}_2 = 10^7$
- We deduce that $\mathcal{CI}_{1,j} = 25.0$ and $\mathcal{CI}_{2,j} = 12.5$
- We invest $W = \$10$ mn

We have:

$$\left\{ \begin{array}{l} \mathcal{CE}_j(x) = W \cdot \left(x_1 \cdot \dfrac{\mathcal{CE}_{1,j}}{\mathcal{MV}_1} + x_2 \cdot \dfrac{\mathcal{CE}_{2,j}}{\mathcal{MV}_2} \right) \\ Y(x) = W \cdot \left(x_1 \cdot \dfrac{Y_1}{\mathcal{MV}_1} + x_2 \cdot \dfrac{Y_2}{\mathcal{MV}_2} \right) \\ \mathcal{CI}_j(x) = x_1 \cdot \mathcal{CI}_{1,j} + x_2 \cdot \mathcal{CI}_{2,j} \end{array} \right.$$

Carbon intensity

Example

- We assume that $\mathcal{CE}_{1,j} = 5 \times 10^6$, $Y_1 = 2 \times 10^5$, $\mathcal{MV}_1 = 10^7$, $\mathcal{CE}_{2,j} = 5 \times 10^7$, $Y_2 = 4 \times 10^6$ and $\mathcal{MV}_2 = 10^7$
- We deduce that $\mathcal{CI}_{1,j} = 25.0$ and $\mathcal{CI}_{2,j} = 12.5$
- We invest $W = \$10$ mn

x_1	x_2	$\mathcal{CE}_j(x)$ (in 10^6)	$Y(x)$ (in 10^6)	$\frac{\mathcal{CE}_j(x)}{Y(x)}$	$\mathcal{CI}_j(x)$
0%	100%	50.00	4.00	12.50	12.50
10%	90%	45.50	3.62	12.57	13.75
20%	80%	41.00	3.24	12.65	15.00
30%	70%	36.50	2.86	12.76	16.25
50%	50%	27.50	2.10	13.10	18.75
70%	30%	18.50	1.34	13.81	21.25
80%	20%	14.00	0.96	14.58	22.50
90%	10%	9.50	0.58	16.38	23.75
100%	0%	5.00	0.20	25.00	25.00

The M&A puzzle

Example

- We assume that $\mathcal{CE}_{1,j} = 5 \times 10^6$, $Y_1 = 2 \times 10^5$, $\mathcal{MV}_1 = 10^7$, $\mathcal{CE}_{2,j} = 5 \times 10^7$, $Y_2 = 4 \times 10^6$ and $\mathcal{MV}_2 = 10^7$
- We deduce that $\mathcal{CI}_{1,j} = 25.0$ and $\mathcal{CI}_{2,j} = 12.5$
- We buy the two companies $\Rightarrow W = \$20$ mn, $x_1 = 50\%$ and $x_2 = 50\%$

W (in 10^6)	x_1	x_2	$\mathcal{CE}_j(x)$ (in 10^6)	$Y(x)$ (in 10^6)	$\dfrac{\mathcal{CE}_j(x)}{Y(x)}$	$\mathcal{CI}_j(x)$
10	0%	100%	50.00	4.00	12.50	12.50
10	100%	0%	5.00	0.20	25.00	25.00
20	50%	50%	55.00	4.20	13.10	18.75

Carbon transition pathway

Net Zero Carbon Emissions

- Carbon neutrality
- Reduction scenario
- Carbon trajectories
  - Carbon trend
  - Reduction targets
  - Specific NZE scenario
- Temperature tags

Carbon reduction scenario

- IPCC report urges action to drastically reduce carbon emissions to net zero by 2050
- The carbon reduction trajectory imposes a reduction of total emissions by at least 7% every year between 2019 and 2050
- International Energy Agency (IEA) NZE scenario
  - This scenario implies a 40.11% reduction of carbon emissions in 2030 and 61.84% in 2035
  - In 2050, gross emissions would be 1.94 $GtCO_2e$ offset by the carbon capture and storage (CCS) technology

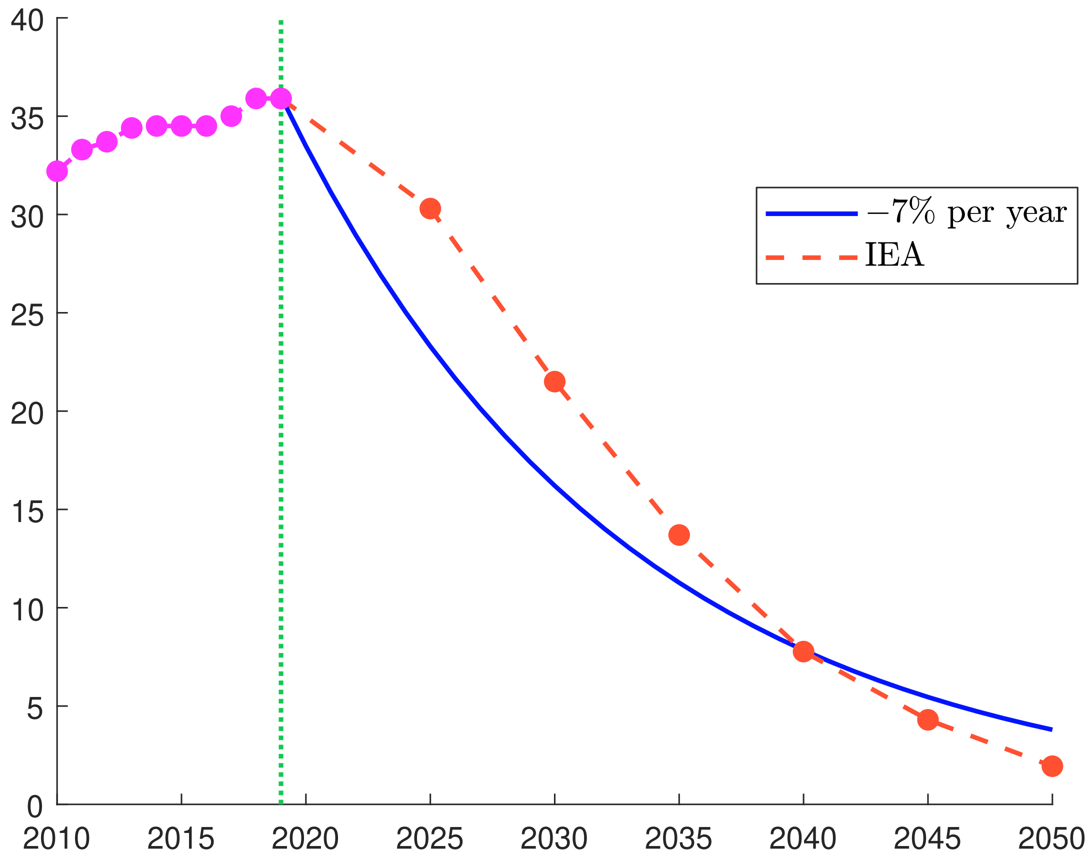
Table 47: IEA NZE scenario (in $GtCO_2e$)

Year	2019	2025	2030	2035	2040	2045	2050
Gross emission	35.90	30.30	21.50	13.70	7.77	4.30	1.94
CCS	0.00	−0.06	−0.32	−0.96	−1.46	−1.80	−1.94
Net emission	35.90	30.24	21.18	12.74	6.31	2.50	0.00
Reduction (in %)	0.00	15.60	40.11	61.84	78.36	88.02	94.60

Source: IEA (2021, Chapter 2, Figure 2.3, page 55).

Carbon reduction scenario

Figure 86: Two net zero emission scenarios



Source: IEA (2021) & Le Guenedal and Roncalli (2022).

Carbon trend

- We have:

$$\mathcal{CE}_i(t) = \beta_{i,0} + \beta_{i,1} t + u_i(t)$$

- The parameters $\beta_{i,0}$ and $\beta_{i,1}$ are estimated using the OLS method
- The carbon trajectory implied by the current trend is equal to:

$$\mathcal{CE}_i^{Trend}(t) := \widehat{\mathcal{CE}}_i(t) = \hat{\beta}_{i,0} + \hat{\beta}_{i,1} t$$

Carbon trend

Example

We consider the company **Λ** and the direct carbon emissions (scope 1) in $MtCO_2e$:

Year	2006	2007	2008	2009	2010	2011	2012
$\mathcal{CE}_{i,1}(t)$	57.80	58.46	57.90	55.13	51.63	46.34	47.09
Year	2013	2014	2015	2016	2017	2018	2019
$\mathcal{CE}_{i,1}(t)$	46.08	44.37	41.75	39.40	36.26	40.71	40.91

Source: Trucost reporting year 2019.

Carbon trend

- We have:

$$Y = \begin{pmatrix} 57.80 \\ 58.46 \\ \vdots \\ 40.71 \\ 40.91 \end{pmatrix} \quad \text{and} \quad X = \begin{pmatrix} 1 & 2006 \\ 1 & 2007 \\ \vdots & \vdots \\ 1 & 2018 \\ 1 & 2019 \end{pmatrix}$$

and:

$$\hat{\beta} = \left(X^\top X\right)^{-1} X^\top Y = \begin{pmatrix} 3479.77 \\ -1.7055 \end{pmatrix}$$

- We obtain $\hat{\beta}_0 = 3479.77$ and $\hat{\beta}_1 = -1.7055$. We deduce that:

$$\begin{aligned} \mathcal{CE}_{i,1}^{\mathrm{trend}}(t) &= 3479.77 - 1.7055 \cdot t \\ &= 3479.77 - 1.7055 \cdot (2019 + h) \\ &= 36.33 - 1.7055 \cdot h \end{aligned}$$

and $\mathcal{CE}_{i,1}^{\mathrm{trend}}(2020) = 34.62$, $\mathcal{CE}_{i,1}^{\mathrm{trend}}(2021) = 32.92$, $\mathcal{CE}_{i,1}^{\mathrm{trend}}(2030) = 17.57$, $\mathcal{CE}_{i,1}^{\mathrm{trend}}(2040) = 0.51$, etc.

Carbon targets

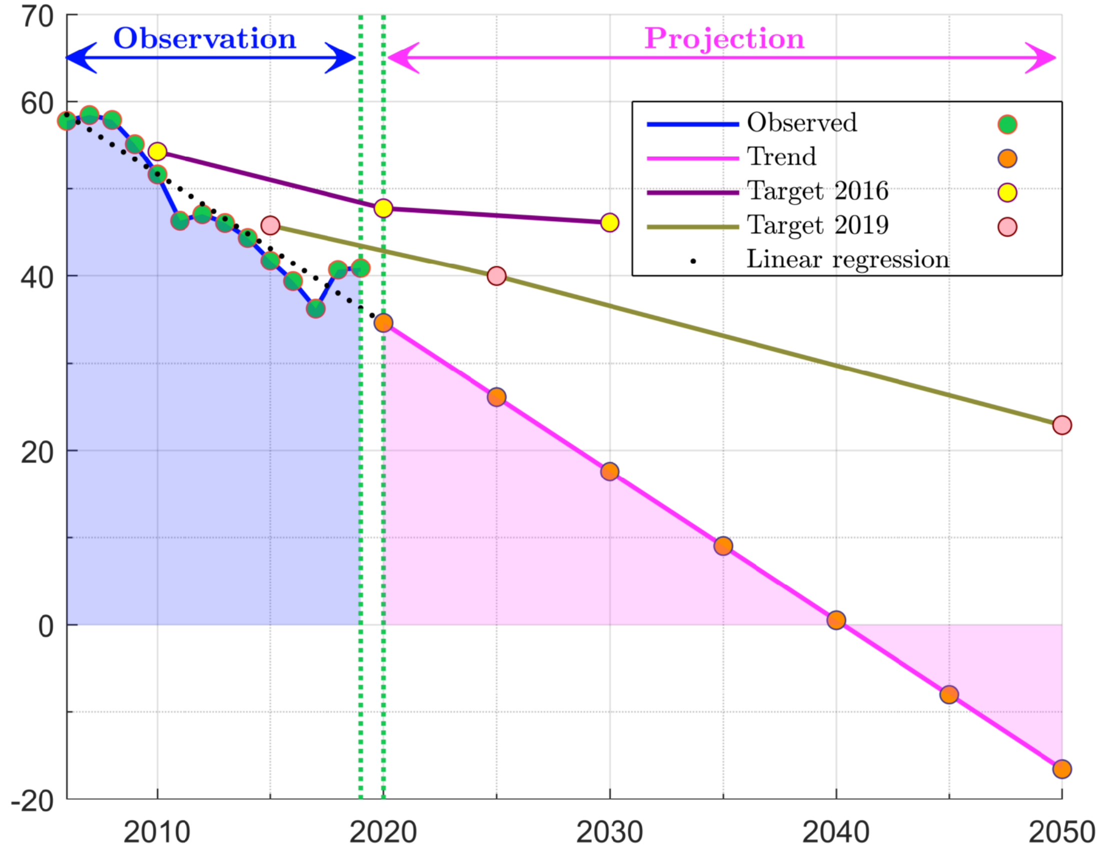
Corporate commitments/pledges

- Companies can directly disclose carbon targets $\mathcal{CE}_{i,j}^{\mathrm{target}}(t)$ at a given horizon date t for a given scope j
- CDP gathers information about reduction targets (base year, target year, target value, scope, percentage of the scope concerned, etc.)

- The company $\boldsymbol{\Lambda}$ has disclosed reduction targets in 2016 and 2019
- We observe that the 2019 targets are more ambitious than the 2016 targets

Carbon trajectories

Figure 87: Scope 1 trajectory of the company **Λ** (in $MtCO_2e$)



Source: Carbon Disclosure Project reporting year 2019 & Le Guenedal and Roncalli (2022).

Implied temperature

- Temperature tags are indicators assigned to companies by mixing various metrics
- Based on the carbon reduction required to achieve a climate scenario, and individual trajectories, it is possible to interpolate a temperature for each issuer
- Each provider has its own methodology:
  - Carbon Disclosure Project (CDP)
  - Iceberg Data Lab
  - Science Based Target initiative (SBTi)
  - Trucost

Implied temperature

Table 48: Global temperature changes in % (wrt year 2005)

Scenario	2010	2020	2030	2040	2050
$1.5^\circ\mathrm{C}$ (SSP2, RCP 1.9W/m^2)	+7.5%	17.1%	−28.6%	−63.9%	−87.3%
$1.8^\circ\mathrm{C}$ (SSP2, RCP 2.6W/m^2)	+8.1%	17.4%	−14.5%	−34.5%	−51.5%
$2.2^\circ\mathrm{C}$ (SSP2, RCP 3.4W/m^2)	+8.1%	19.9%	+8.2%	−5.8%	−20.6%
$3.0^\circ\mathrm{C}$ (SSP2, RCP 4.5W/m^2)	+8.1%	21.5%	+24.4%	+22.2%	+11.3%
$4.0^\circ\mathrm{C}$ (SSP2, RCP 6.0W/m^2)	+8.1%	22.2%	+33.6%	+42.7%	+45.9%
$5.0^\circ\mathrm{C}$ (SSP2, Baseline)	+8.1%	26.8%	+43.7%	+58.7%	+70.0%

Source: SSP Database (Shared Socioeconomic Pathways), Version 2.0.

If we would like to achieve a $1.8^\circ\mathrm{C}$ scenario, this implies reducing absolute carbon emissions with respect to year 2005 by 51.5%

Implied temperature

Table 49: Frequency of temperature ratings (in %)

Range	CDP Scope 1 + 2 + 3	CDP Short term	CDP Mid term	CDP Long term	Iceberg
$\mathcal{T} \leq 1.0°\mathrm{C}$	0.00	0.00	0.00	0.00	1.01
$1.0°\mathrm{C} < \mathcal{T} \leq 1.5°\mathrm{C}$	1.44	2.92	10.68	2.71	2.60
$1.5°\mathrm{C} < \mathcal{T} \leq 2.0°\mathrm{C}$	6.20	1.26	13.03	3.94	3.14
$2.0°\mathrm{C} < \mathcal{T} \leq 2.5°\mathrm{C}$	6.86	3.07	7.46	2.68	21.76
$2.5°\mathrm{C} < \mathcal{T} \leq 3.0°\mathrm{C}$	7.64	1.99	4.21	0.48	30.87
$3.0°\mathrm{C} < \mathcal{T} \leq 3.5°\mathrm{C}$	76.95	89.77	62.80	90.07	32.30
$3.5°\mathrm{C} < \mathcal{T} \leq 4.0°\mathrm{C}$	0.78	0.81	1.44	0.09	2.23
$4.0°\mathrm{C} < \mathcal{T} \leq 4.5°\mathrm{C}$	0.12	0.18	0.36	0.03	3.31
$4.5°\mathrm{C} < \mathcal{T} \leq 5.0°\mathrm{C}$	0.00	0.00	0.00	0.00	0.77
$\mathcal{T} = 3.2°\mathrm{C}$	52.09	88.50	61.39	89.95	0.01

Source: CDP Temperature Ratings Dataset, version 1.1, February 2021 & Iceberg Data Lab (2021).

Climate transition risk

Definition

- Transition risks arise from the sudden shift towards a low-carbon economy
- Such transitions could mean that some sectors of the economy face big shifts in asset values or higher costs of doing business

" It's not that policies stemming from deals like the Paris Climate Agreement are bad for our economy — in fact, the risk of delaying action altogether would be far worse. Rather, it's about the speed of transition to a greener economy — and how this affects certain sectors and financial stability" (Bank of England, 2021)

Climate transition risk

The previous approach assumes that
the **climate-related market risk** of a company
is measured by its **current carbon intensity**

...But the **market perception**
of the climate change may be different

Climate transition risk

Fundamental-based analysis

- Carbon footprint and pathway are measured by CO_2 emissions
- They are fundamental data

Market-based analysis

- Financial market's perception of the potentially reduced impact of climate policies' on securities issued by corporations
- These carbon risk metrics use market data
- How an increase in carbon prices and taxes influences the credit risk of the issuer?
- How sensitive the asset price is to a carbon market factor?

Carbon price

Two main pricing systems:

1. Carbon tax
2. Emissions trading system (ETS)

Underlying idea

- A high carbon tax impacts the creditworthiness of corporates
- This impact is different from one issuer to another one
- Identifying for each company the carbon price that would lead the default probability in the Merton model to exceed a certain threshold

Carbon price

Based on the assumptions that the enterprise value V is proportional to the earnings before interest, taxes, depreciation, and amortization (EBITDA) and that the debt D remains constant, we can define the carbon price margin as[24]:

$$\mathcal{CPM}_i = \left(1 - \exp\left(\sigma_i\sqrt{\tau}\Phi\left(-\theta\right) - \left(r + \frac{1}{2}\sigma_i^2\right)\tau\right)\frac{D_i}{V_i}\right)\frac{\mathrm{EBITDA_i}}{\mathcal{CE}_{i,1}}$$

where σ_i is the volatility of the enterprise value, τ is the maturity and r is the risk-free rate

[24] The parameter θ is the threshold of default probability

Carbon beta

- Introduced by Harris (2015) and Görgen *et al.* (2019)
- The underlying idea of the carbon beta is to estimate the sensitivity of the stock return with respect to a carbon/climate risk factor
- Climate risk is not only an idiosyncratic risk for the issuer, but also a systematic risk factor like the Fama-French-Carhart market factors

Carbon price

Cross-section factor

- Long/short portfolio
- Long on stocks highly exposed to carbon risk
- Short on stocks lowly exposed to carbon risk
- The value of the factor is the return of the L/S portfolio
- High carbon beta = highly exposed to carbon risk

Time-series factor

- Synthetic index that represents the financial perception of climate risk
- Textual analysis of climate change-related news published by newspapers and media
- High carbon beta = highly exposed to carbon risk

Risk measure = carbon beta

Carbon beta

Let $R_i(t)$ be the return of stock i at time t. We assume that:

$$\begin{aligned} R_i(t) &= \alpha_i(t) + \beta_{i,\mathrm{mkt}}(t) R_{\mathrm{mkt}}(t) + \sum_{j=1}^{m} \beta_{i,\mathcal{F}_j}(t) R_{\mathcal{F}_j}(t) + \\ & \qquad \boldsymbol{\beta_{i,\mathrm{Carbon}}(t) R_{\mathrm{Carbon}}(t)} + \varepsilon_i(t) \end{aligned}$$

where $R_{\mathrm{mkt}}(t)$ is the return of the market risk factor, $R_{\mathcal{F}_j}(t)$ is the return of the j^{th} alternative risk factor, $R_{\mathrm{Carbon}}(t)$ is the return of the carbon risk factor and $\varepsilon_i(t)$ is a white noise process

Remark

The carbon risk factor corresponds to a long/short portfolio between "green" and "brown" stocks

Climate beta

Engle *et al.* (2020) proposed a related approach where the carbon risk factor is replaced by a climate risk news index $\mathcal{I}_{\mathrm{Climate}}$:

$$\begin{aligned} R_i(t) &= \alpha_i(t) + \beta_{i,\mathrm{mkt}}(t) R_{\mathrm{mkt}}(t) + \sum_{j=1}^{m} \beta_{i,\mathcal{F}_j}(t) R_{\mathcal{F}_j}(t) + \\ & \quad \boldsymbol{\beta_{i,\mathrm{Climate}}(t) \mathcal{I}_{\mathrm{Climate}}(t)} + \varepsilon_i(t) \end{aligned}$$

Remark

The climate index $\mathcal{I}_{\mathrm{Climate}}$ corresponds to a time series that measures the sentiment about the climate change. It is built using text mining and natural langage processing (NLP)

Carbon beta

The carbon risk factor approach

Goal

The main objective is to define a **market** measure of carbon risk

Three-step approach

- Defining a brown green score (BGS) for each stock (scoring model)
- Building a brown minus green factor (Fama-French approach)
- Estimating the carbon beta of a stock with respect to the BMG factor (Multi-factor regression analysis)

Carbon beta = **market** measure of carbon risk

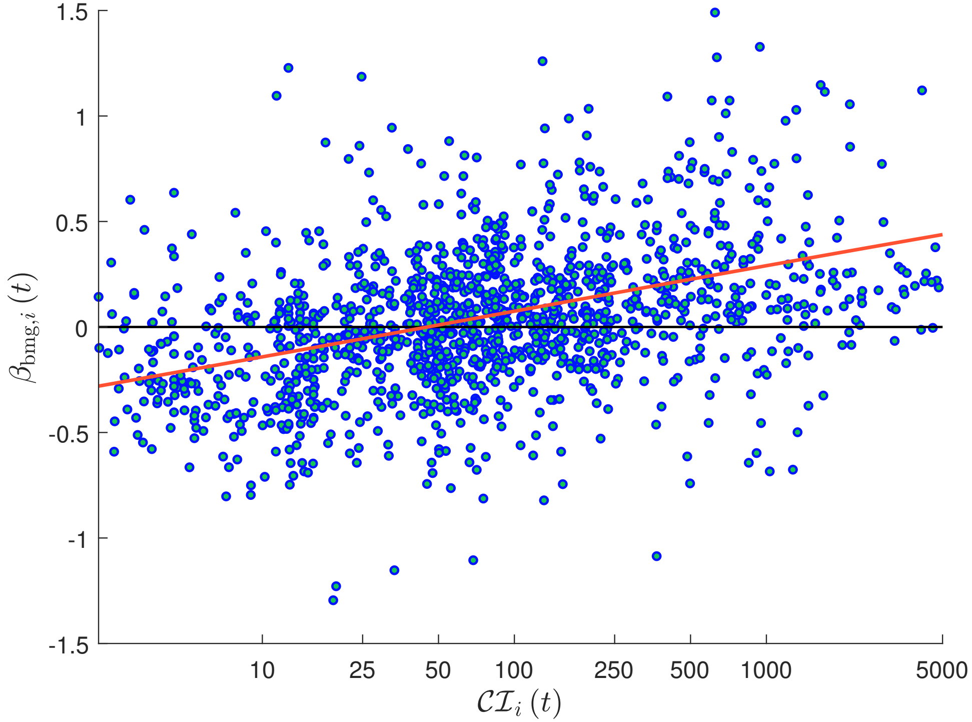
$\neq$

Carbon intensity = **fundamental** measure of carbon risk

Carbon beta

The carbon risk factor approach

Figure 88: Market-based vs fundamental-based measures of carbon risk



Source: Roncalli *et al.* (2021).

⇒ The market perception of a carbon risk measure depends on several dimensions: sector, country, etc.

Carbon beta

The carbon risk factor approach

Systematic carbon risk

- Common risk
- Carbon beta

Market measure ($\approx$ general carbon risk exposure, e.g. market repricing risk)

Idiosyncratic carbon risk

- Specific risk
- Carbon intensity

Fundamental measure ($\approx$ specific carbon risk exposure, e.g. reputational risk)

Carbon beta

The carbon risk factor approach

	Green	Neutral	Brown
Small	SG	SN	SB
Big	BG	BN	BB

The BMG factor return $R_{\mathrm{bmg}}(t)$ is derived from the Fama-French method:

$$R_{\mathrm{bmg}}(t) = \frac{1}{2}\left(R_{\mathrm{SB}}(t) + R_{\mathrm{BB}}(t)\right) - \frac{1}{2}\left(R_{\mathrm{SG}}(t) + R_{\mathrm{BG}}(t)\right)$$

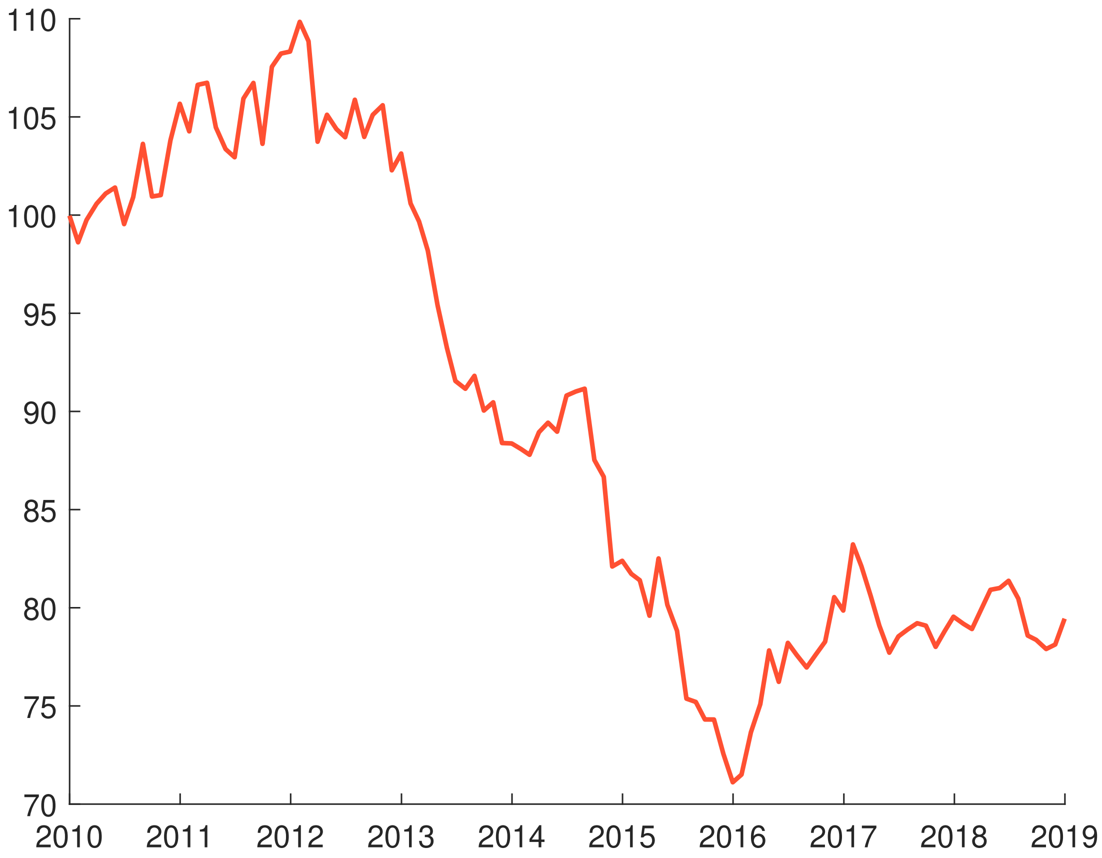
where the returns of each portfolio $R_j(t)$ (small green SG, big green BG, small brown SB, big brown BB) is value-weighted by the market capitalisation

$\Rightarrow$ The BMG factor is a Fama-French risk factor based on a scoring system (brown green score or BGS)

Carbon beta

The carbon risk factor approach

Figure 89: Cumulative performance of the BMG factor

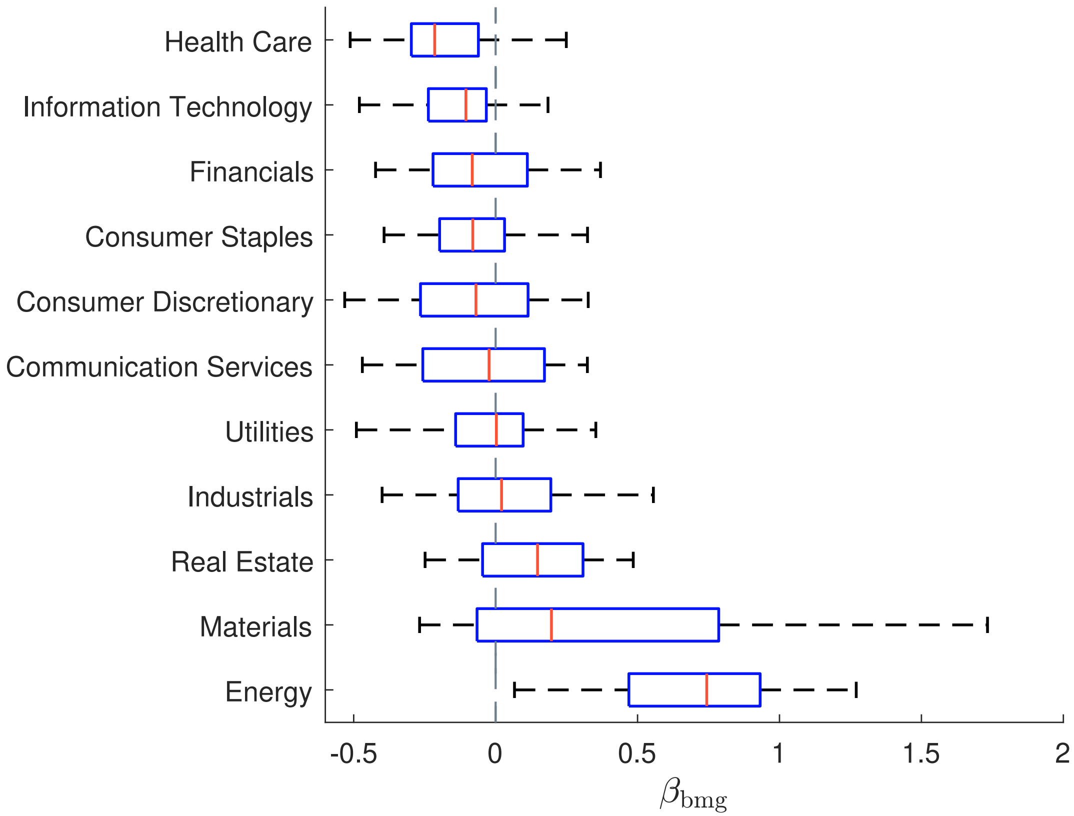


Source: Görgen *et al.* (2019).

Carbon beta

The carbon risk factor approach

Figure 90: Box plots of the carbon sensitivities[25]



Source: Roncalli *et al.* (2020).

[25] The box plots provide the median, the quartiles and the 5% and 95% quantiles

Carbon beta

The carbon risk factor approach

Relative carbon risk

- The right measure is β_{bmg}
- Sign matters
- **Negative exposure** is preferred

Absolute carbon risk

- The right measure is $|\beta_{\text{bmg}}|$
- Sign doesn't matter
- **Zero exposure** is preferred

Two examples

1. We consider three portfolios with a carbon beta of -0.30, -0.05 and $+0.30$ respectively
2. We consider two portfolios with the following characteristics:
   - The value of the carbon beta is $+0.10$ and the stock dispersion of carbon beta is 0.20
   - The value of the carbon beta is -0.30 and the stock dispersion of carbon beta is 1.50

$\Rightarrow$ Impact of portfolio management and theory

Climate beta

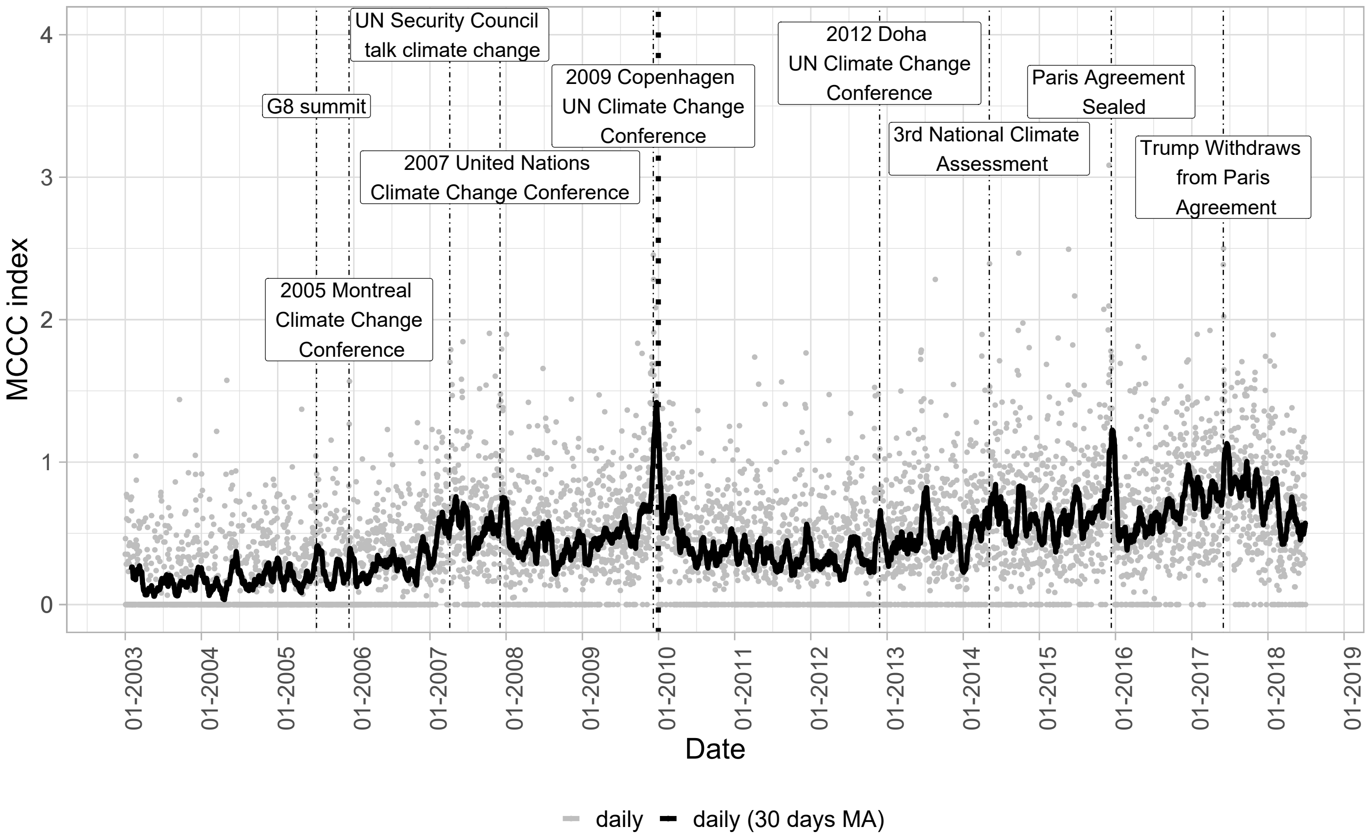
The climate index approach

- Two main references: Engle *et al.* (2020) & Ardia *et al.* (2021)
- We recall that brown assets must exhibit a positive risk premium
- Nevertheless, "*[...] If ESG concerns strengthen unexpectedly and sufficiently, green assets outperform brown ones despite having lower expected returns*" (Pástor *et al.*, 2021)
- Academics proxy concerns about climate change using climate indices based on news

Climate beta

The climate index approach

Figure 91: Media Climate Change Concerns (MCCC) index



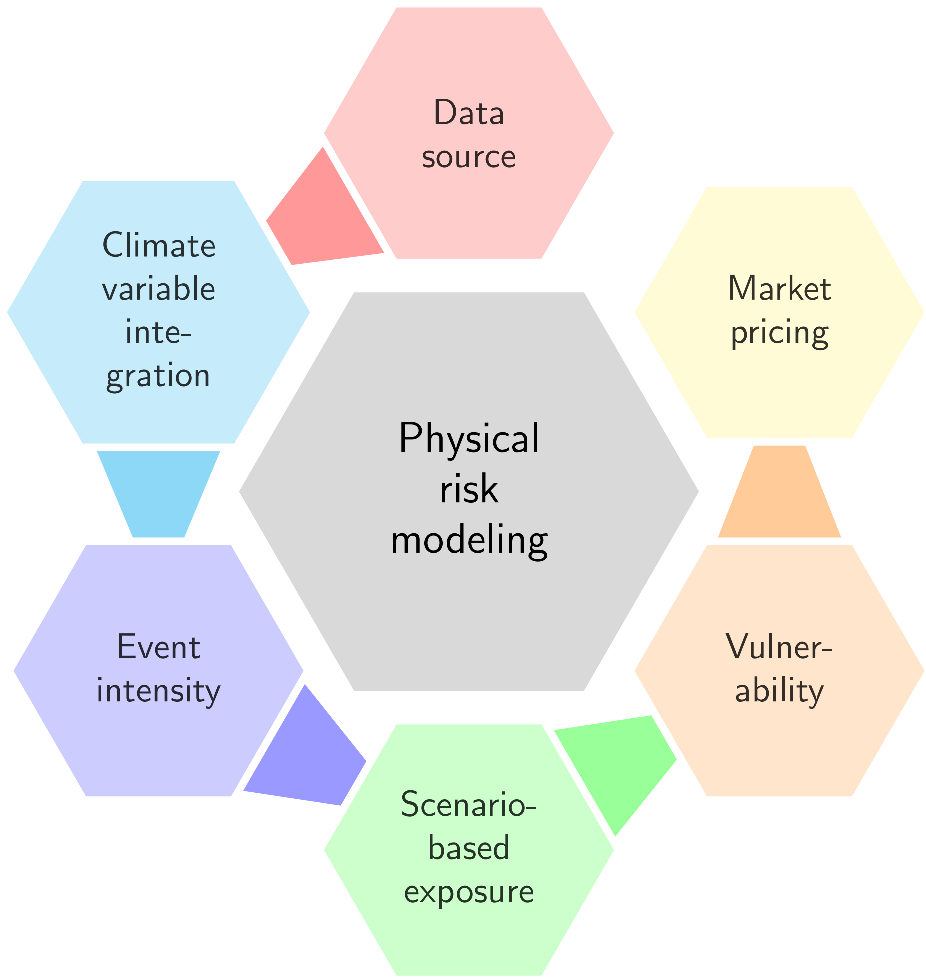
Source: Ardia *et al.* (2021).

Climate physical risk

"Responsible investors have paid more attention to the transition risk than to the physical risk. However, recent events show that physical risk is also a big concern. It corresponds to the financial losses that really come from climate change, and not from the adaptation of the economy to prevent them. It includes droughts, floods, storms, etc." (Le Guenedal and Roncalli, 2022).

Climate physical risk

Figure 92: Physical risk modeling



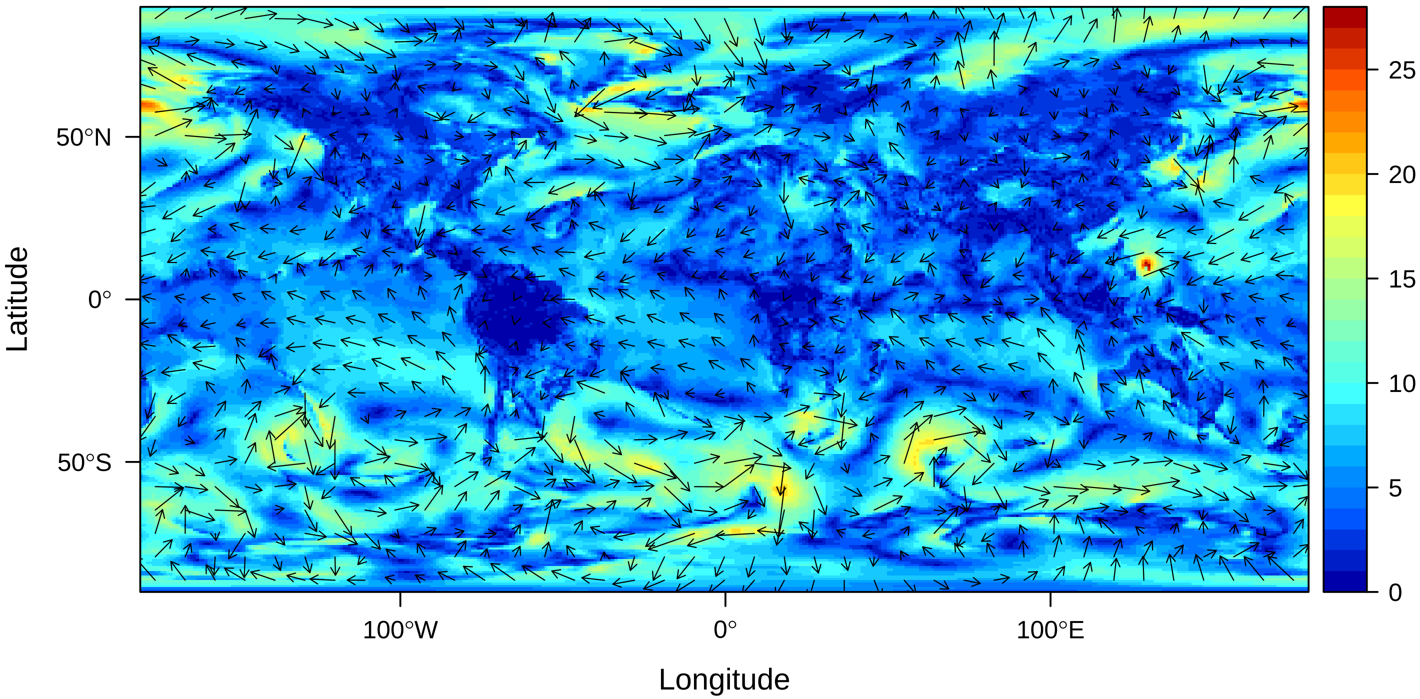
Climate physical risk

Climate variable and data source

- The climate data source is the set $\Theta_s = \{\theta(\lambda, \varphi, z, t)\}$
- $\theta = (\theta_1, \ldots, \theta_k)$ is a vector of k climate variables such as temperature, pressure or wind speed
- Each variable θ_k has four coordinates:
  1. Latitude λ
  2. Longitude φ
  3. Height (or altitude) z
  4. Time t
- Three types of sources:
  1. Meteorological records
  2. Reanalysis
  3. Historical simulations by a climate model

Climate physical risk

Figure 93: Slice* of wind speed (07/11/2013, tropical cyclone Haiyan)



Source: Modern-Era Retrospective analysis for Research and Applications, Version 2, Global Modeling and Assimilation Office, NASA.

*This is a slice of the MERRA-2 reanalysis at a height of 10 meters on 7^{th} November 2013. The red dot is the location of the eye of the tropical cyclone Haiyan, which affected more than 10 million people in the Philippines

Climate physical risk

Event intensity sensitivity

- We first have define the sensitivity of the intensity of extreme events to climate change
- Let $\mathbb{E}\left[I\left(\Theta_s\left(C\right)\right)\right]$ be the expected intensity of the event in the scenario associated with the GHG concentration C
- The sensitivity of the event is equal to:

$$\Delta I\left(C\right) = \mathbb{E}\left[I\left(\Theta_s\left(C\right)\right)\right] - I\left(\Theta_s\left(C_0\right)\right)$$

  where $I\left(\Theta_s\left(C_0\right)\right)$ is the current intensity or the reference intensity in a scenario where climate objectives are met
- For instance, we know that the maximum wind of tropical cyclones increases by more than 10% in scenarios with a high GHG concentration

Climate physical risk

Asset exposure

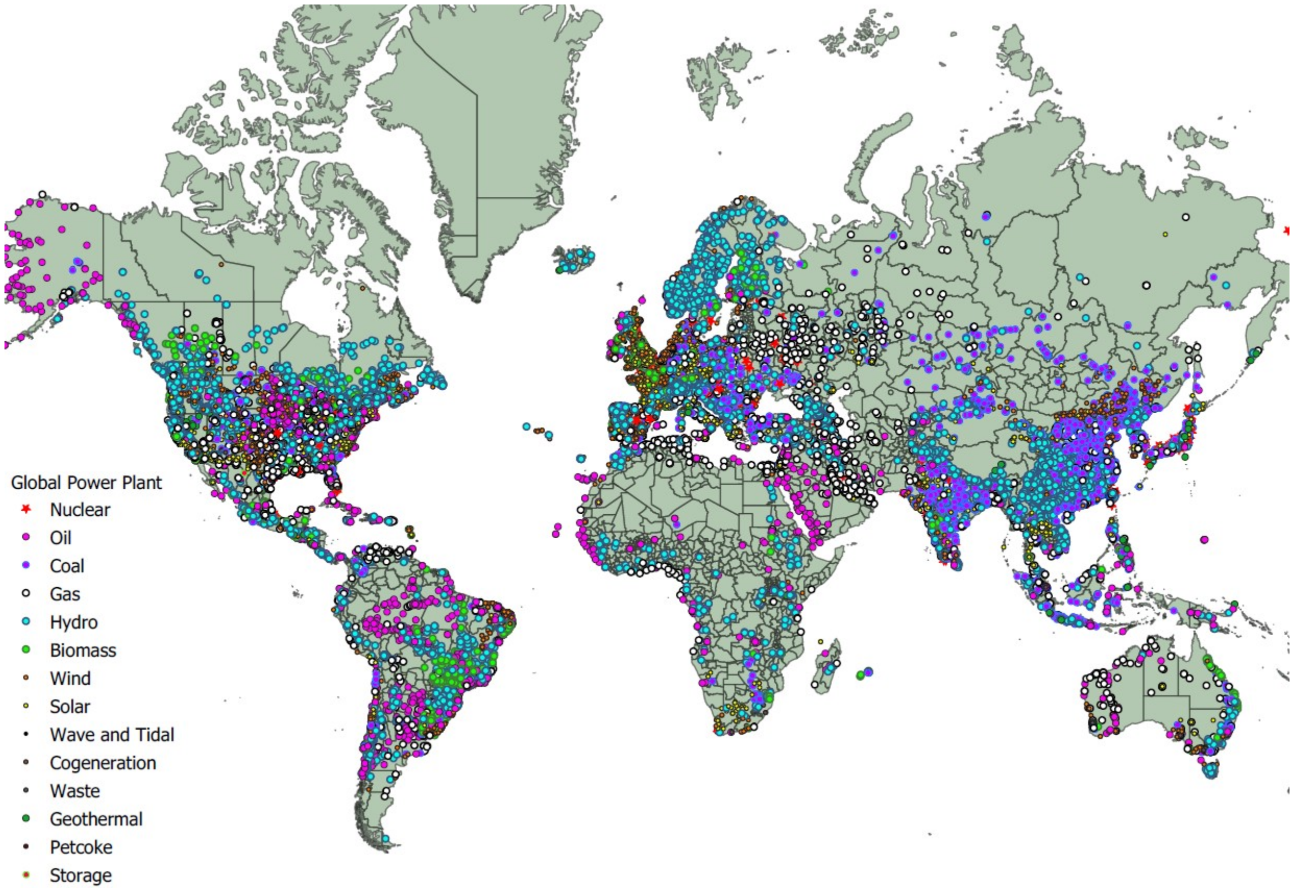
- The asset value of the portfolio can then be written as:

$$\Psi(t) = \sum_{j=1}^{n} x_j \Psi_j(\lambda, \varphi, t)$$

  where $\Psi_j(\lambda, \varphi, t)$ is the geolocated asset value estimated at time t and x_j is the weight of asset j in the portfolio
- This requires the geolocation of the portfolio

Climate physical risk

Figure 94: Geolocation of world power plants by energy source



Source: Global Power Database version 1.3 (June 2021).

Climate physical risk

Vulnerability

- The damage function $\Omega_j(I) \in [0,1]$ is the fraction of property loss with respect to the intensity
- It is generally calibrated on past damages (insurance claims, economic loss, etc.) and disasters

Climate physical risk

Market pricing

- The physical risk implied by the concentration scenario C is equal to:

$$\Delta \mathcal{L}oss\left(t,C\right)=\beta\cdot\mathcal{DD}\left(t,C\right)=\beta\sum_{j=1}^{n}x_j\Psi_j\left(\lambda,\varphi,t\right)\Omega_j\left(\Delta I\left(t,C\right)\right)$$

- $\Delta \mathcal{L}oss\left(t,C\right)$ is the relative loss due to the events on the portfolio
- β is the transmission factor of the direct damage $\mathcal{DD}\left(t,C\right)$ on the underlying to the loss of financial value in the investment portfolio
- For example, if the facilities of an energy producer are damaged at 50%, the securities issued by this company will be impacted at $50\% \times \beta$

Climate physical risk
Tropical cyclone damage modeling

Le Guenedal, Drobinski, and Tankov (2021), Measuring and Pricing Cyclone-Related Physical Risk under Changing Climate, *Amundi Working Paper*, `www.ssrn.com/abstract=3850673`

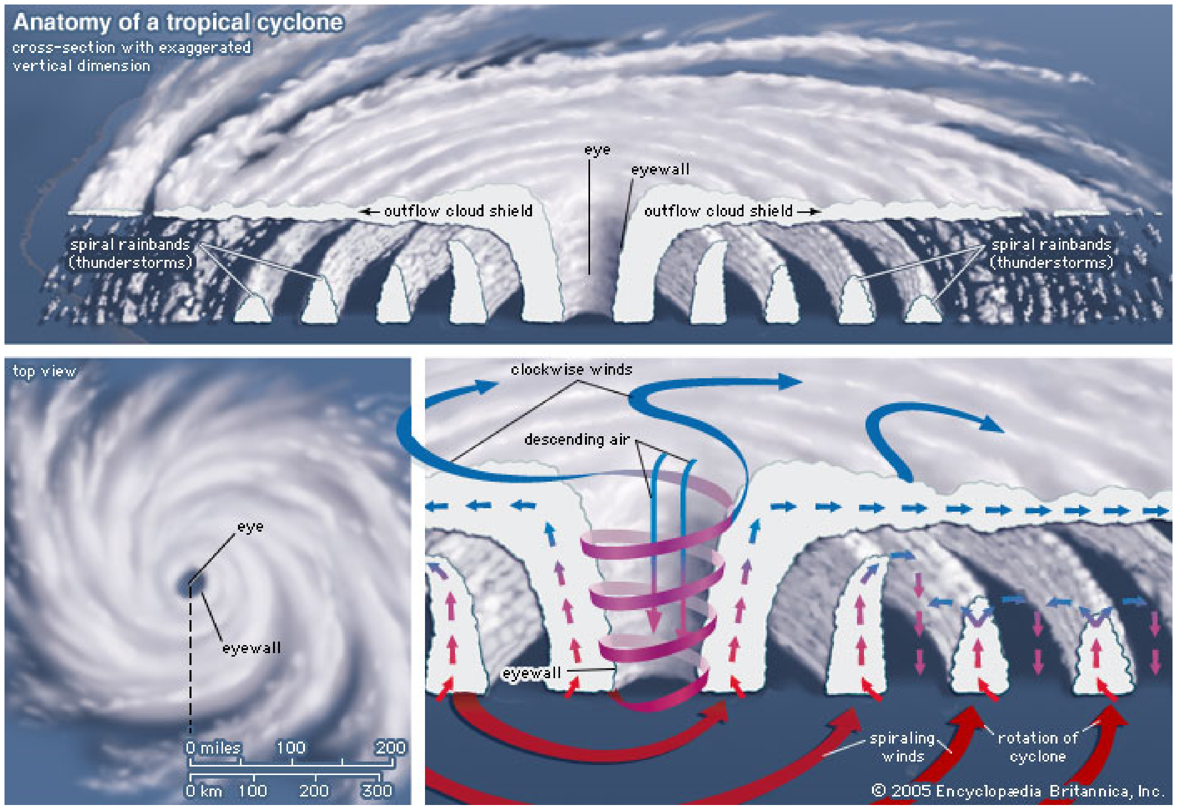
Two main modules:

- Simulation and generation of tropical cyclones under a given climate change scenario
- Geolocation of assets, damage modeling and loss estimation

Climate physical risk

Tropical cyclone damage modeling

Figure 95: What is a cyclone?

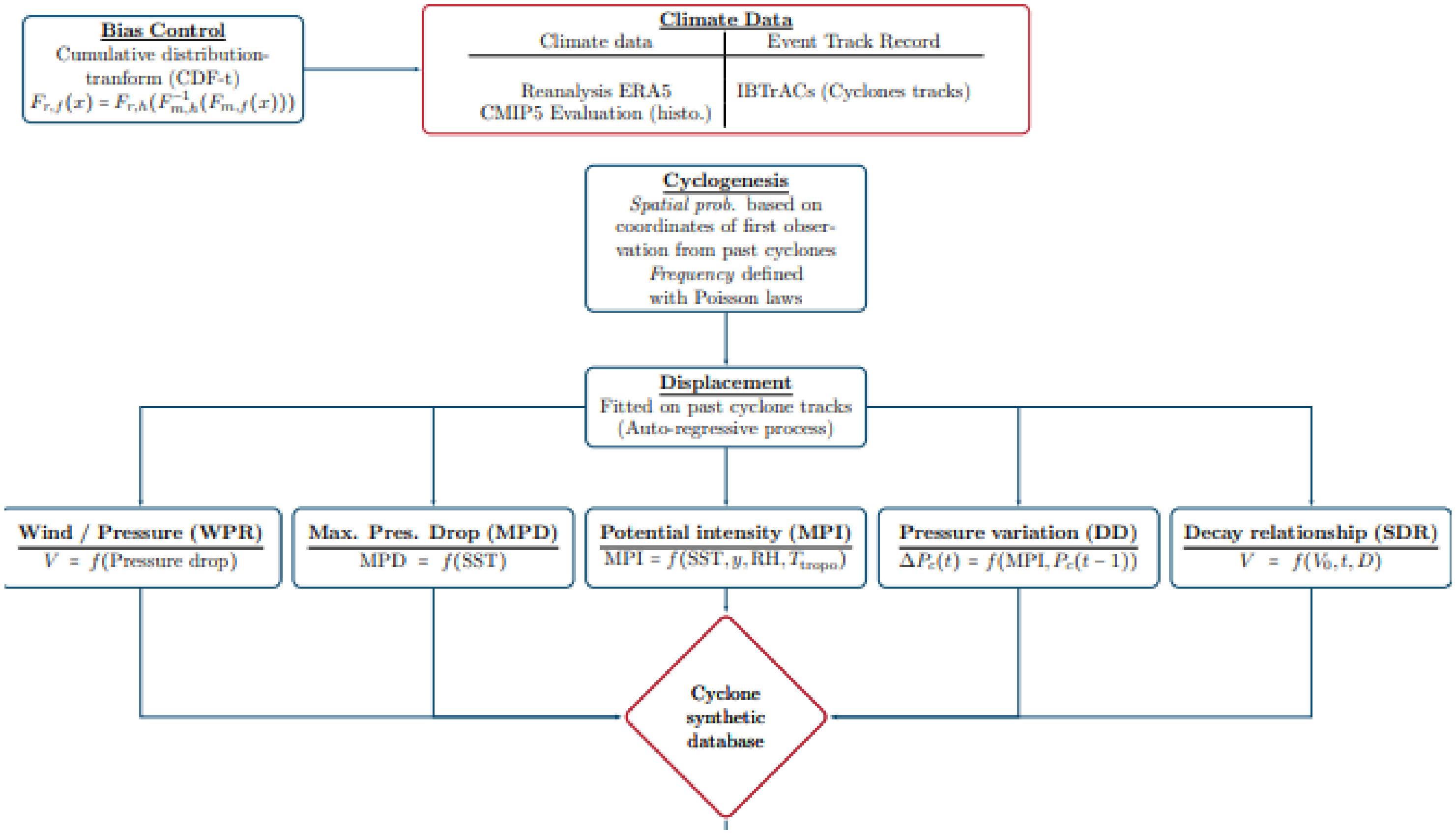


Source: `www.geosci.usyd.edu.au/users/prey/teaching/geos-2111gis/cyclone/cln006.html`

Climate physical risk

Tropical cyclone damage modeling

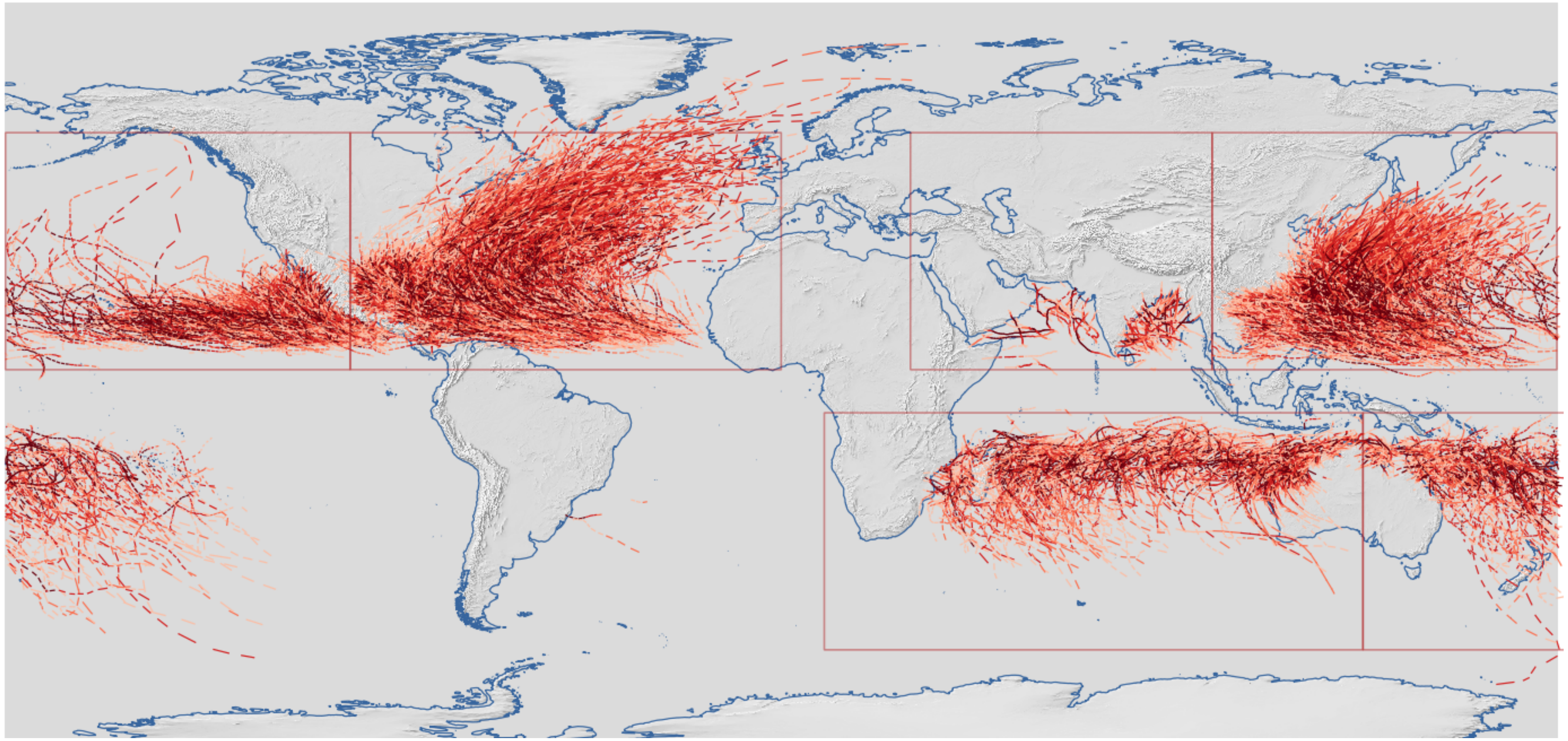
Figure 96: Modeling framework (Module 1)



Source: Le Guenedal *et al.* (2021).

Climate physical risk
Tropical cyclone damage modeling

Figure 97: Sample of storms (ERA-5 climate data)



Source: Le Guenedal *et al.* (2021).

Climate physical risk

Tropical cyclone damage modeling

Physics of cyclones

1. Wind pressure relationship (Bloemendaal *et al.*, 2020):

$$V = a \left(P_{\mathrm{env}} - P_c\right)^b$$

2. Maximum potential intensity (Holland, 1997; Emanuel, 1999):

$$MPI = f\left(y, SST, T_{tropo}, MSLP, RH, P_c\right)$$

3. Maximum pressure drop (Bloemendaal *et al.*, 2020):

$$MPD \sim P_{\mathrm{env}} - P_c = A + Be^{C(\mathrm{SST} - T_0)} \qquad T_0 = 30^{o}\mathrm{C}$$

4. Pressure incremental variation (James and Mason, 2005):

$$\begin{array}{rcl} \Delta_t P_c\left(t\right) & = & c_0 + c_1 \Delta_t P_c\left(t-1\right) + c_2 e^{-c_3\left(P_c(t) - MPI(x,y,t)\right)} + \varepsilon\left(P_c, t\right) \\ \varepsilon\left(P_c, t\right) & \sim & \mathcal{N}\left(0, \sigma^2_{P_c}\right) \end{array}$$

5. Decay function (Kaplan and DeMaria, 1995):

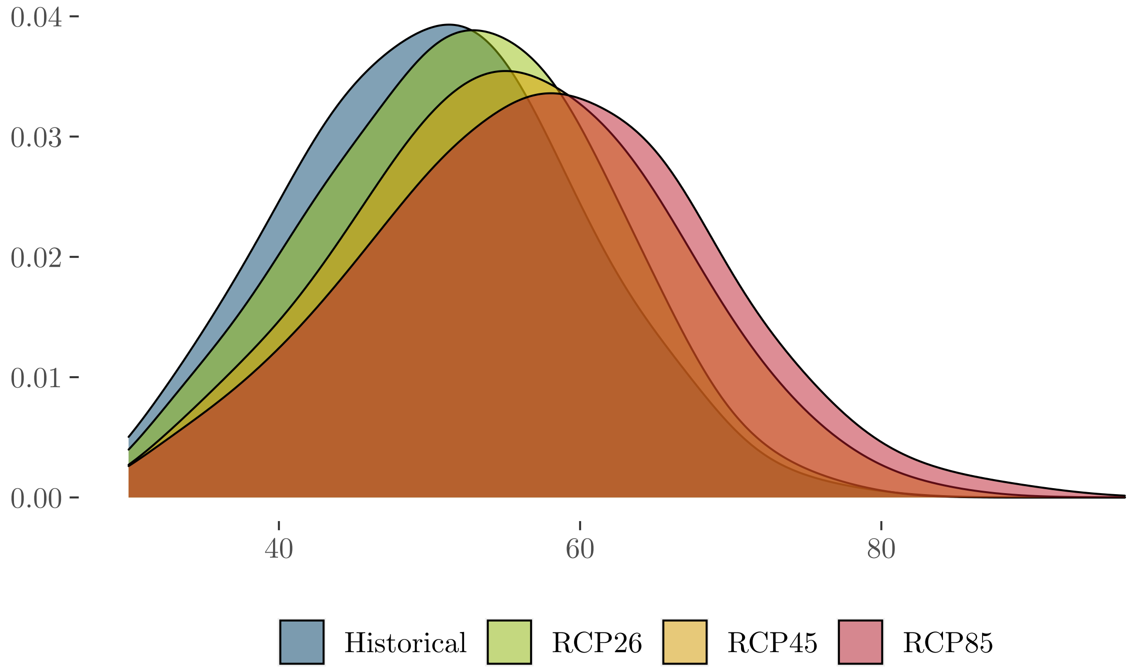
$$V\left(t_L\right) = V_b + \left(R \cdot V_0 - V_b\right)e^{-\alpha t} - C$$

where $C = m\left(\ln \frac{D}{D_0}\right) + b$, $m = \tilde{c}_1 t_L\left(t_{0,L} - t_L\right)$ and $b = d_1 t_L\left(t_{0,L} - t_L\right)$

Climate physical risk

Tropical cyclone damage modeling

Figure 98: Maximum wind speed in m/s (2070-2100)

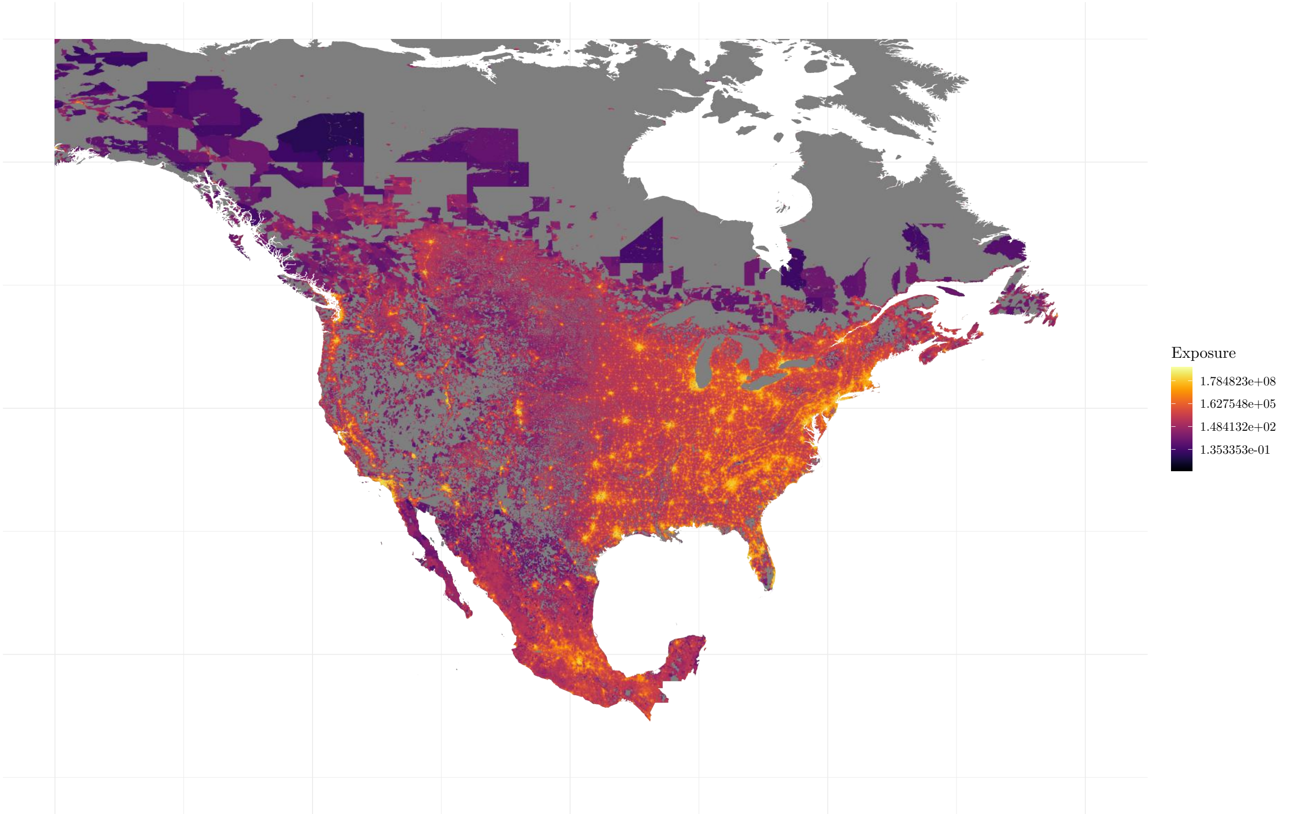


Source: Le Guenedal *et al.* (2021).

The cyclone simulation database must be sensitive to the climate change scenario

Climate physical risk
Tropical cyclone damage modeling

Figure 99: GDP decomposition of North America (or physical asset values) (Litpop database)

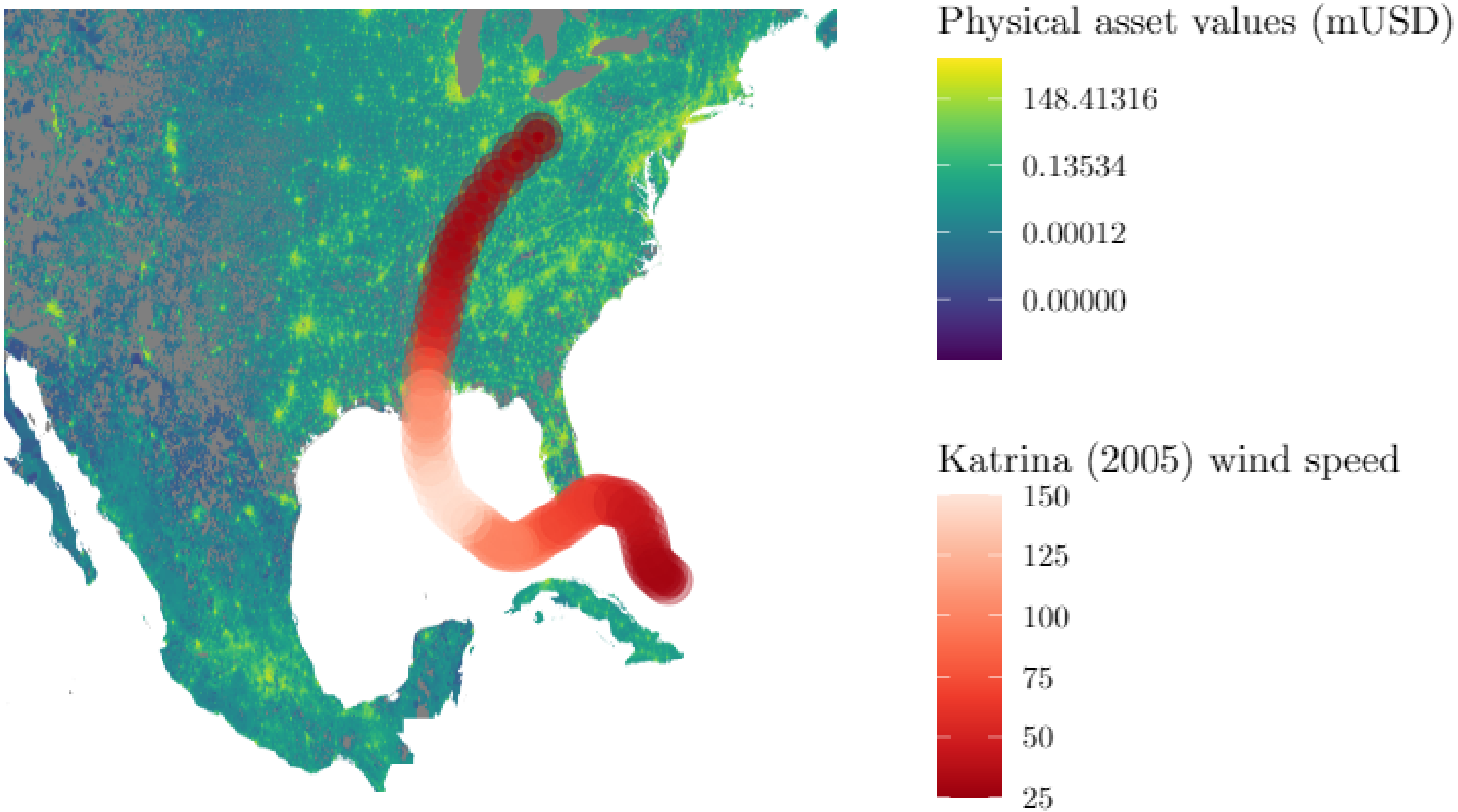


Source: Le Guenedal *et al.* (2021).

Climate physical risk

Tropical cyclone damage modeling

Figure 100: The case of Katrina (2005)

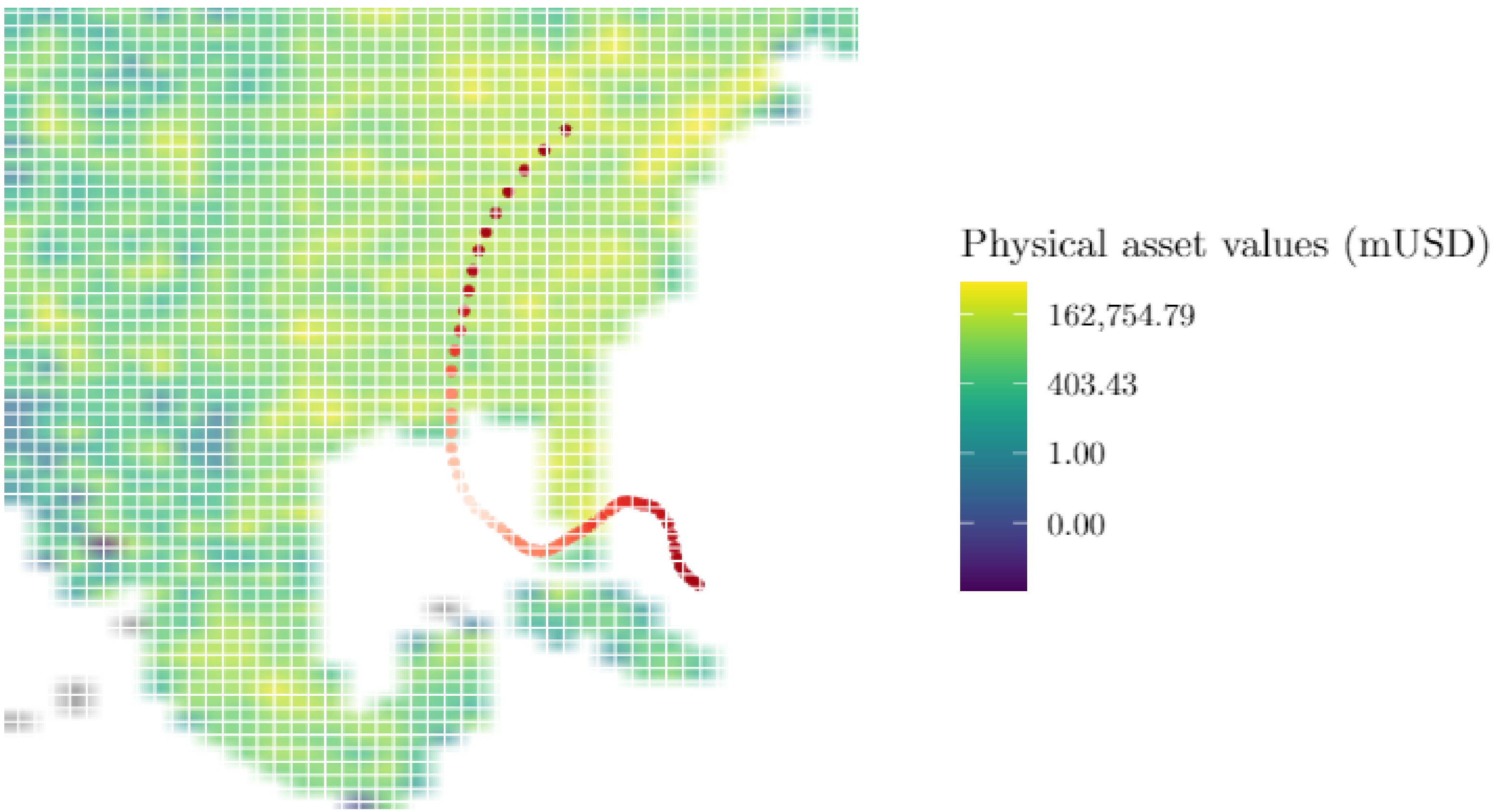


Source: Le Guenedal *et al.* (2021).

Climate physical risk

Tropical cyclone damage modeling

Figure 101: The grid approach

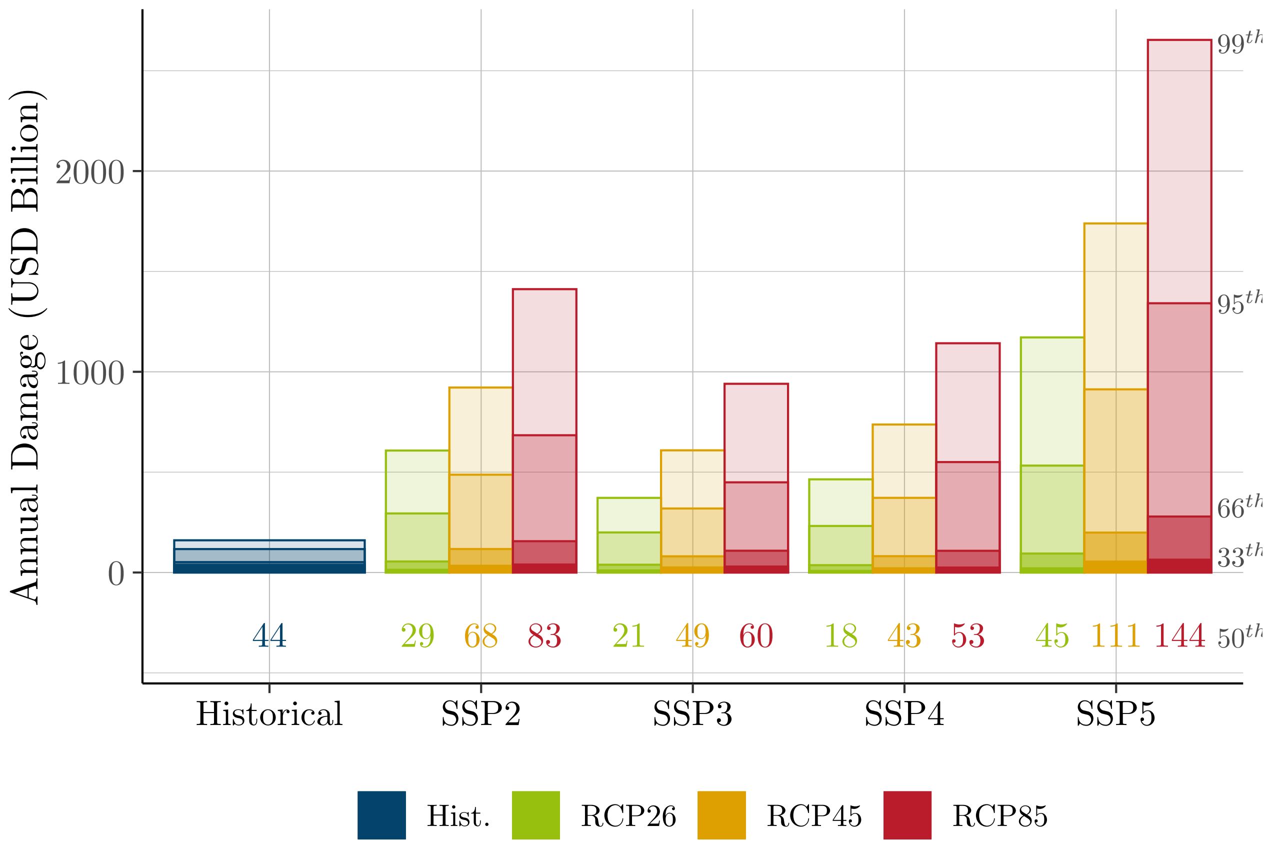


Source: Le Guenedal *et al.* (2021).

Climate physical risk

Tropical cyclone damage modeling

Figure 102: Average global losses



Source: Le Guenedal *et al.* (2021).

Climate physical risk

Tropical cyclone damage modeling

Table 50: Average increase of financial losses per year

SSP	RCP 2.6	RCP 4.5	RCP 8.5
SSP2	+43%	+153%	+247%
SSP5	+157%	+360%	+543%

Source: Le Guenedal *et al.* (2021).

Remark

- There are simulations that lead to annual losses that easily exceed 2 or 3 trillion dollars per year
- 1 Katrina = $180 billion in 2005

Scoring

⇒ Application of ESG scoring systems to climate risk

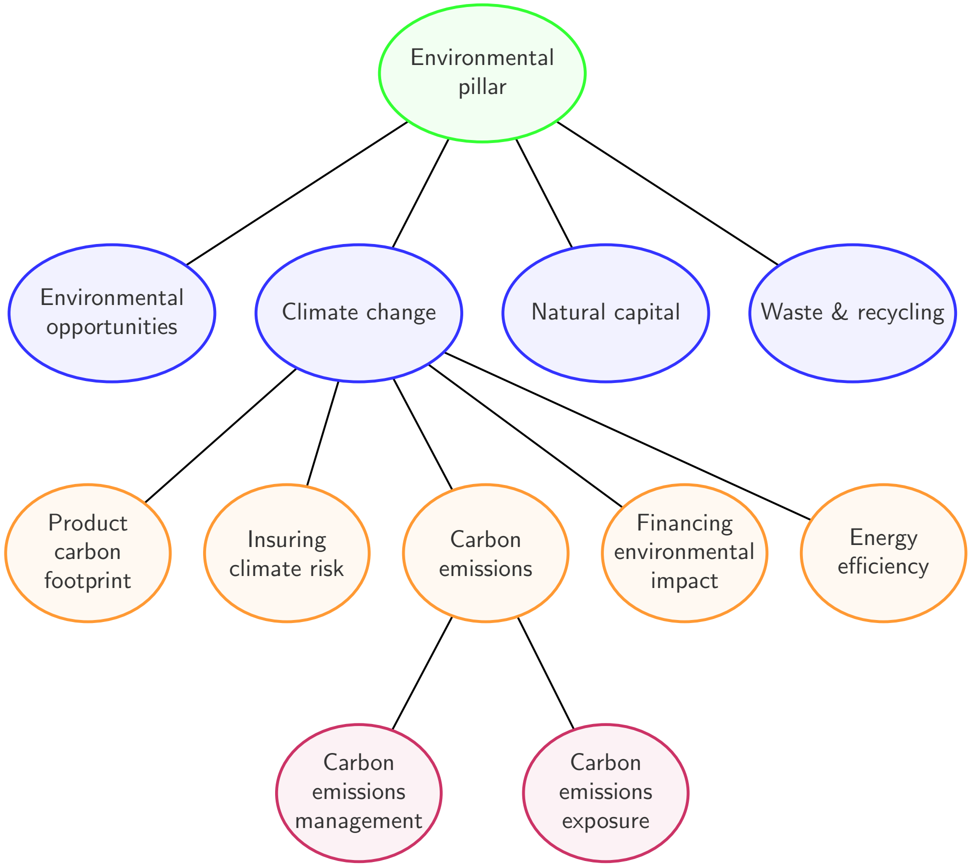


Figure 103: An example of E score

Source: MSCI (2020)

Key performance indicators

- Avoided emissions
- Green revenues
- Energy mix
- Reserves-based indicators (capital stranding risk)
- Green patent, R&D and capital expenditure
- Etc.

Highly related to **Net Zero**

Avoided emissions

- This metric compares the carbon emissions of a product or an issuer to a reference or benchmark
- For instance, a hybrid car emits[26] CO_2, but it also avoid carbon emissions compared to a petrol car
- The avoided emissions is defined as:

$$\mathcal{AE}_i = \sum_{k=1}^{n_p} \sum_{j=1}^{3} \left(\mathcal{CE}_j \left(k; \mathrm{reference} \right) - \mathcal{CE}_j \left(k; \mathrm{green} \right) \right)$$

where:

  - n_p is the products or services offered by the company i
  - $\mathcal{CE}_j \left(k; \mathrm{green} \right)$ and $\mathcal{CE}_j \left(k; \mathrm{reference} \right)$ are the scope j emissions of the green and reference products k

[26] Especially if we take into account the life cycle of batteries

Avoided emissions

- There is no standards to compute avoided emissions
- World Resources Institute (2019), *Estimating and Reporting The Comparative Emissions Impacts of Products*, `https://ghgprotocol.org/estimating-and-reporting-avoided-emissions`
- Avoided emissions calculator: `https://www.irena.org/climatechange/Avoided-Emissions-Calculator`
- Avoided emissions depend on the sector, region, country, product, etc.
- Again, we notice a $\mathcal{SC}_{1+2}$ vs. $\mathcal{SC}_3$ puzzle $\Rightarrow$ the example of smartphones

Green revenues

- The green revenues measure the share of the company's business in sustainable activities
- An issuer with 100% of green revenues is called a *pure player*
- Example of green revenues
  - Revenues from electric cars for the automobile sector
  - Renewable production (wind, solar, etc.) for the Utilities sector.

$\Rightarrow$ Extension to green CAPEX or OPEX

Green revenues

Green revenues

1. Renewable energy
2. Direct contribution to the low-carbon transition
3. Indirect contribution to the low-carbon transition

Brown revenues

1. Coal mining
2. Oil & gas revenues
3. Activities using coal, oil & gas?

We need a **taxonomy** = **What is Green?**

By sector? activities? products?

Taxonomy

European Taxonomy (EUT)

There are 6 objectives:

1. Climate change mitigation
2. Climate change adaptation
3. Sustainable and protection of water and marine resources
4. Transition to a circular economy
5. Pollution prevention and control
6. Protection and restoration of biodiversity and ecosystem

Taxonomy

1. SC — **Substantially contribute to at least one of the six objectives**

2. DNSH — **Do No Significant Harm** to any other five objectives

3. MS — Comply with **Minimum (Social) Safeguards**

4. TSC — Comply with **Technical Screening Criteria**

Figure 104: EU taxonomy

Taxonomy

Activities

1. Low carbon activities (or "**green**" activities)
   Activities associated with sequestration or very low absolute emissions
2. Transition activities (or "**greening of**" activities)
   Activities that contribute to a transition to a net zero emissions economy in 2050 but are not currently close to a net zero carbon emissions level
3. Enabling activities (or "**greening by**" activities)
   Activities that enable low-carbon performance or enable substantial emissions reductions (life-cycle considerations)

Controversies

- Gas
- Nuclear

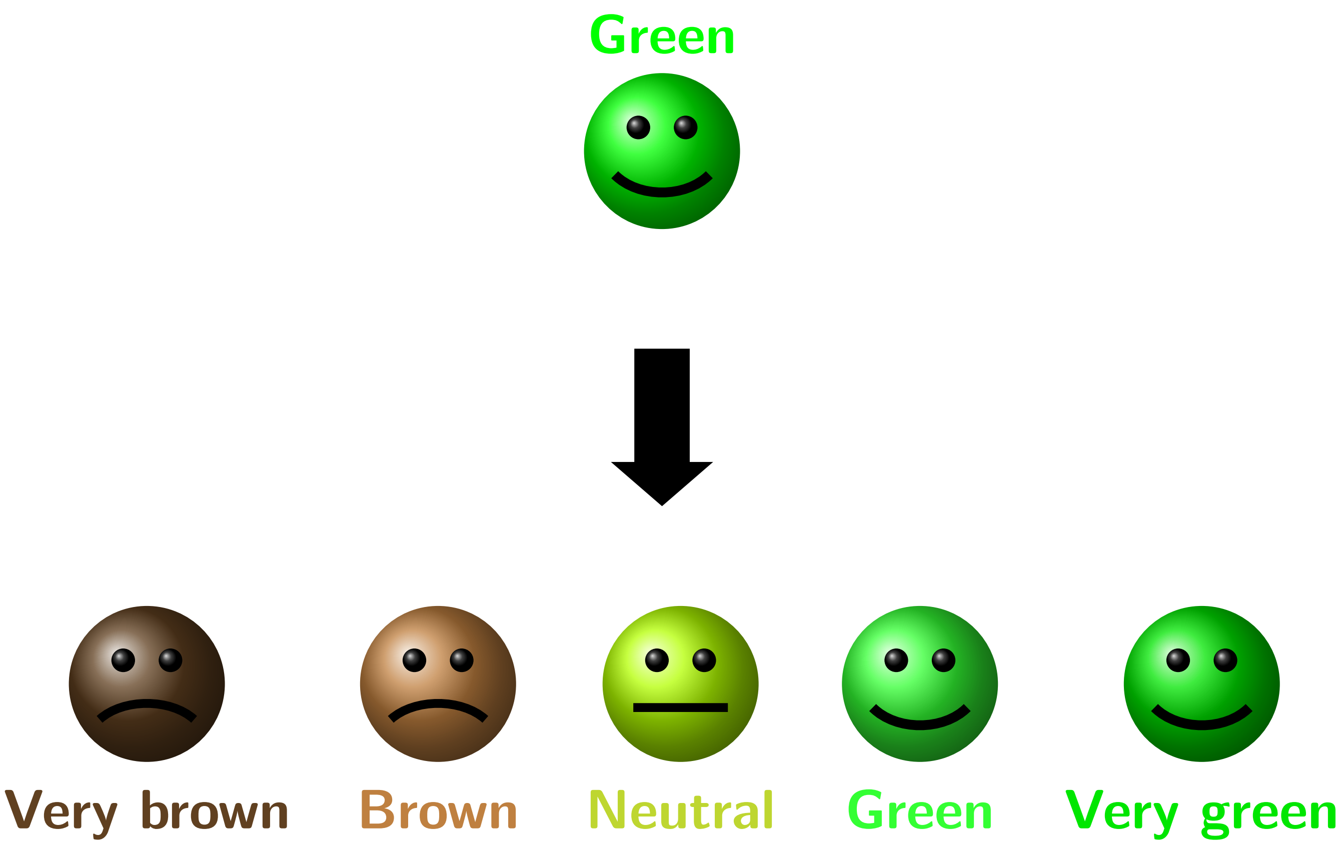
Taxonomy

The EU taxonomy leads to a narrow definition of **GREEN**:

- It generally concerns less than 5% of the allocation of cap-weighted indices
- It is difficult to commit on EU taxonomy alignment, except for thematics (green bonds, cleantech, etc.)
- The most represented sectors are: softwares & services, semiconductors, real estate, automobiles, capital goods, materials & utilities
- Some sectors are not in the EU taxonomy: banks, food, health care, insurance, media, retailing
- Sector biases are incompatible with portfolio diversification

Taxonomy

What we need

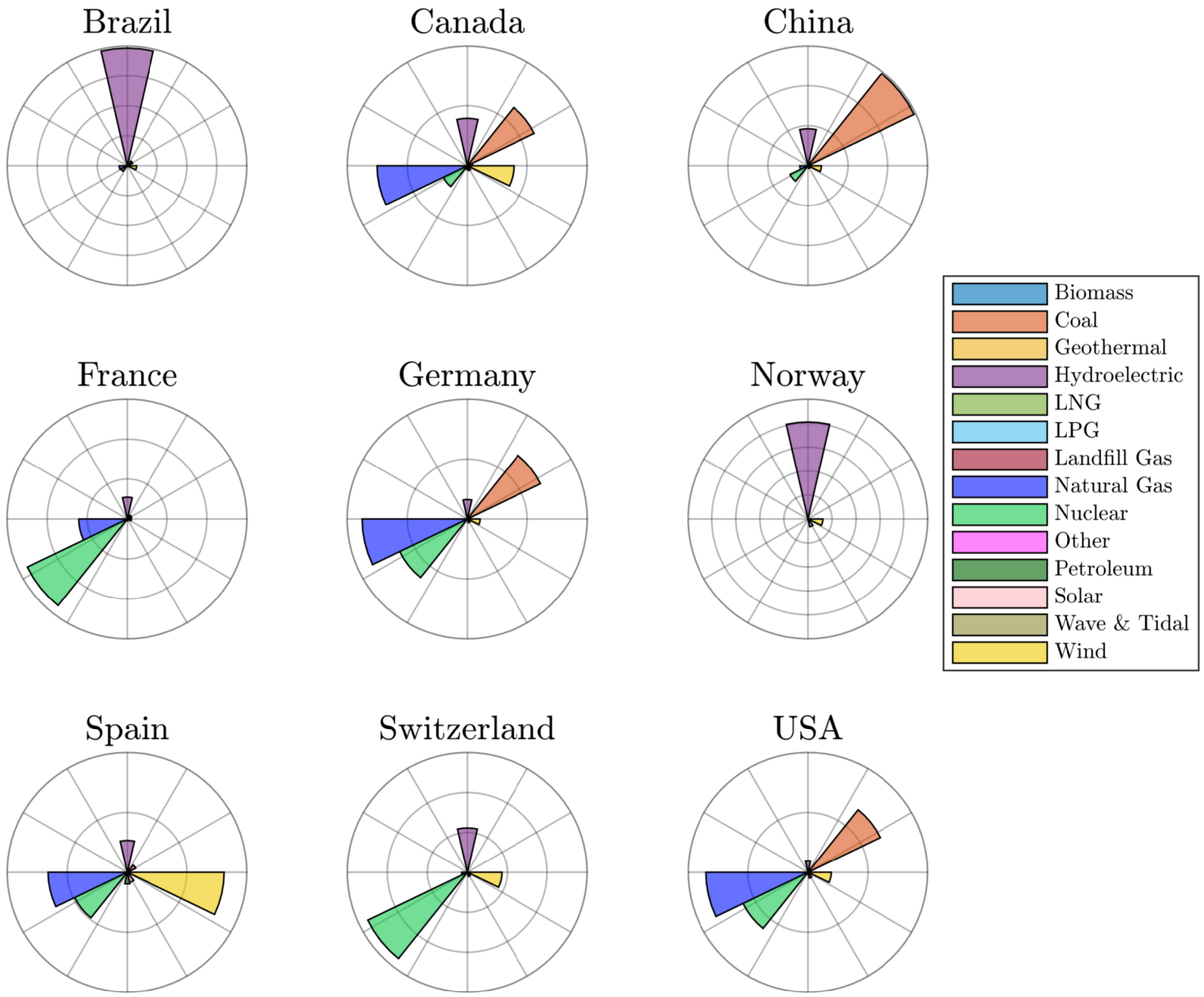


Energy mix

- How to measure the environmental performance of a Utility company?
- How to measure the environmental performance of a country?
- How to compare a company located in a country with a bad enery meix

Bottom up energy mix$^{(*)}$ (in %)

This figure presents the energy generation breakdown for some countries. We can distinguish countries that rely on hydroelectric power (Brazil, Norway), nuclear (France, Switzerland) and mixed solutions (Canada, Germany, Spain, USA)



$^{(*)}$ Each grid circle represents 20% of energy generation. The scale of the radar chart is then 40% for Canada, Germany, Spain and USA, 60% for China, France and Switzerland, 80% for Brazil and 100% for Norway

Course 2021-2022 in ESG and Climate Risks
Lecture 5. Climate Investing

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February 2022

[27] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Portfolio decarbonization

Two approaches:

- Portfolio optimization by minimizing the tracking error and imposing a reduction in terms of carbon intensity (max-threshold approach)
- Elimination of the worst performers in terms of carbon intensity (order-statistic approach)

Portfolio optimization with a benchmark

The γ-optimization problem is:

$$\begin{aligned} x^\star &= \arg\min \frac{1}{2}\sigma^2(x \mid b) - \gamma\mu(x \mid b) \\ \text{u.c.} & \left\{ \begin{array}{ll} \mathbf{1}_n^\top x = 1 & \\ \mathbf{0}_n \leq x \leq \mathbf{1}_n & \qquad \text{(no short selling)} \\ x \in \Omega & \end{array} \right. \end{aligned}$$

where $x = (x_1, \ldots, x_n)$ is the portfolio, $b = (b_1, \ldots, b_n)$ is the benchmark, $\sigma(x \mid b) = \sqrt{(x-b)^\top \Sigma (x-b)}$ is the volatility of the tracking error, $\mu(x \mid b) = (x-b)^\top \mu$ is the expected excess return and $x \in \Omega$ corresponds to additional constraints

Portfolio optimization with a benchmark

We have:

$$\begin{aligned}(*) &= \frac{1}{2}\sigma^2(x \mid b) - \gamma\mu(x \mid b) \\ &= \frac{1}{2}(x-b)^\top \Sigma (x-b) - \gamma (x-b)^\top \mu \\ &= \frac{1}{2}x^\top \Sigma x - x^\top(\gamma\mu + \Sigma b) + \left(\frac{1}{2}b^\top \Sigma b + \gamma b^\top \mu\right) \\ &= \frac{1}{2}x^\top \Sigma x - x^\top(\gamma\mu + \Sigma b) + \mathrm{cons\,tan\,t}\end{aligned}$$

Remark

The objective function can be cast into a QP problem:

$$x^\star = \arg\min \frac{1}{2}x^\top \Sigma x - x^\top(\gamma\mu + \Sigma b)$$

Quadratic programming problem

Definition

The formulation of a standard QP problem is:

$$\begin{aligned} x^\star & = & \arg\min \frac{1}{2} x^\top Q x - x^\top R \\ & & \text{u.c.} \quad \left\{ \begin{array}{l} Ax = B \\ Cx \leq D \\ x^- \leq x \leq x^+ \end{array} \right. \end{aligned}$$

Portfolio decarbonization

Some examples of portfolio decarbonization:

- Limiting the carbon emissions

$$\mathcal{CE}_j(x) \leq \mathcal{CE}_j^+$$

- Limiting the carbon intensity

$$\mathcal{CI}_j(x) \leq \mathcal{CI}_j^+$$

- Reducing the carbon emissions with respect to a benchmark:

$$\mathcal{CE}_j(x) \leq (1 - \mathcal{R})\,\mathcal{CE}_j(b)$$

  where $\mathcal{R} > 0$ is the reduction rate

- Reducing the carbon intensity with respect to a benchmark:

$$\mathcal{CI}_j(x) \leq (1 - \mathcal{R})\,\mathcal{CI}_j(b)$$

Portfolio decarbonization

Portfolio decarbonization is equivalent to add a new constraint:

$$\Omega = \left\{ x : \mathcal{C}(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{C}_i \leq \mathcal{C}^+ \right\}$$

where $\mathcal{C}(x)$ is the climate risk measure

Max-threshold approach

In the sequel, we omit the subscript j that defines the scope to simplify the notations

- The carbon intensity of the benchmark is equal to:

$$\mathcal{CI}(b) = \sum_{i=1}^{n} b_i \cdot \mathcal{CI}_i = b^\top \mathcal{CI}$$

where $\mathcal{CI} = (\mathcal{CI}_1, \ldots, \mathcal{CI}_n)$ is the vector of carbon intensities

- The carbon intensity of the portfolio is equal to:

$$\mathcal{CI}(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{CI}_i = x^\top \mathcal{CI}$$

$\mathcal{CI}(x)$ is also called the weighted average carbon intensity (WACI)

Remark

Until 2020, portfolio decarbonization is generally done using carbon intensity and not absolute carbon emissions

Max-threshold approach

- We deduce that the optimization problem is:

$$
\begin{aligned}
x^{\star}\left(\mathcal{R}\right) & = & \arg\min \frac{1}{2}\left(x-b\right)^{\top}\Sigma\left(x-b\right) \\
& \text{s.t.} & \left\{\begin{array}{l}
\mathbf{1}_n^{\top}x = 1 \\
x \geq \mathbf{0}_n \\
\sum_{i=1}^{n} x_i \cdot \mathcal{CI}_i \leq \left(1-\mathcal{R}\right)\cdot\mathcal{CI}\left(b\right)
\end{array}\right.
\end{aligned}
$$

  where $\mathcal{R}$ is the reduction rate
- The underlying idea is to obtain a decarbonized portfolio $x^{\star}$ such that the tracking error with respect to the benchmark b is the lowest
- The benchmark b can be a current portfolio (active management) or an index portfolio (passive management)

Max-threshold approach

- Since the constraint on the carbon intensity is equivalent to:

$$\mathcal{CI}^\top x \leq (1 - \mathcal{R}) \cdot \mathcal{CI}(b)$$

We obtain the following QP problem:

$$\begin{array}{rcl} x^\star & = & \dfrac{1}{2} x^\top \Sigma x - x^\top \Sigma b \\ & \text{u.c.} & \left\{ \begin{array}{l} \mathbf{1}_n^\top x = 1 \\ \mathcal{CI}^\top x \leq (1 - \mathcal{R}) \cdot \left(b^\top \mathcal{CI} \right) \\ \mathbf{0}_n \leq x \leq \mathbf{1}_n \end{array} \right. \end{array}$$

Max-threshold approach

The QP problem is:

$$
\begin{aligned}
x^{\star} &= \arg\min \frac{1}{2} x^{\top} Q x - x^{\top} R \\
\text{u.c.} & \left\{
\begin{array}{l}
Ax = B \\
Cx \leq D \\
x^{-} \leq x \leq x^{+}
\end{array}
\right.
\end{aligned}
$$

We have the following QP correspondences:

$$
\begin{aligned}
Q &= \Sigma \\
R &= \Sigma b \\
A &= \mathbf{1}_n^{\top} \\
B &= 1 \\
C &= \mathcal{CI}^{\top} \\
D &= \mathcal{CI}^{+} = (1 - \mathcal{R}) \cdot \left(b^{\top} \mathcal{CI} \right) \\
x^{-} &= \mathbf{0}_n \\
x^{+} &= \mathbf{1}_n
\end{aligned}
$$

Max-threshold approach

Example

We consider a capitalization-weighted equity index, which is composed of 8 stocks. The weights are equal to 23%, 19%, 17%, 13%, 9%, 8%, 6% and 5%. We assume that their volatilities are equal to 22%, 20%, 25%, 18%, 35%, 23%, 13% and 29%. The correlation matrix is given by:

$$\rho = \left(\begin{array}{cccccccc} 100\% & & & & & & & \\ 80\% & 100\% & & & & & & \\ 70\% & 75\% & 100\% & & & & & \\ 60\% & 65\% & 80\% & 100\% & & & & \\ 70\% & 50\% & 70\% & 85\% & 100\% & & & \\ 50\% & 60\% & 70\% & 80\% & 60\% & 100\% & & \\ 70\% & 50\% & 70\% & 75\% & 80\% & 50\% & 100\% & \\ 60\% & 65\% & 70\% & 75\% & 65\% & 70\% & 80\% & 100\% \end{array}\right)$$

The carbon intensities (expressed in $tCO_2e/\$$ mn) are respectively equal to: 100.5, 57.2, 250.4, 352.3, 27.1, 54.2, 78.6 and 426.7.

Max-threshold approach

Table 51: Optimal decarbonization portfolios (max-threshold approach)

$\mathcal{R}$	0.00	0.10	0.20	0.30	0.40	0.50
$x_1^\star$	23.00	20.98	18.97	16.95	14.91	11.96
$x_2^\star$	19.00	21.15	23.30	25.46	28.25	33.40
$x_3^\star$	17.00	16.79	16.59	16.38	14.79	9.05
$x_4^\star$	13.00	9.12	5.24	1.36	0.00	0.00
$x_5^\star$	9.00	10.33	11.67	13.00	14.51	16.92
$x_6^\star$	8.00	9.18	10.37	11.55	12.63	13.59
$x_7^\star$	6.00	8.20	10.40	12.59	14.21	15.06
$x_8^\star$	5.00	4.23	3.47	2.70	0.70	0.00
$\sigma(x^\star \mid b)$ (in bps)	0.00	19.32	38.64	57.96	84.74	141.97
$\mathcal{CI}(x)$	155.18	139.66	124.14	108.62	93.11	77.59

- The carbon intensity of the index is equal to 155.18 $tCO_2/\$$ mn
- The tracking error of the portfolio is equal to 141.97 bps if we target a 50% reduction of the carbon intensity

Max-threshold approach

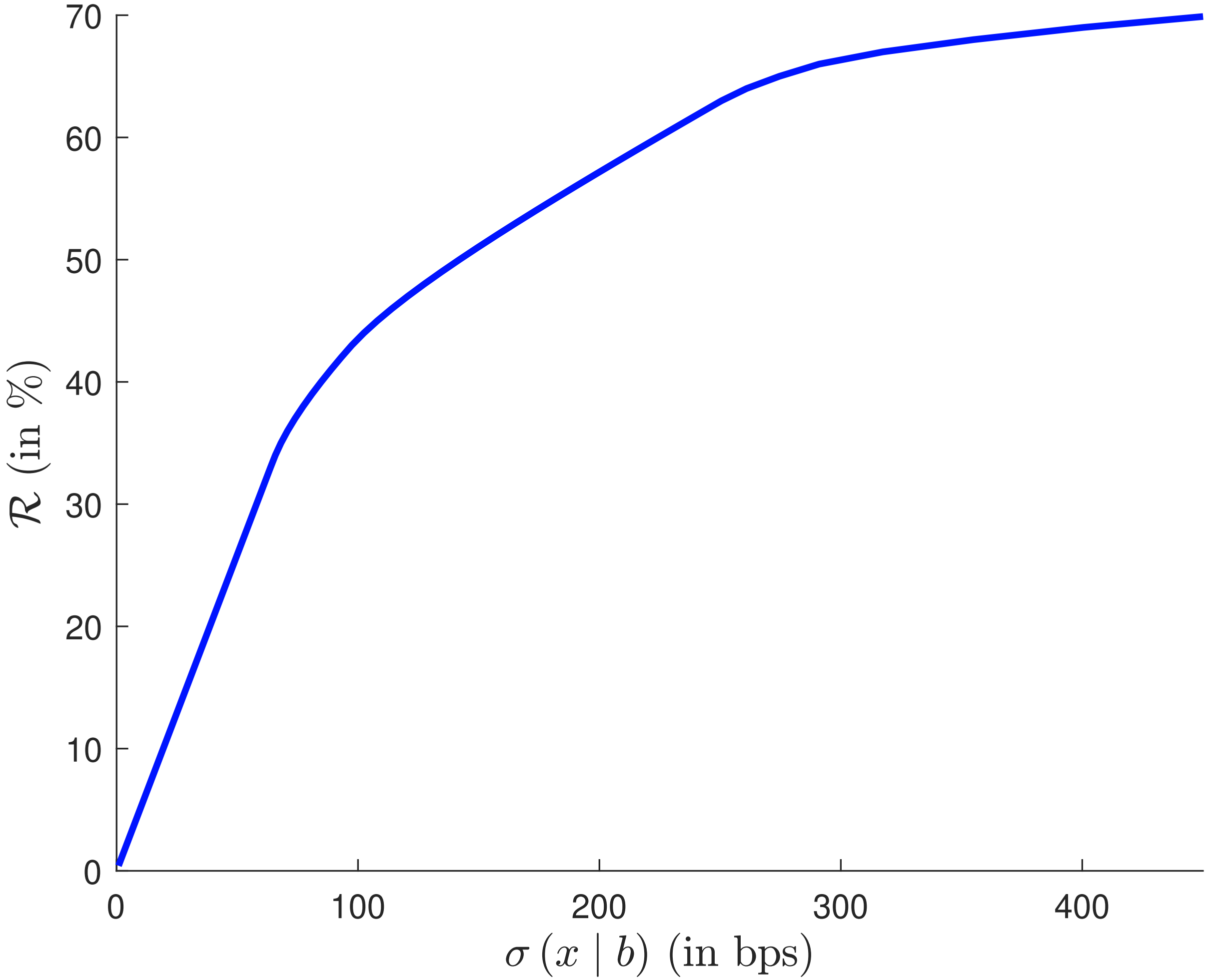


Figure 105: The efficient frontier of optimal decarbonization portfolios

Order-statistic approach

Andersson *et al.* (2016) propose a second portfolio decarbonization approach by eliminating the m worst performing issuers in terms of carbon intensity

- We note $\mathcal{CI}_{i:n}$ the order statistics of $(\mathcal{CI}_1, \ldots, \mathcal{CI}_n)$:

$$\min \mathcal{CI}_i = \mathcal{CI}_{1:n} \leq \mathcal{CI}_{2:n} \leq \cdots \leq \mathcal{CI}_{i:n} \leq \cdots \leq \mathcal{CI}_{n:n} = \max \mathcal{CI}_i$$

- The carbon intensity bound $\mathcal{CI}^{(m,n)}$ is defined as:

$$\mathcal{CI}^{(m,n)} = \mathcal{CI}_{n-m+1:n}$$

  where $\mathcal{CI}_{n-m+1:n}$ is the $(n-m+1)$-th order statistic of $(\mathcal{CI}_1, \ldots, \mathcal{CI}_n)$

- Eliminating the m worst performing assets is equivalent to imposing the following constraint:

$$\mathcal{CI}_i \geq \mathcal{CI}^{(m,n)} \Rightarrow x_i = 0$$

Order-statistic approach

- The optimization problem becomes:

$$
\begin{aligned}
x^{\star} &= \frac{1}{2} x^{\top} \Sigma x - x^{\top} \Sigma b \\
\text{u.c.} & \quad \left\{ \begin{array}{l} \mathbf{1}_n^{\top} x = 1 \\ x_i \in \left\{ \begin{array}{ll} [0, 1] & \text{if } \mathcal{CI}_i < \mathcal{CI}^{(m,n)} \\ \{0\} & \text{if } \mathcal{CI}_i \geq \mathcal{CI}^{(m,n)} \end{array} \right. \end{array} \right.
\end{aligned}
$$

- The last constraint can be written as:

$$\mathbf{0}_n \leq x \leq x^{+}$$

where:

$$x_i^{+} = \mathbb{1}\left\{ \mathcal{CI}_i < \mathcal{CI}^{(m,n)} \right\}$$

We obtain again a QP problem

Order-statistic approach

The QP problem is:

$$
\begin{aligned}
x^{\star}(m) &= \frac{1}{2} x^{\top} \Sigma x - x^{\top} \Sigma b \\
\text{s.t.} & \left\{
\begin{array}{l}
\mathbf{1}_n^{\top} x = 1 \\
\mathbf{0}_n \leq x \leq x^{+} \\
x_i^{+} = \mathbb{1}\left\{\mathcal{CI}_i < \mathcal{CI}^{(m,n)}\right\}
\end{array}
\right.
\end{aligned}
$$

We have the following QP correspondences:

$$
\begin{aligned}
Q &= \Sigma \\
R &= \Sigma b \\
A &= \mathbf{1}_n^{\top} \\
B &= 1 \\
x^{-} &= \mathbf{0}_n \\
x^{+} &= \mathbb{1}\left\{\mathcal{CI} < \mathcal{CI}^{(m,n)}\right\}
\end{aligned}
$$

Order-statistic approach

Table 52: Optimal decarbonization portfolios (order-statistic approach)

m	0	1	2	3	4	5	6	7	$\mathcal{CI}$
$x_1^\star$	23.00	18.68	15.94	14.00	**0.00**	0.00	0.00	0.00	100.5
$x_2^\star$	19.00	23.54	26.26	35.84	45.65	56.44	**0.00**	0.00	57.2
$x_3^\star$	17.00	17.46	17.50	**0.00**	0.00	0.00	0.00	0.00	250.4
$x_4^\star$	13.00	6.50	**0.00**	0.00	0.00	0.00	0.00	0.00	352.3
$x_5^\star$	9.00	11.88	13.63	17.98	21.18	26.14	34.73	100.00	27.1
$x_6^\star$	8.00	10.85	12.44	15.84	13.20	17.42	65.27	**0.00**	54.2
$x_7^\star$	6.00	11.11	14.23	16.34	19.98	**0.00**	0.00	0.00	78.6
$x_8^\star$	5.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	426.7
$\sigma(x^\star \mid b)$ (in bps)	0.00	77.78	84.51	240.71	278.40	400.71	11.4%	21.6%	
$\mathcal{CI}(x)$	155.18	116.66	96.48	60.87	54.70	48.81	44.79	27.10	
$\mathcal{R}$ (in %)	0.00	24.82	37.82	60.77	64.75	68.55	71.14	82.54	

- The reduction of carbon intensity is equal to 24.82% if we eliminate the worst performer
- In this case, we obtain a tracking error of 77.78 bps

Order-statistic approach

The "*naive*" solution consists in re-weighting the remaining assets:

$$x_i = \frac{\mathbb{1}\left\{\mathcal{CI}_i < \mathcal{CI}^{(m,n)}\right\} \cdot b_i}{\sum_{k=1}^{n} \mathbb{1}\left\{\mathcal{CI}_k < \mathcal{CI}^{(m,n)}\right\} \cdot b_k}$$

Order-statistic approach

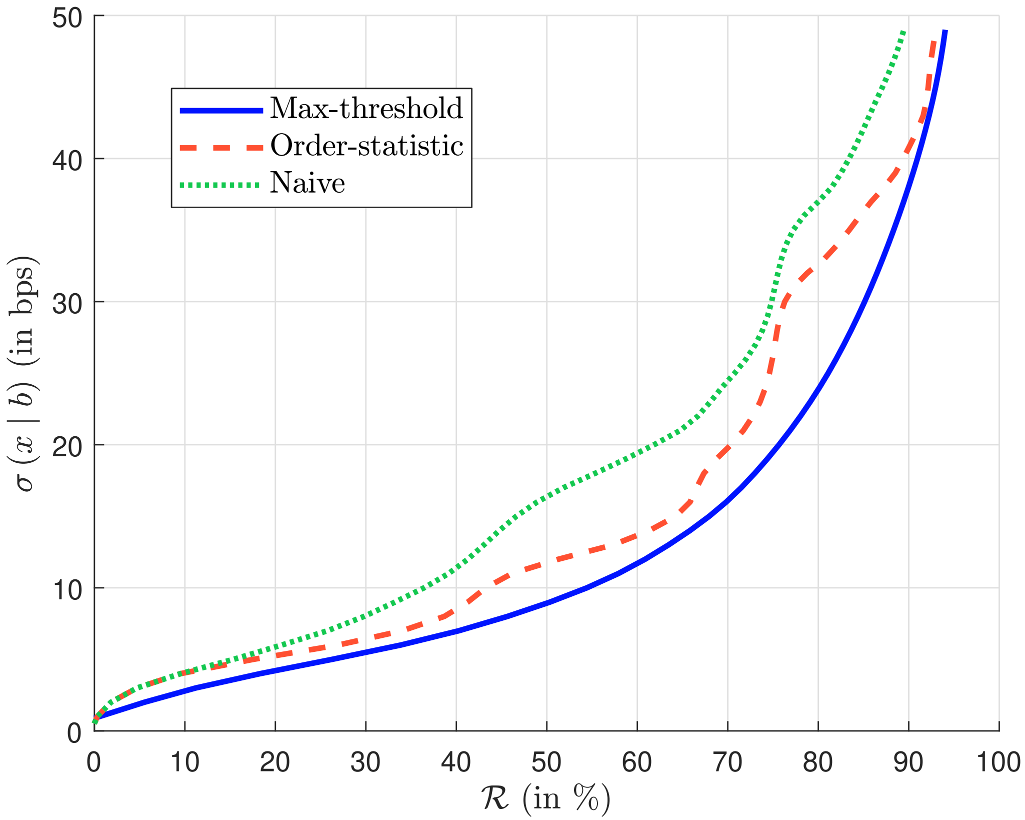
Table 53: Optimal decarbonization portfolios (order-statistic naive approach)

m	0	1	2	3	4	5	6	7	$\mathcal{CI}$
$x_1^\star$	23.00	24.21	28.05	35.38	**0.00**	0.00	0.00	0.00	100.50
$x_2^\star$	19.00	20.00	23.17	29.23	45.24	52.78	**0.00**	0.00	57.20
$x_3^\star$	17.00	17.89	20.73	**0.00**	0.00	0.00	0.00	0.00	250.40
$x_4^\star$	13.00	13.68	**0.00**	0.00	0.00	0.00	0.00	0.00	352.30
$x_5^\star$	9.00	9.47	10.98	13.85	21.43	25.00	52.94	100.00	27.10
$x_6^\star$	8.00	8.42	9.76	12.31	19.05	22.22	47.06	**0.00**	54.20
$x_7^\star$	6.00	6.32	7.32	9.23	14.29	**0.00**	0.00	0.00	78.60
$x_8^\star$	5.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	426.70
$\sigma(x^\star \mid b)$ (in bps)	0.00	92.73	186.22	355.15	301.43	409.44	12.5%	21.6%	
$\mathcal{CI}(x)$	55.18	140.89	107.37	69.96	53.24	49.01	39.85	27.10	
$\mathcal{R}$ (in %)	0.00	9.21	30.81	54.92	65.69	68.42	74.32	82.54	

- The reduction of carbon intensity is equal to 9.21% if we eliminate the worst performer
- In this case, we obtain a tracking error of 92.73 bps

Efficient frontier

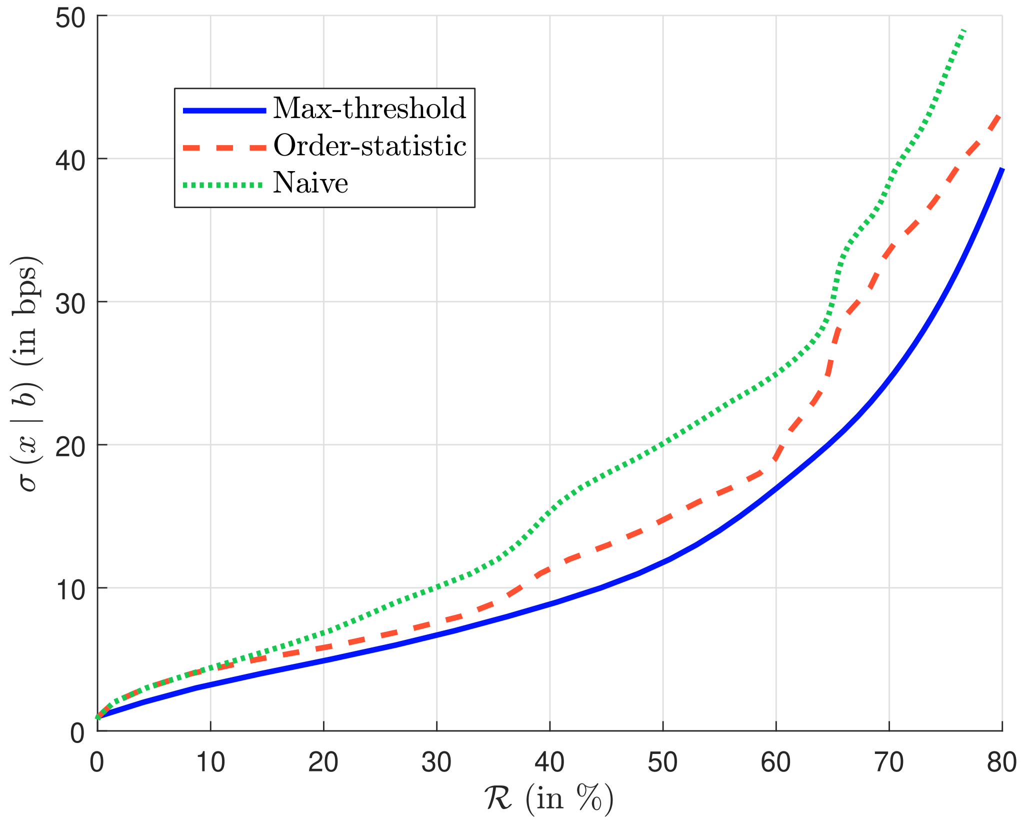
Figure 106: Efficient frontier of optimal decarbonization portfolios (S&P 500 index, October 2021, scope 1)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Efficient frontier

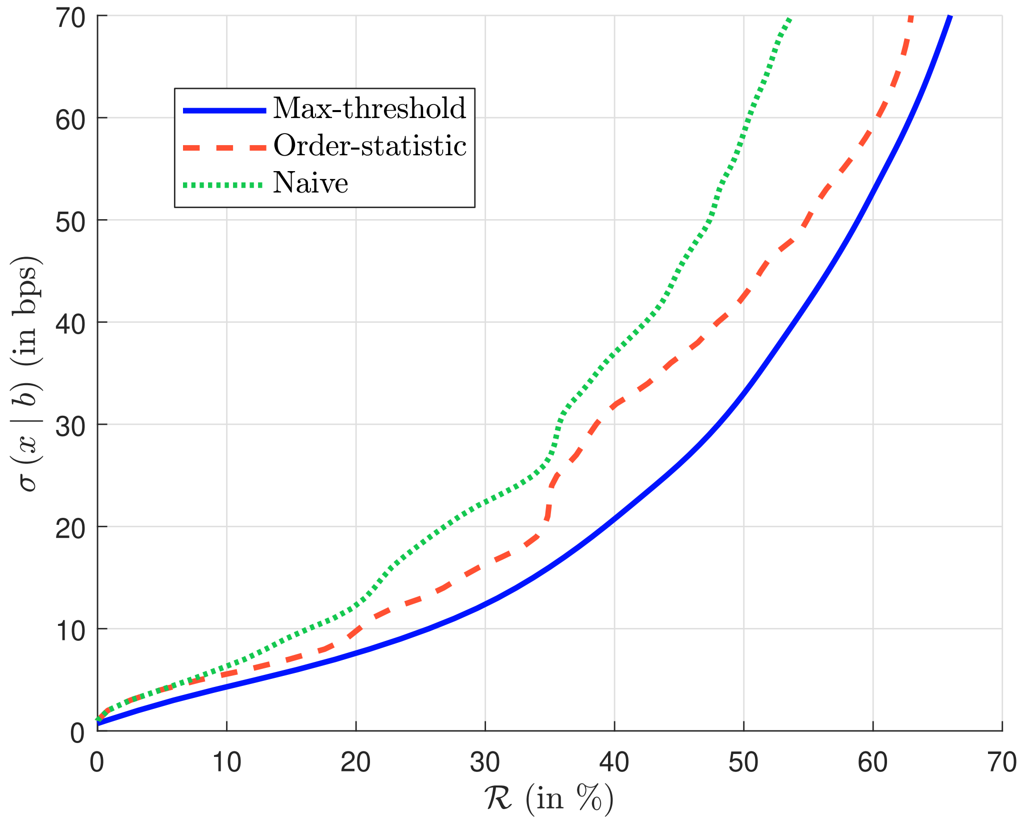
Figure 107: Efficient frontier of optimal decarbonization portfolios (S&P 500 index, October 2021, scope $1 + 2$)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Efficient frontier

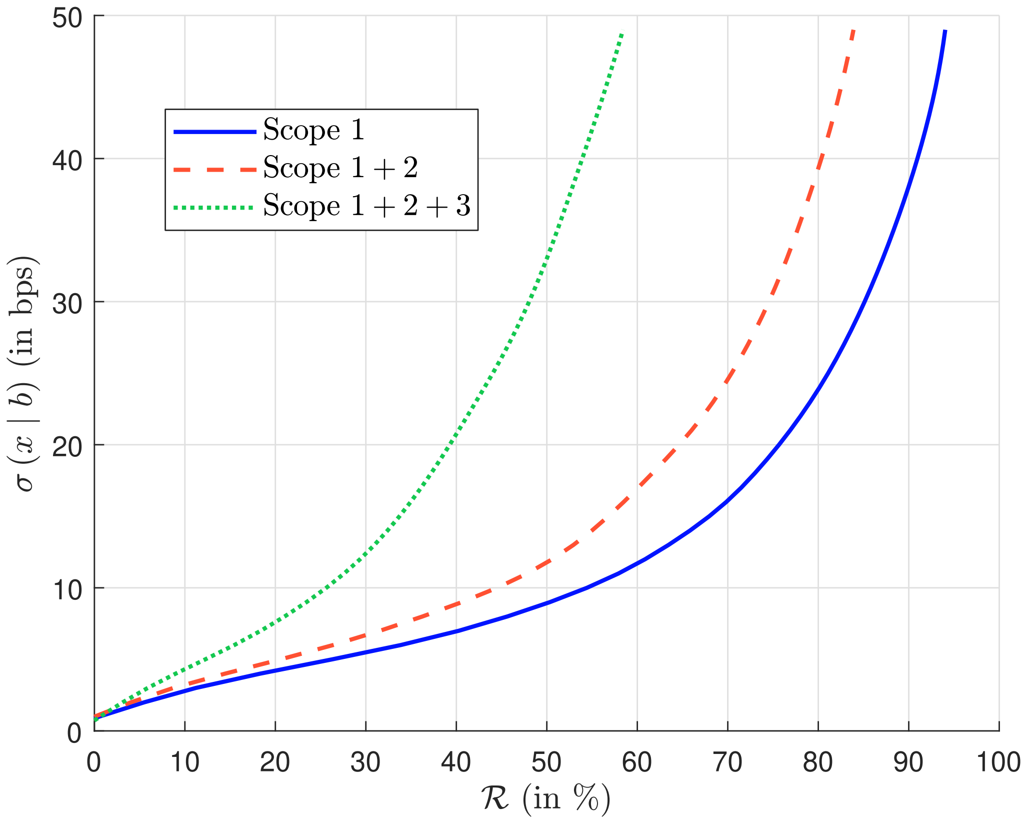
Figure 108: Efficient frontier of optimal decarbonization portfolios (S&P 500 index, October 2021, scope $1+2+3$)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Efficient frontier

Figure 109: Impact of the carbon scope on the tracking error volatility (S&P 500 index, October 2021, max-threshold approach)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Overlap statistics

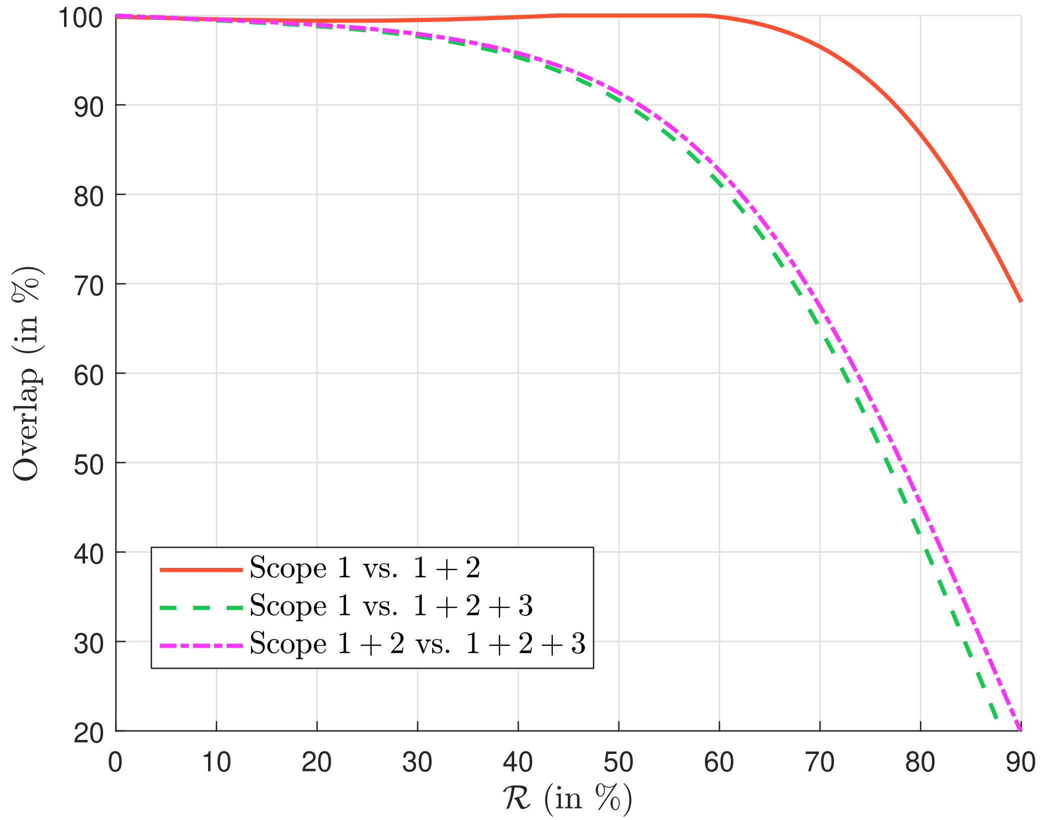
The overlap measure between two portfolios x and y is defined as:

$$\text{overlap}(x, y) = 1 - \frac{1}{2}\sum_{i=1}^{n} |x_i - y_i| = \sum_{i=1}^{n} \min(x_i, y_i)$$

It is equal to 100% if the two portfolios are the same and 0% if the two portfolios have no common trading positions

Overlap statistics

Figure 110: Overlap of optimal decarbonization portfolios (S&P 500 index, October 2021, max-threshold approach)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Lessons from portfolio decarbonization

- 2010: Scope 1 $\Rightarrow$ 2015: Scope $1 + 2$ $\Rightarrow$ 2020's: Scope $1 + 2 + 3$
- Big differences between Scope $1 + 2$ and Scope $1 + 2 + 3$
  - High tracking error risk
  - Measurement uncertainty
  - Less diversification?

Carbon emissions contribution

- The carbon emissions contribution of a nominal exposure W_i to the stock i is equal to:

$$\boldsymbol{\mathcal{CEC}}_i(W_i) = \frac{W_i}{\mathcal{MC}_i} \cdot (\mathcal{FP}_i \cdot \boldsymbol{\mathcal{CE}}_i)$$

  where $\mathcal{FP}_i$ is the float percentage associated with the stock i and $\mathcal{MC}_i$ is the free-float market capitalization
- $\mathcal{FP}_i \cdot \boldsymbol{\mathcal{CE}}_i$ is the quantity of carbon emissions emitted by the issuer i that is attributed to public investors
- We normalize the carbon emissions amount $\mathcal{FP}_i \cdot \boldsymbol{\mathcal{CE}}_i$ by the holding ratio $W_i / \mathcal{MC}_i$

If we assume that $\mathcal{FP}_i = 90\%$, $\mathcal{MC}_i = \$20$ bn, $\boldsymbol{\mathcal{CE}}_i = 3\,116\,272$ tCO_2e and $W_i = \$100$ mn, we obtain:

$$\boldsymbol{\mathcal{CEC}}_i(\$100 \text{ mn}) = \frac{100}{20 \times 10^3} \times (90\% \times 3\,116\,272) = 14\,023.22 \text{ tCO}_2\text{e}$$

Carbon emissions contribution

- The market value of the company is:

$$\mathcal{MV}_i = \frac{\mathcal{MC}_i}{\mathcal{FP}_i}$$

- The carbon emissions contribution of a nominal exposure W_i to the stock i is equal to:

$$\boldsymbol{\mathcal{CEC}}_i (W_i) = \varpi_i \cdot \boldsymbol{\mathcal{CE}}_i = \frac{W_i}{\mathcal{MV}_i} \cdot \boldsymbol{\mathcal{CE}}_i$$

where $\varpi_i = W_i / \mathcal{MV}_i$ is the ownership ratio of the company

If we assume that $\mathcal{FP}_i = 90\%$, $\mathcal{MC}_i = \$20$ bn, $\boldsymbol{\mathcal{CE}}_i = 3\,116\,272$ tCO_2e and $W_i = \$100$ mn, we obtain:

$$\mathcal{MV}_i = \frac{\mathcal{MC}_i}{\mathcal{FP}_i} = \$22.22\text{bn}, \ \varpi_i = \frac{W_i}{\mathcal{MV}_i} = \frac{\$100 \text{ mn}}{\$22.22 \text{ bn}} = 0.45\%$$

$$\boldsymbol{\mathcal{CEC}}_i (\$100 \text{ mn}) = 0.45\% \times 3\,116\,272 = 14\,023.22 \text{ tCO}_2\text{e}$$

Carbon emissions contribution

- We have:

$$\mathcal{CI}_i^{\mathcal{MV}} = \frac{\mathcal{CE}_i}{\mathcal{MV}_i}$$

- It follows that:

$$\mathcal{CEC}_i\left(W_i\right) = W_i \cdot \mathcal{CI}_i^{\mathcal{MV}}$$

If we assume that $\mathcal{FP}_i = 90\%$, $\mathcal{MC}_i = \$20$ bn, $\mathcal{CE}_i = 3\,116\,272$ tCO_2e and $W_i = \$100$ mn, we obtain:

$$\begin{aligned}
\mathcal{MV}_i &= \frac{\mathcal{MC}_i}{\mathcal{FP}_i} = \$22.22\text{bn} \\
\mathcal{CI}_i^{\mathcal{MV}} &= \frac{\mathcal{CE}_i}{\mathcal{MV}_i} = \frac{3\,116\,272}{22\,222.22} = 140.2322 \text{ tCO}_2\text{e}/\$ \text{ mn} \\
\mathcal{CEC}_i\left(\$100 \text{ mn}\right) &= 100 \times 140.2322 = 14\,023.22\text{tCO}_2\text{e}
\end{aligned}$$

Carbon emissions of a portfolio

- W is the nominal value of the portfolio
- $W_i = W \cdot x_i$ is the wealth invested in asset i
- The carbon emissions of the portfolio is the sum of the carbon emissions contributions:

$$\begin{aligned}\mathcal{CE}(x; W) &= \sum_{i=1}^{n} \mathcal{CEC}_i(W_i) \\ &= \sum_{i=1}^{n} \frac{W_i \cdot \mathcal{FP}_i}{\mathcal{MC}_i} \cdot \mathcal{CE}_i \\ &= W \cdot \overline{\mathcal{CE}}(x; W)\end{aligned}$$

where $\overline{\mathcal{CE}}(x; W)$ is the normalized carbon emissions for a \$1 investment:

$$\overline{\mathcal{CE}}(x; W) = \sum_{i=1}^{n} \frac{x_i \cdot \mathcal{FP}_i}{\mathcal{MC}_i} \cdot \mathcal{CE}_i$$

- $\overline{\mathcal{CE}}(x; W)$ is generally expressed in tCO_2e per 1\$ mn invested

Carbon emissions of a portfolio

Remark

If we assume that $\mathcal{FP}_i = 100\%$ and the portfolio is an index ($x_i \propto \mathcal{MC}_i$), the carbon emissions of the portfolio is equal to the ownership ratio of the index portfolio times the sum of carbon emissions of all constituents times:

$$\mathcal{CE}(x; W) = \frac{W}{\sum_{i=1}^{n} \mathcal{MC}_i} \sum_{i=1}^{n} \mathcal{CE}_i$$

Carbon intensity of a portfolio

- We have:

$$\mathcal{CI}^{\mathrm{direct}}(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{CI}_i$$

- The carbon intensity of the portfolio is:

$$\mathcal{CI}^{\mathrm{exact}}(x; W) = \frac{\mathcal{CE}(x; W)}{Y(x; W)}$$

where:

$$Y(x; W) = \sum_{i=1}^{n} \frac{W_i \cdot \mathcal{FP}_i}{\mathcal{MC}_i} \cdot Y_i$$

Computation of the portfolio's carbon emissions

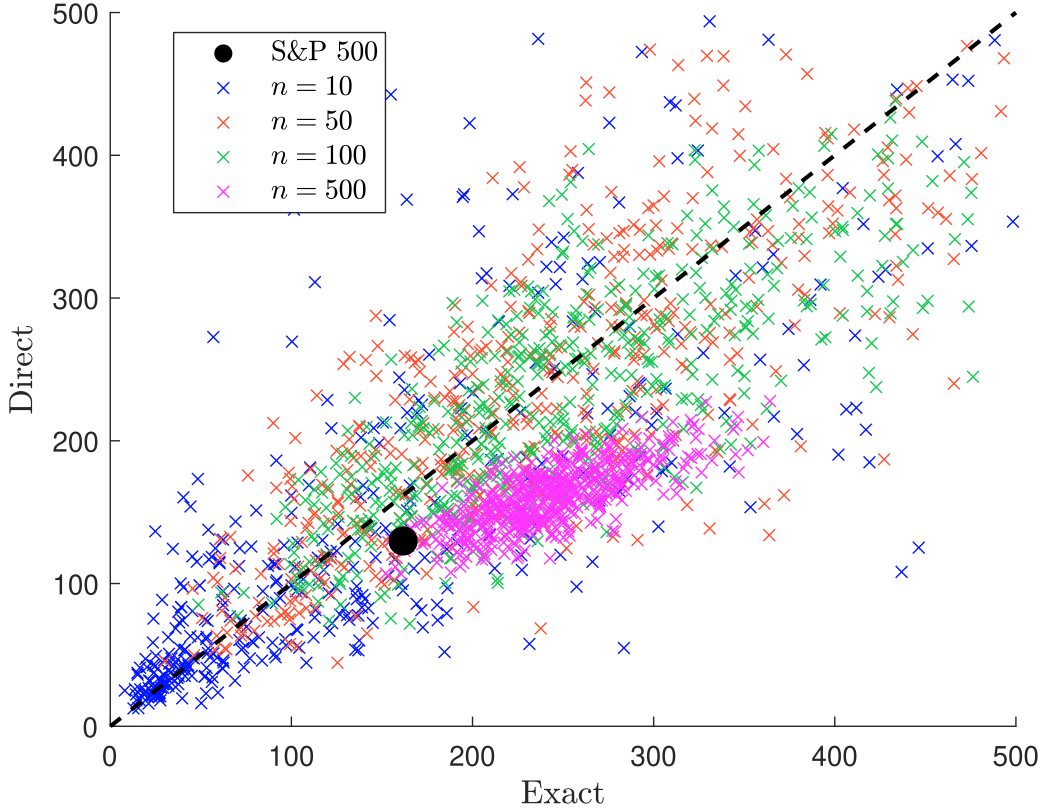
Table 54: Carbon emission (in tCO_2e) and intensity (tCO_2e/\$ mn) of S&P 500 index portfolios

Scope	$\mathcal{CE}(x; W)$			$\mathcal{CI}(x)$	
	S&P 500	\$1 bn	\$5 bn	Exact	Direct
1	1.66×10^9	40.5×10^3	202.5×10^3	133.8	99.2
$1+2$	2.01×10^9	48.9×10^3	244.7×10^3	161.7	129.8
$1+2+3$	3.75×10^9	91.4×10^3	457.2×10^3	302.1	245.2

Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Computation of the portfolio's carbon emissions

Figure 111: Exact vs. direct computation of scope 1 + 2 carbon intensity (S&P 500 index, October 2021)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

Portfolio optimization with carbon emissions

- We have:

$$\mathcal{CE}(x;W) \leq \mathcal{CE}^{+} \quad \Leftrightarrow \quad \sum_{i=1}^{n} \frac{W_i \cdot \mathcal{FP}_i}{\mathcal{MC}_i} \cdot \mathcal{CE}_i \leq \mathcal{CE}^{+}$$

$$= \quad \sum_{i=1}^{n} x_i \cdot \mathcal{CI}_i^{\mathcal{MV}} \leq \frac{\mathcal{CE}^{+}}{W}$$

where $\mathcal{CI}_i^{\mathcal{MV}}$ is the carbon intensity measure normalized by the market value of the company i:

$$\mathcal{CI}_i^{\mathcal{MV}} = \frac{\mathcal{FP}_i}{\mathcal{MC}_i} \cdot \mathcal{CE}_i = \frac{\mathcal{CE}_i}{\mathcal{MV}_i}$$

- In the case where $\mathcal{CE}^{+} = (1-\mathcal{R}) \cdot \mathcal{CE}(b;W)$, we obtain:

$$\frac{\mathcal{CE}^{+}}{W} = (1-\mathcal{R}) \cdot \sum_{i=1}^{n} b_i \cdot \mathcal{CI}_i^{\mathcal{MV}}$$

Portfolio optimization with carbon emissions

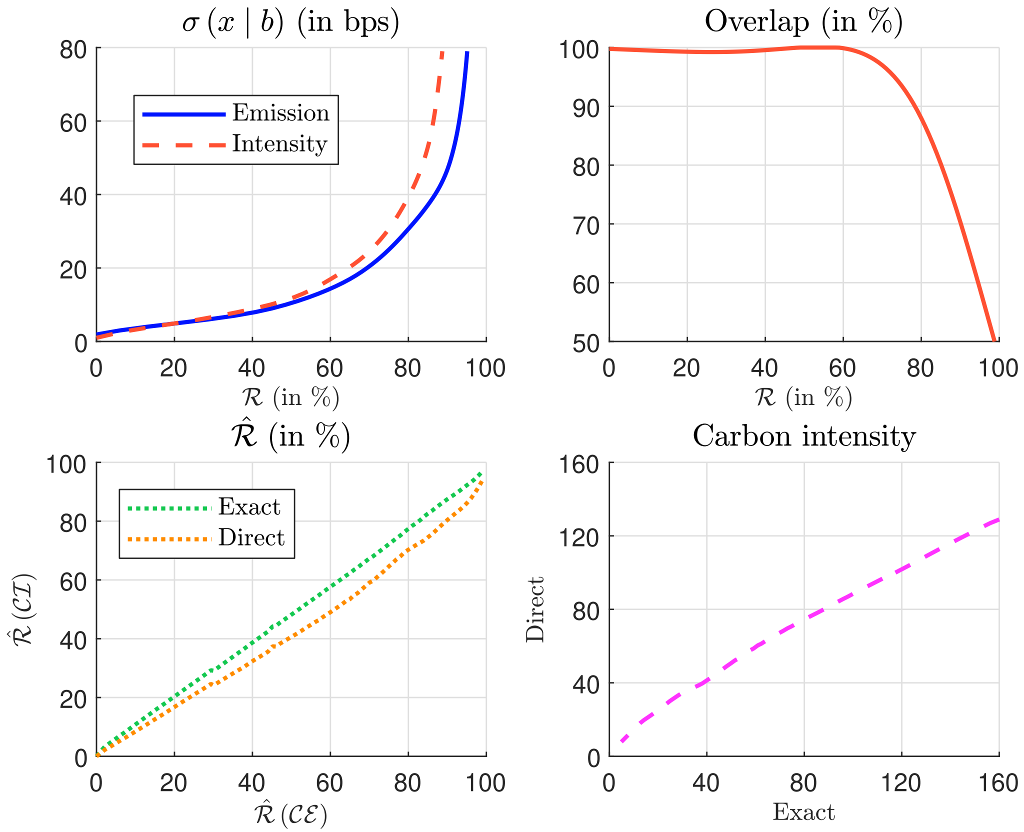
- The optimization problem becomes:

$$
\begin{aligned}
x^{\star}(\mathcal{R}) & = \arg\min \frac{1}{2}(x-b)^{\top}\Sigma(x-b) \\
& \text{s.t.} \quad \begin{cases}
\mathbf{1}_n^{\top} x = 1 \\
x \geq \mathbf{0}_n \\
\sum_{i=1}^{n} x_i \cdot \mathcal{CI}_i^{\mathcal{MV}} \leq (1-\mathcal{R}) \cdot \left(\sum_{i=1}^{n} b_i \cdot \mathcal{CI}_i^{\mathcal{MV}}\right)
\end{cases}
\end{aligned}
$$

- The implied reduction rates are $\hat{\mathcal{R}}(\mathcal{CE}) = 1 - \mathcal{CE}(x^{\star}) / \mathcal{CE}(b)$ and $\hat{\mathcal{R}}(\mathcal{CI}) = 1 - \mathcal{CI}(x^{\star}) / \mathcal{CI}(b)$

Portfolio optimization with carbon emissions

Figure 112: Portfolio decarbonization with carbon emissions (S&P 500 index, October 2021, scope $1+2$)



Source: Trucost reporting year 2020 & Le Guenedal and Roncalli (2022).

The arithmetic of net zero

"Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 $GtCO_2e$ for a 50% probability of limiting warming to $1.5°\mathrm{C}$, and 420 $GtCO_2e$ for a 66% probability (medium confidence)" (IPCC, 2018).

$$
\begin{aligned}
\Pr\left\{\mathcal{T} \leq 1.5°\mathrm{C} \mid \mathcal{CB}(2019, 2050) \leq 580 \text{ GtCO}_2\text{e}\right\} &\geq 50\% \\
\Pr\left\{\mathcal{T} \leq 1.5°\mathrm{C} \mid \mathcal{CB}(2019, 2050) \leq 420 \text{ GtCO}_2\text{e}\right\} &\geq 66\% \\
\Pr\left\{\mathcal{T} \leq 1.5°\mathrm{C} \mid \mathcal{CB}(2019, 2050) \leq 300 \text{ GtCO}_2\text{e}\right\} &\geq 83\%
\end{aligned}
$$

NZE framework

Net zero emission tools

- **Absolute carbon emissions**
- Carbon target
- Carbon trend
- Carbon budget

Carbon budget

- The carbon budget defines the amount of GHG emissions that a country, a company or an organization produces over the time period $[t_0, t]$.
- The gross carbon budget is equal to:

$$\mathcal{CB}_i(t_0, t) = \int_{t_0}^{t} \mathcal{CE}_i(s)\,\mathrm{d}s$$

- The net carbon budget is equal to:

$$\begin{aligned}\mathcal{CB}_i(t_0, t) &= \int_{t_0}^{t} \left(\mathcal{CE}_i(s) - \mathcal{CE}_i^{\star}\right)\mathrm{d}s \\ &= -(t - t_0) \cdot \mathcal{CE}_i^{\star} + \int_{t_0}^{t} \mathcal{CE}_i(s)\,\mathrm{d}s\end{aligned}$$

Carbon budget

We assume that $\mathcal{CE}_i(t)$ is known for $t \in \{t_0, t_1, \ldots, t_m\}$ and $\mathcal{CE}_i(t)$ is linear between two consecutive dates:

$$\mathcal{CE}_i(t) = \mathcal{CE}_i(t_{k-1}) + \frac{\mathcal{CE}_i(t_k) - \mathcal{CE}_i(t_{k-1})}{t_k - t_{k-1}}(t - t_{k-1}) \qquad \text{if } t \in [t_{k-1}, t_k]$$

We can show that:

$$\begin{aligned}
\mathcal{CB}_i(t_0, t) \quad = \quad & \frac{1}{2}\sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t_k) - \mathcal{CE}_i(t_{k-1})\right)(t_k + t_{k-1}) + \\
& \sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t_{k-1}) - \mathcal{CE}_i^\star\right) t_k - \sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t_k) - \mathcal{CE}_i^\star\right) t_{k-1} + \\
& \frac{1}{2}\left(\mathcal{CE}_i(t) - \mathcal{CE}_i\left(t_{k(t)}\right)\right)\left(t + t_{k(t)}\right) + \\
& \left(\mathcal{CE}_i\left(t_{k(t)}\right) - \mathcal{CE}_i^\star\right) t - \sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t) - \mathcal{CE}_i^\star\right) t_{k(t)}
\end{aligned}$$

Carbon budget

Example 1

The data corresponds to observed values before 2019, and estimated values after this date. After year 2020, we assume that the carbon emissions are linear between two dates.

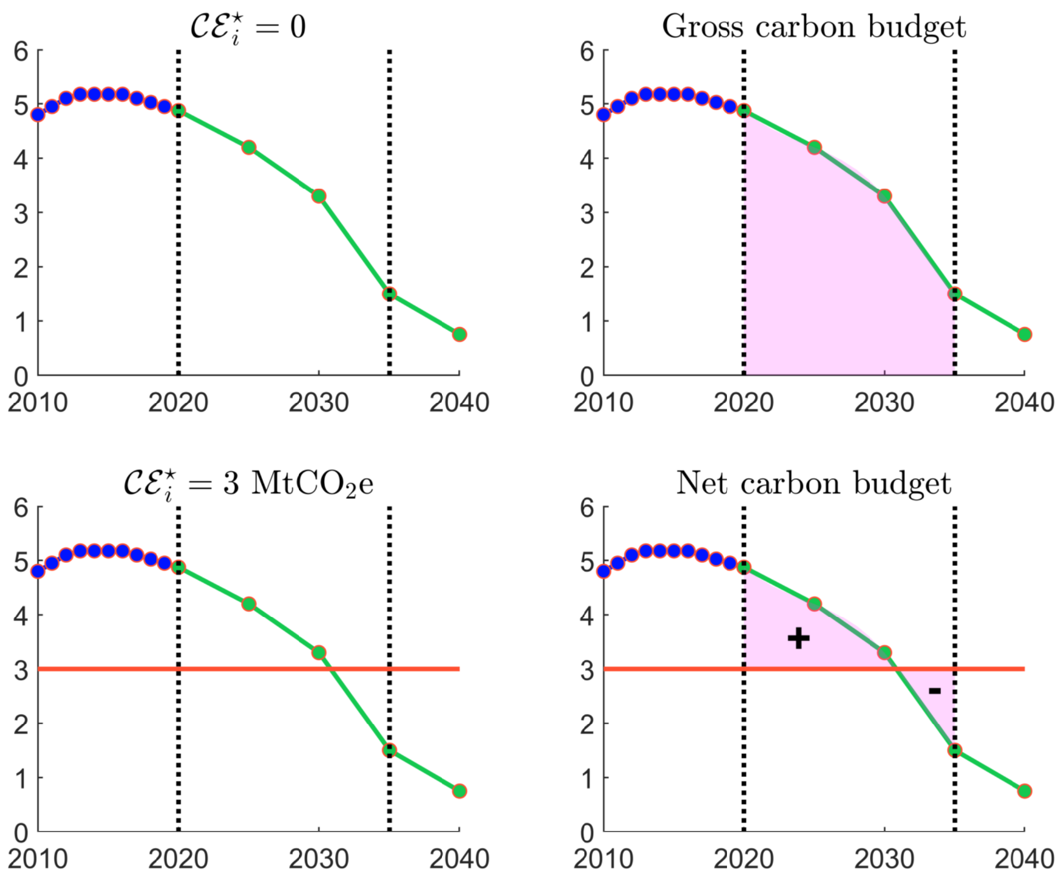
Table 55: Carbon emissions in $MtCO_2e$

Year	2010	2011	2012	2013	2014	2015	2016	2017
$\mathcal{CE}_i$	4.800	4.950	5.100	5.175	5.175	5.175	5.175	5.100
Year	2018	2019	2020*	2025*	2030*	2035*	2040*	2050*
$\mathcal{CE}_i$	5.025	4.950	4.875	4.200	3.300	1.500	0.750	0.150

Source: Le Guenedal *et al.* (2022).

Carbon budget

Figure 113: The gross carbon budget $\mathcal{CB}_i\,(2020, 2035)$ is equal to 53.4375 $MtCO_2e$ whereas the net carbon budget is equal to 8.4375 $MtCO_2e$



Source: Le Guenedal *et al.* (2022).

Carbon reduction

- $t_{\mathcal{L}ast}$ is the last reporting date.
- The estimated carbon emissions are:

$$\mathcal{CE}_i(t) := \widehat{\mathcal{CE}}_i(t) = \left(1 - \mathcal{R}_i(t_{\mathcal{L}ast}, t)\right) \cdot \mathcal{CE}_i(t_{\mathcal{L}ast})$$

where $\mathcal{R}_i(t_{\mathcal{L}ast}, t)$ is the carbon reduction between $t_{\mathcal{L}ast}$ and t

- We have

$$\begin{aligned} \mathcal{CB}_i(t_{\mathcal{L}ast}, t) &= (t - t_{\mathcal{L}ast})\left(\mathcal{CE}_i(t_{\mathcal{L}ast}) - \mathcal{CE}_i^\star\right) - \\ & \quad \mathcal{CE}_i(t_{\mathcal{L}ast}) \int_{t_{\mathcal{L}ast}}^{t} \mathcal{R}_i(t_{\mathcal{L}ast}, s)\,\mathrm{d}s \end{aligned}$$

Carbon reduction

1. Global approach

$$\mathcal{R}_i\left(t_{\mathcal{L}ast}, t\right) = \mathcal{R}_{\mathcal{G}lobal}\left(t_{\mathcal{L}ast}, t\right)$$

2. Country approach

$$\mathcal{R}_i\left(t_{\mathcal{L}ast}, t\right) = \mathcal{R}_{\mathcal{C}ountry(c)}\left(t_{\mathcal{L}ast}, t\right) \qquad \text{if } i \in \mathcal{C}ountry\left(c\right)$$

3. Sector approach

$$\mathcal{R}_i\left(t_{\mathcal{L}ast}, t\right) = \mathcal{R}_{\mathcal{S}ector(s)}\left(t_{\mathcal{L}ast}, t\right) \qquad \text{if } i \in \mathcal{S}ector\left(s\right)$$

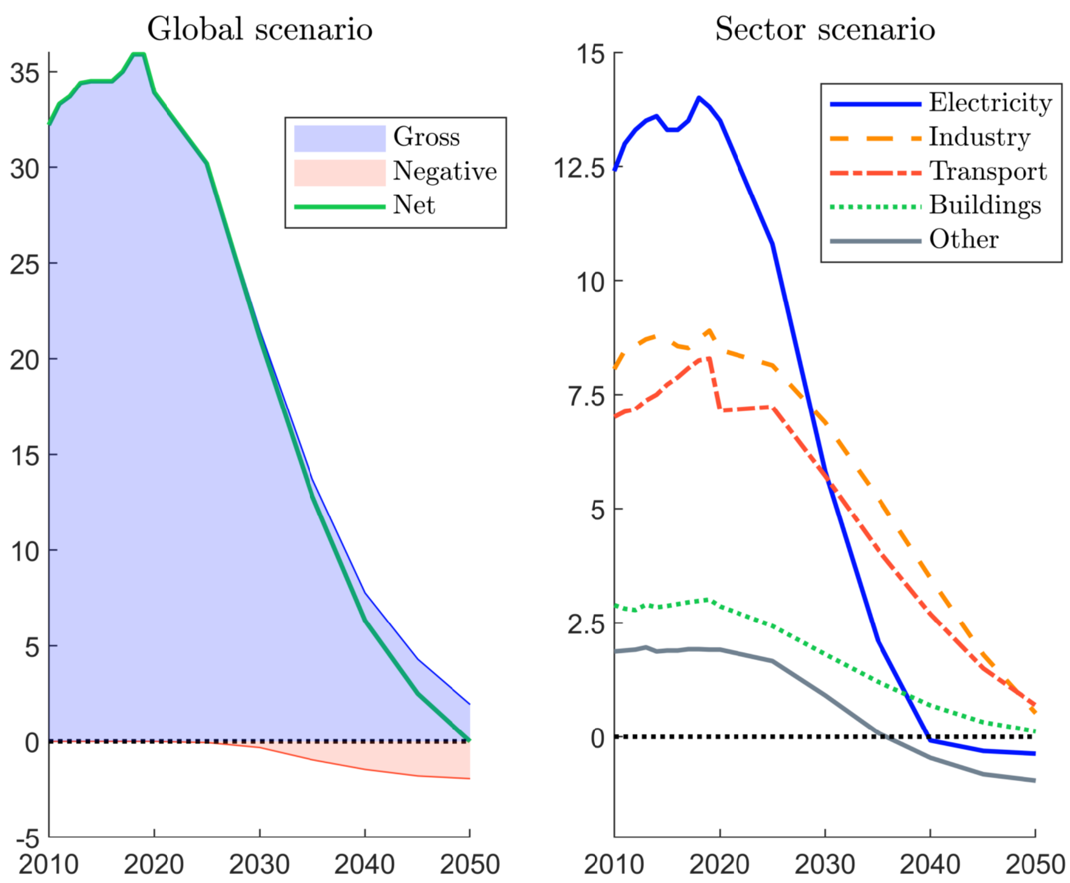
4. Issuer approach

$$\mathcal{R}_i\left(t_{\mathcal{L}ast}, t\right) = \hat{\mathcal{R}}_i\left(t_{\mathcal{L}ast}, t\right)$$

where $\hat{\mathcal{R}}_i\left(t_{\mathcal{L}ast}, t\right)$ is the estimated value by the issuer

Carbon reduction

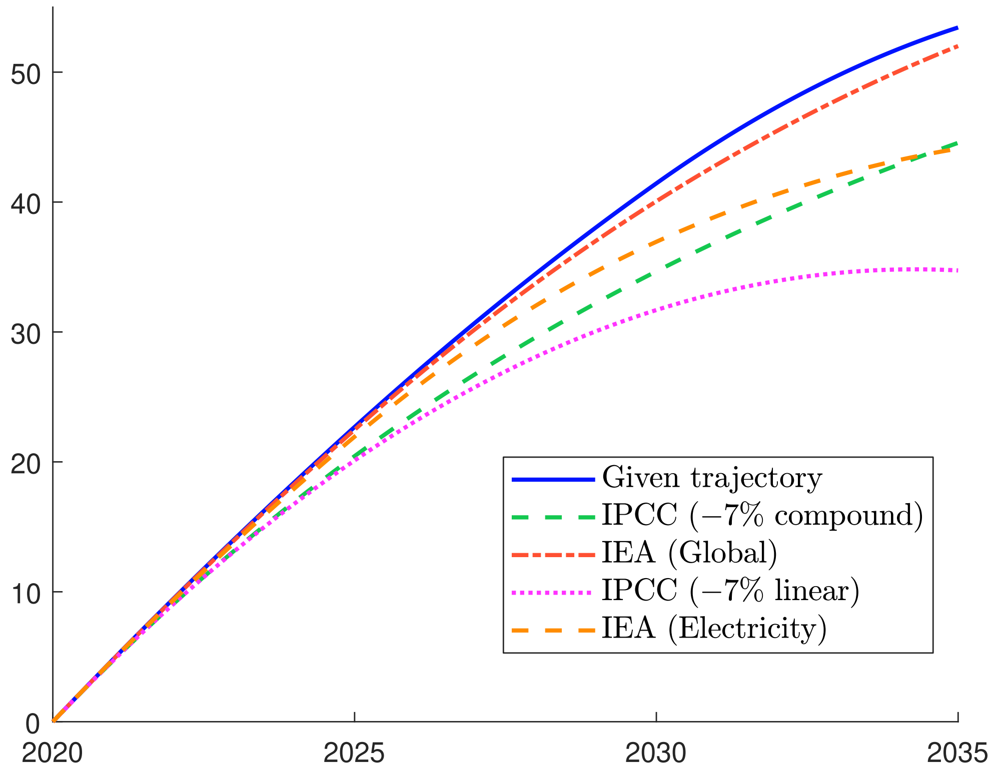
Figure 114: CO_2 emissions in the IEA NZE scenario



Source: IEA (2021).

Carbon reduction

Figure 115: Comparison of gross carbon budget with different scenarios*



Source: IEA (2021), IPCC (2018) & Le Guenedal *et al.* (2022).

*Reduction scenarios: given trajectory (Example 1), IPCC (−7% compound reduction), IEA (global scenario), IPCC (−7% linear reduction) and IEA (electricity sector scenario)

Carbon target

The carbon target setting is defined from the following space:

$$\mathcal{T} = \left\{ k \in [1, m] : \left(i, j, t_1^k, t_2^k, \boldsymbol{\mathcal{R}}_{i,j}\left(t_1^k, t_2^k \right) \right) \right\}$$

where k is the target index, m is the number of historical targets, i is the issuer, j is the scope, t_1^k is the beginning of the target period, t_2^k is the end of the target period, and $\boldsymbol{\mathcal{R}}_{i,j}\left(t_1^k, t_2^k \right)$ is the carbon reduction between t_1^k and t_2^k for the scope j announced by issuer i

Carbon target

Here are the steps to compute the target trajectory

1. The linear annual reduction rate for scope j and target k is given by:

$$\mathcal{R}_{i,j}^{k}(t) = \mathbb{1}\left\{t \in \left[t_1^k, t_2^k\right]\right\} \cdot \frac{\mathcal{R}_{i,j}\left(t_1^k, t_2^k\right)}{t_2^k - t_1^k}$$

2. We aggregate the targets to obtain the annual reduction rate:

$$\mathcal{R}_{i,j}(t) = \sum_{k=1}^{m} \mathcal{R}_{i,j}^{k}(t)$$

3. We compute the global reduction at time t:

$$\mathcal{R}_{i}(t) = \frac{1}{\sum_{j=1}^{3} \mathcal{CE}_{i,j}(t_0)} \cdot \sum_{j=1}^{3} \mathcal{CE}_{i,j}(t_0) \cdot \mathcal{R}_{i,j}(t)$$

4. Finally, we have:

$$\mathcal{CE}_i^{\mathcal{T}arget}(t) := \widehat{\mathcal{CE}}_i(t) = \left(1 - \mathcal{R}_i\left(t_{\mathcal{L}ast}, t\right)\right) \cdot \mathcal{CE}_i\left(t_{\mathcal{L}ast}\right)$$

where $\mathcal{R}_i\left(t_{\mathcal{L}ast}, t\right) = \sum_{s=t_{\mathcal{L}ast}+1}^{t} \mathcal{R}_i(s)$

Carbon target

Example 2

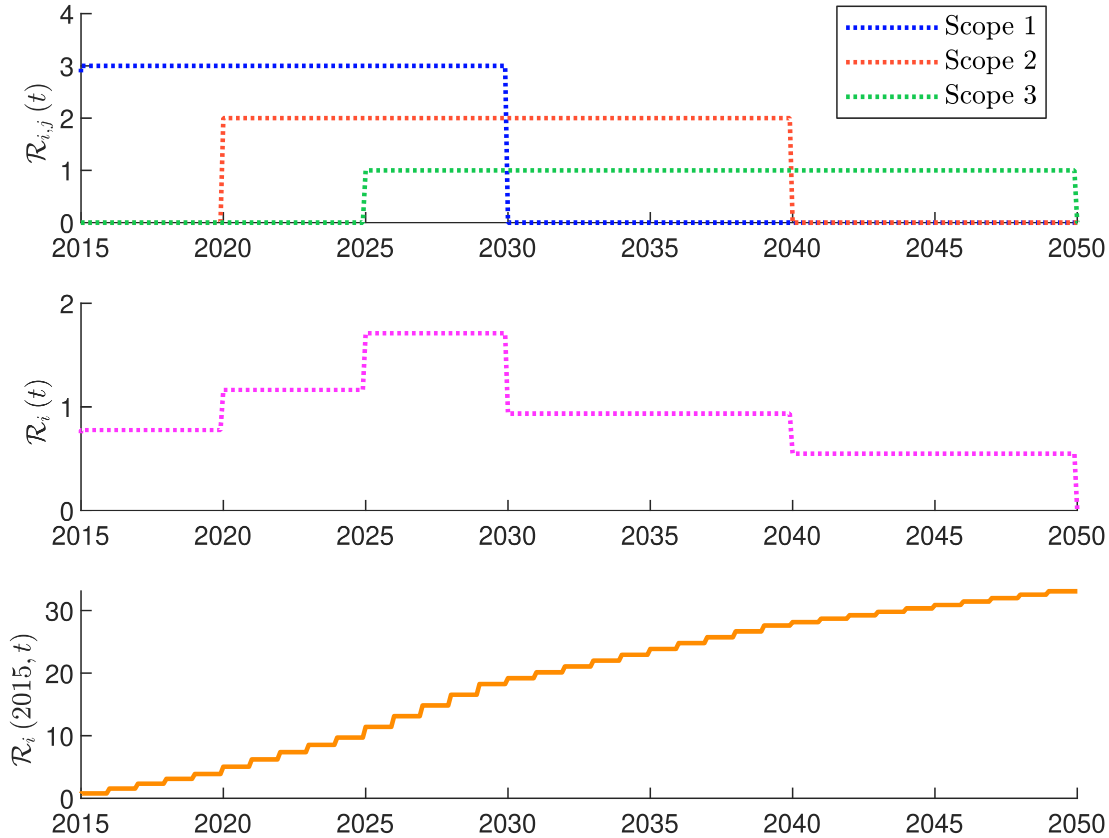
- The dates t_1^k and t_2^k correspond to the 1st January
- We assume that $\mathcal{CE}_{i,1}(2020) = 10.33$, $\mathcal{CE}_{i,2}(2020) = 7.72$ and $\mathcal{CE}_{i,3}(2020) = 21.86$

Table 56: Carbon reduction targets (Example 2)

k	Release Date	Scope	t_1^k	t_2^k	$\mathcal{R}(t_1^k, t_2^k)$
1	01/08/2013	$\mathcal{SC}_1$	2015	2030	45%
2	01/10/2019	$\mathcal{SC}_2$	2020	2040	40%
3	01/01/2019	$\mathcal{SC}_3$	2025	2050	25%

Carbon target

Figure 116: Reduction of the carbon emissions deduced from the three targets (Example 2)



Source: Le Guenedal *et al.* (2022).

Carbon trend

We define the carbon trend by considering a linear constant trend model:

$$\mathcal{CE}_i(t) = \beta_{i,0} + \beta_{i,1} t + u_i(t)$$

where $t \in [t_{\mathcal{F}irst}, t_{\mathcal{L}ast}]$

The carbon trajectory implied by the current trend is given by:

$$\mathcal{CE}_i^{\mathcal{T}rend}(t) := \widehat{\mathcal{CE}}_i(t) = \hat{\beta}_{i,0} + \hat{\beta}_{i,1} t$$

for $t > t_{\mathcal{L}ast}$

Carbon trend

Example 4

Table 57: Carbon emissions in $MtCO_2e$

Year	2007	2008	2009	2010	2011	2012	2013
$\mathcal{CE}_i(t)$	57.82	58.36	57.70	55.03	51.73	46.44	47.19
Year	2014	2015	2016	2017	2018	2019	2020
$\mathcal{CE}_i(t)$	46.18	45.37	40.75	39.40	36.16	38.71	39.91

We obtain:

$$\begin{aligned}\mathcal{CE}_i^{\mathcal{T}rend}(t) &= 3\,637.73 - 1.7832 \cdot t \\ &= 35.61 - 1.7822 \cdot (t - 2020)\end{aligned}$$

The rescaled trend model is:

$$\mathcal{CE}_i^{\mathcal{T}rend}(t) = 39.91 - 1.7822 \cdot (t - 2020)$$

NZE metrics

Net zero emission metrics

Static NZE metrics

- Gap
- Slope
- Budget
- Duration
  - Gap
  - Budget

Dynamic NZE metrics

- Time contribution
  - Error contribution
  - Revision contribution
- Velocity
- Scenarios
  - Zero-velocity scenario
  - Burn-out scenario

Static NZE measures

- t_0 is the current date
- $t^\star$ is the time/target horizon
- $\mathcal{CE}_i^{\mathrm{nze}}(t^\star)$ is the net zero emission scenario for issuer i
  - It can be computed using the targets of the issuer
  - It can be calculated using a market-based consensus scenario:

    $$\mathcal{CE}_i^{\mathrm{nze}}(t^\star) = (1 - \mathcal{R}^\star(t_0, t^\star)) \cdot \mathcal{CE}_i(t_0)$$

    where $\mathcal{R}^\star(t_0, t^\star)$ is the carbon reduction between t_0 and $t^\star$ expected by the market for this issuer
- We use the generic notation $\widehat{\mathcal{CE}}_i(t)$ to name $\mathcal{CE}_i^{Target}(t)$ and $\mathcal{CE}_i^{Trend}(t)$

The NZE duration

The time to reach the NZE scenario (or NZE duration) is defined as follows:

$$\tau_i = \left\{ \inf t : \widehat{\mathcal{CE}}_i\left(t\right) \leq \mathcal{CE}_i^{\mathrm{nze}}\left(t^\star\right) \right\}$$

- If $\widehat{\mathcal{CE}}_i\left(t\right) = \mathcal{CE}_i^{\mathcal{T}arget}\left(t\right)$, we obtain the NZE duration $\tau_i^{\mathcal{T}arget}$ $\Rightarrow$This measure indicates if the carbon targets announced by the company are in line with the consensus scenario $\mathcal{CE}_i^{\mathrm{nze}}\left(t^\star\right)$
- If $\widehat{\mathcal{CE}}_i\left(t\right) = \mathcal{CE}_i^{\mathcal{T}rend}\left(t\right)$, we obtain the NZE duration $\tau_i^{\mathcal{T}rend}$ $\Rightarrow$ This measure indicates if the track record of the issuer is in line with its targets or the consensus scenario

The NZE duration

For the trend approach, we remind that:

$$\mathcal{CE}_i^{\mathcal{T}rend}(t) = \hat{\beta}_{i,0} + \hat{\beta}_{i,1} t$$

We distinguish two cases:

1. If the slope $\hat{\beta}_{i,1}$ is positive, we have:

$$\tau_i^{\mathcal{T}rend} = \begin{cases} t_0 & \text{if } \mathcal{CE}_i(t_0) \leq \mathcal{CE}_i^{\mathrm{nze}}(t^\star) \\ +\infty & \text{otherwise} \end{cases}$$

2. If the slope $\hat{\beta}_1$ is negative, we have:

$$\tau_i^{\mathcal{T}rend} = t_0 + \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \hat{\beta}'_{i,0}}{\hat{\beta}_{i,1}}$$

where $\hat{\beta}'_{i,0} = \hat{\beta}_{i,0} + \hat{\beta}_{i,1} t_0$ is the intercept of the trend model when we use t_0 as the pivot date

The NZE duration

Proof.

$$
\begin{aligned}
\mathcal{CE}_i^{\mathcal{T}rend}(t) \leq \mathcal{CE}_i^{\mathrm{nze}}(t^\star) & \Leftrightarrow \quad \hat{\beta}_{i,0} + \hat{\beta}_{i,1} t \leq \mathcal{CE}_i^{\mathrm{nze}}(t^\star) \\
& \Leftrightarrow \quad t \geq \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \hat{\beta}_{i,0}}{\hat{\beta}_{i,1}} \\
& \Leftrightarrow \quad t \geq t_0 + \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \left(\hat{\beta}_{i,0} + \hat{\beta}_{i,1} t_0\right)}{\hat{\beta}_{i,1}} \\
& \Leftrightarrow \quad t \geq t_0 + \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \hat{\beta}'_{i,0}}{\hat{\beta}_{i,1}}
\end{aligned}
$$

$\blacksquare$

The NZE duration

Example 5 is the combination of Example 2 + Example 4

Table 58: Carbon reduction targets (Example 2)

k	Release Date	Scope	t_1^k	t_2^k	$\mathcal{R}\left(t_1^k, t_2^k\right)$
1	01/08/2013	$\mathcal{SC}_1$	2015	2030	45%
2	01/10/2019	$\mathcal{SC}_2$	2020	2040	40%
3	01/01/2019	$\mathcal{SC}_3$	2025	2050	25%

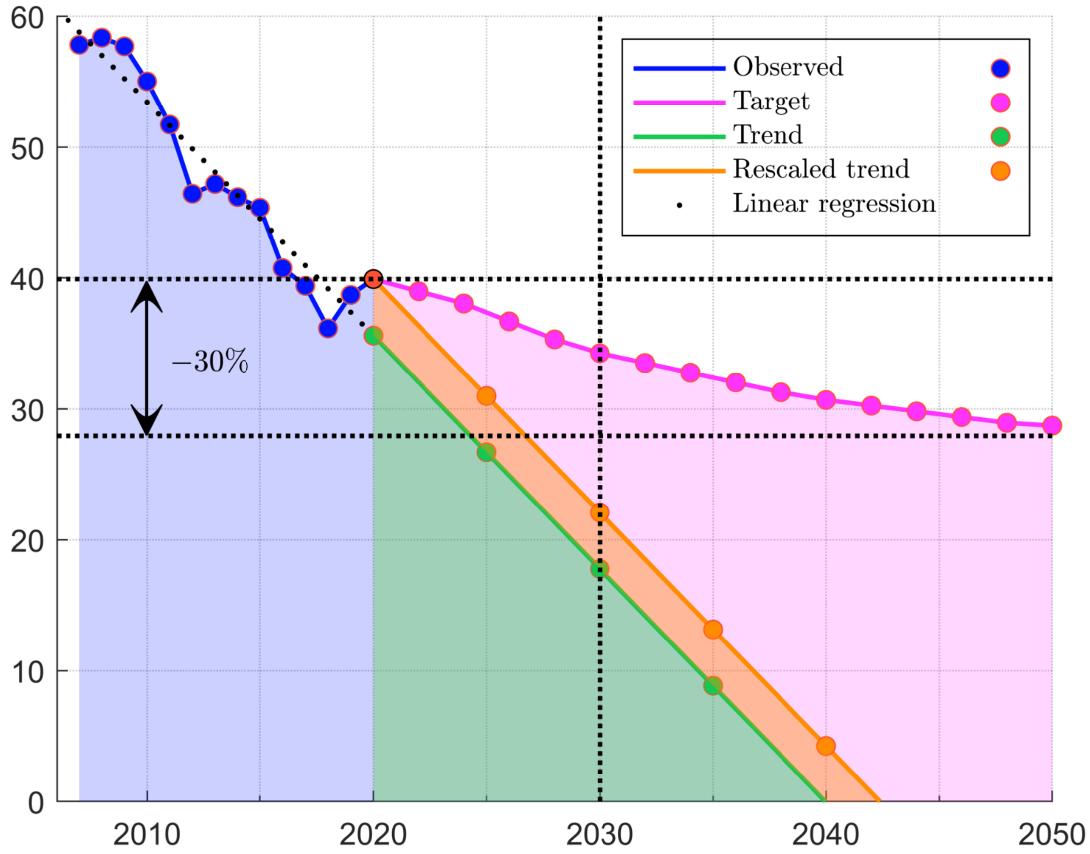
Table 59: Carbon emissions in $MtCO_2e$ (Example 4)

Year	2007	2008	2009	2010	2011	2012	2013
$\mathcal{CE}_i(t)$	57.82	58.36	57.70	55.03	51.73	46.44	47.19
Year	2014	2015	2016	2017	2018	2019	2020
$\mathcal{CE}_i(t)$	46.18	45.37	40.75	39.40	36.16	38.71	39.91

The market-based NZE scenario for 2030 is a reduction of carbon emissions by 30%: $\mathcal{CE}_i^{\text{nze}}(2030) = 39.91 \times (1 - 30\%) = 27.94$ $MtCO_2e$

The NZE duration

Figure 117: $\tau_i^{Target} = +\infty$, $\tau_i^{Trend} = 2024.3$ (2026.7 if rescaled) (Example 5)



Source: Le Guenedal *et al.* (2022).

The NZE duration

- A special case of NZE scenario is to set $\mathcal{CE}_i^{\mathrm{nze}} = 0$
- In this case, $\boldsymbol{\tau}_i$ corresponds to the date when the company is expected to emit zero carbon emissions
- For the rescaled trend, if $\hat{\beta}_1 < 0$, we have

$$\boldsymbol{\tau}_i^{\mathcal{T}rend} = t_0 - \frac{\mathcal{CE}_i\left(t_0\right)}{\hat{\beta}_1}$$

- For instance, we obtain $\boldsymbol{\tau}_i^{\mathcal{T}rend} = 2042.38$, meaning that the company can reach a carbon neutrality by 2043 if it continues the same effort of carbon emissions reduction as observed during the period 2007–2020

The NZE gap

- The NZE gap is the expected distance between the estimated carbon emissions and the NZE scenario:

$$\mathcal{G}ap_i\left(t^{\star}\right)=\widehat{\mathcal{CE}}_i\left(t^{\star}\right)-\mathcal{CE}_i^{\mathrm{nze}}\left(t^{\star}\right)$$

- Again, we can use the target scenario:

$$\mathcal{G}ap_i^{\mathcal{T}arget}\left(t^{\star}\right)=\mathcal{CE}_i^{\mathcal{T}arget}\left(t^{\star}\right)-\mathcal{CE}_i^{\mathrm{nze}}\left(t^{\star}\right)$$

or the trend model:

$$\mathcal{G}ap_i^{\mathcal{T}rend}\left(t^{\star}\right)=\mathcal{CE}_i^{\mathcal{T}rend}\left(t^{\star}\right)-\mathcal{CE}_i^{\mathrm{nze}}\left(t^{\star}\right)$$

The NZE gap

We consider Example 5:

- We have $\mathcal{CE}_i^{\mathrm{nze}}(2030) = 27.94$, $\mathcal{CE}_i^{\mathcal{T}arget}(2030) = 34.27$ and $\mathcal{CE}_i^{\mathcal{T}rend}(2030) = 22.08$ for the rescaled trend model
- We deduce that the NZE gaps are $\mathcal{G}ap_i^{\mathcal{T}arget}(2030) = 6.33$ and $\mathcal{G}ap_i^{\mathcal{T}rend}(2030) = -5.86$
- If we define the NZE scenario by the target scenario $\mathcal{CE}_i^{\mathrm{nze}}(2030) = \mathcal{CE}_i^{\mathcal{T}arget}(2030) = 34.27$, we obtain $\mathcal{G}ap_i^{\mathcal{T}rend}(2030) = -12.19$

The NZE slope

- The NZE slope is the value of $\hat{\beta}_{i,1}$ such that the NZE gap is closed, meaning that $\mathcal{G}ap_i^{\mathcal{T}rend}(t^{\star}) = 0$
- We have:

$$\mathcal{S}lope_i(t^{\star}) = \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^{\star}) - \mathcal{CE}_i(t_0)}{t^{\star} - t_0}$$

- The slope is generally negative because the gap is negative if the NZE scenario is not already reached

The NZE slope

Proof.

- This solution is not acceptable because it depends on $\hat{\beta}_{i,0}$:

$$\mathcal{G}ap_i^{\mathcal{T}rend}(t^\star) = 0 \Leftrightarrow \hat{\beta}_{i,0} + \hat{\beta}_{i,1} t^\star - \mathcal{CE}_i^{\mathrm{nze}}(t^\star) = 0$$
$$\Leftrightarrow \hat{\beta}_{i,1} = \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \hat{\beta}_{i,0}}{t^\star}$$

- Using the rescaled trend model and the pivot date t_0, we obtain:

$$\mathcal{G}ap_i^{\mathcal{T}rend}(t^\star) = 0 \Leftrightarrow \hat{\beta}'_{i,0} + \hat{\beta}_{i,1}(t^\star - t_0) - \mathcal{CE}_i^{\mathrm{nze}}(t^\star) = 0$$
$$\Leftrightarrow \hat{\beta}_{i,1} = \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \hat{\beta}'_{i,0}}{t^\star - t_0}$$
$$\Leftrightarrow \mathcal{S}lope_i(t^\star) = \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star) - \mathcal{CE}_i(t_0)}{t^\star - t_0}$$

$\blacksquare$

The NZE slope

We can normalize the slope metric by the current carbon emissions:

$$\overline{\mathcal{S}lope}_i\left(t^{\star}\right)=\frac{\mathcal{S}lope_i\left(t^{\star}\right)}{\mathcal{CE}_i\left(t_0\right)}$$

Another normalization consists in using the current slope $\hat{\beta}_{i,1}$ of the trend model. In this case, we obtain the slope multiplier:

$$m_i^{\mathcal{S}lope}=\frac{\mathcal{S}lope_i\left(t^{\star}\right)}{\hat{\beta}_{i,1}}$$

The NZE slope

- If we consider Example 5, we obtain:

$$\mathcal{S}lope_i\left(2030\right) = \frac{27.94 - 39.91}{2030 - 2020} = -1.1973$$

- We have:

$$\left|\mathcal{S}lope_i\left(2030\right)\right| = 1.1973 \leq \left|\hat{\beta}_{i,1}\right| = 1.7832$$

- The slope multiplier is equal to 67.14%

The NZE budget

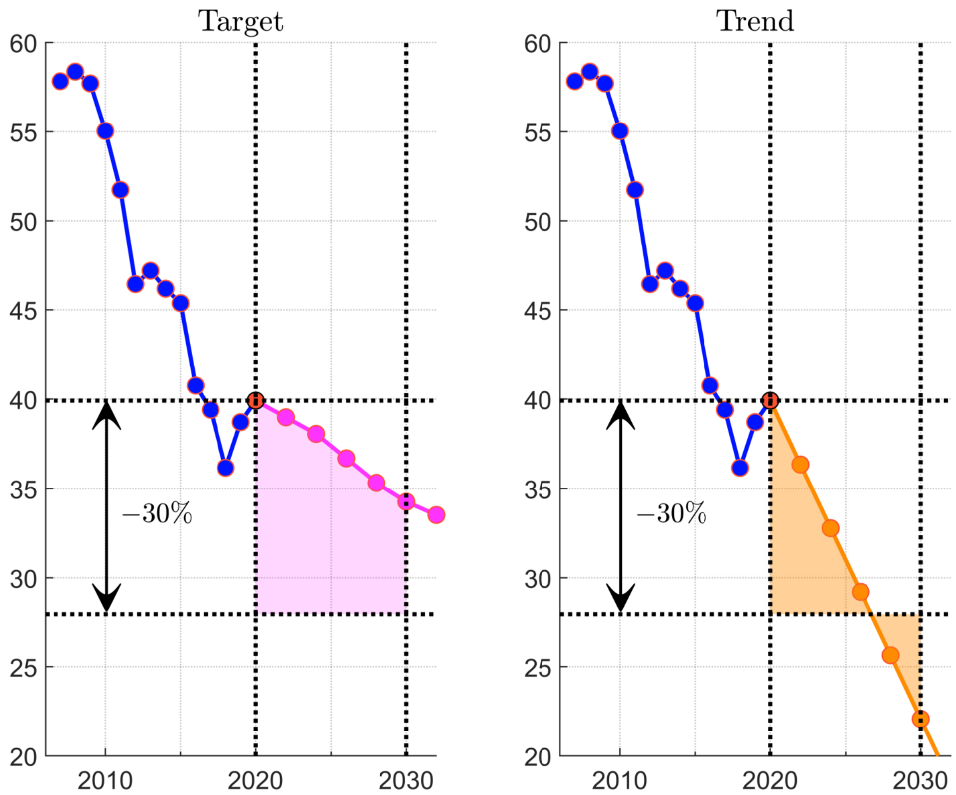
- The NZE budget corresponds to the carbon budget between the current date t_0 and the NZE date $t^\star$:

$$\mathcal{CB}_i\left(t_0, t^\star\right) = \int_{t_0}^{t^\star} \left(\widehat{\mathcal{CE}}_i\left(s\right) - \mathcal{CE}_i^{\mathrm{nze}}\left(t^\star\right)\right) \mathrm{d}s$$

- As previously, we can compute the carbon budget with respect to the target trajectory or the trend. We note them respectively by $\mathcal{CB}_i^{\mathcal{T}arget}\left(t_0, t^\star\right)$ and $\mathcal{CB}_i^{\mathcal{T}rend}\left(t_0, t^\star\right)$

The NZE budget

Figure 118: $\mathcal{CB}_i^{\mathcal{T}arget}(2020, 2030) = 92.735$ $MtCO_2e$ and $\mathcal{CB}_i^{\mathcal{T}rend}(2020, 2030) = 30.568$ $MtCO_2e$ (Example 5)



Source: Le Guenedal *et al.* (2022).

The NZE (budget) duration

- We can define the duration with respect to the carbon budget:

$$\boldsymbol{\tau}_i = \inf \left\{ t : \boldsymbol{\mathcal{CB}}_i \left(t_0, t \right) \leq 0 \right\}$$

- $\boldsymbol{\tau}_i$ indicates the time required to obtain a zero carbon budget since the current date t_0
- In the case of the trend model, we have:

$$\boldsymbol{\tau}_i^{\mathcal{T}rend} = t_0 + 2 \frac{\boldsymbol{\mathcal{CE}}_i^\star - \hat{\beta}_0'}{\hat{\beta}_1}$$

- For instance, using the rescaled trend model of Example 5, we obtain $\boldsymbol{\tau}_i^{\mathcal{T}rend} = 2033.43$ when $\boldsymbol{\mathcal{CE}}_i^\star = 27.94$ $MtCO_2e$.

Dynamic analysis of the track record

- Let $t_1 > t_0$ be a future reporting date. We have:

$$\mathcal{CB}_i(t_0, t^\star) = \int_{t_0}^{t_1} \left(\widehat{\mathcal{CE}}_i(s) - \mathcal{CE}_i^{\mathrm{nze}}(t^\star) \right) \mathrm{d}s + \int_{t_1}^{t^\star} \left(\widehat{\mathcal{CE}}_i(s) - \mathcal{CE}_i^{\mathrm{nze}}(t^\star) \right) \mathrm{d}s$$

When the current date becomes t_1, we obtain:

$$\mathcal{CB}_i(t_0, t^\star) = \underbrace{\mathcal{CB}_i(t_0, t_1)}_{\text{observed}} + \underbrace{\mathcal{CB}_i(t_1, t^\star)}_{\text{estimated}}$$

- A new reported value $\mathcal{CE}_i(t_1)$ of carbon emissions can change the expectations, meaning that:

$$\mathbb{E}\left[\mathcal{CE}_i(t) \mid \mathcal{F}_{t_0}\right] \neq \mathbb{E}\left[\mathcal{CE}_i(t) \mid \mathcal{F}_{t_1}\right] \qquad \text{for } t \geq t_1$$

Time contribution

- Let $\mathcal{CB}_i(t_0, t_1, t^\star)$ be the carbon budget between the starting date t_0 and the target date $t^\star$, which is evaluated at the current date t_1
- We have:

$$\mathcal{CB}_i(t_0, t_1, t^\star) = \mathcal{CB}_i(t_0, t_1, t_1) + \mathcal{CB}_i(t_1, t_1, t^\star)$$

- The contribution $\mathcal{TC}_i(t_1 \mid t_0, t^\star)$ of the new information observed at the date t_1 satisfies:

$$\mathcal{CB}_i(t_0, t_1, t^\star) = \mathcal{CB}_i(t_0, t_0, t^\star) + \mathcal{TC}_i(t_1 \mid t_0, t^\star)$$

- We have:

$$\mathcal{TC}_i(t_1 \mid t_0, t^\star) = \int_{t_0}^{t^\star} \left(\mathbb{E}\left[\mathcal{CE}_i(s) \middle| \mathcal{F}_{t_1}\right] - \mathbb{E}\left[\mathcal{CE}_i(s) \middle| \mathcal{F}_{t_0}\right]\right) \mathrm{d}s$$

Time contribution

The time contribution is made up of two components:

$$\mathcal{TC}_i\left(t_1 \mid t_0, t^\star\right) = \mathcal{TC}_i^{\mathrm{error}}\left(t_1 \mid t_0, t^\star\right) + \mathcal{TC}_i^{\mathrm{revision}}\left(t_1 \mid t_0, t^\star\right)$$

where:

1. $\mathcal{TC}_i^{\mathrm{error}}\left(t_1 \mid t_0, t^\star\right)$ measures the forecast error between the observed trajectory and the estimate done at time t_0:

$$\mathcal{TC}_i^{\mathrm{error}}\left(t_1 \mid t_0, t^\star\right) = \int_{t_0}^{t_1} \left(\mathcal{CE}_i\left(s\right) - \mathbb{E}\left[\mathcal{CE}_i\left(s\right) \mid \mathcal{F}_{t_0}\right]\right) \mathrm{d}s$$

2. $\mathcal{TC}_i^{\mathrm{revision}}\left(t_1 \mid t_0, t^\star\right)$ measures the forecast revision:

$$\mathcal{TC}_i^{\mathrm{revision}}\left(t_1 \mid t_0, t^\star\right) = \int_{t_1}^{t^\star} \left(\mathbb{E}\left[\mathcal{CE}_i\left(s\right) \mid \mathcal{F}_{t_1}\right] - \mathbb{E}\left[\mathcal{CE}_i\left(s\right) \mid \mathcal{F}_{t_0}\right]\right) \mathrm{d}s$$

Time contribution

We can normalize the previous quantities by current carbon emissions and the corresponding time period:

$$\left\{\begin{array}{l}\overline{\mathcal{TC}}_i\left(t_1 \mid t_0, t^\star\right) = \dfrac{\mathcal{TC}_i\left(t_1 \mid t_0, t^\star\right)}{\left(t^\star - t_0\right) \cdot \mathcal{CE}_i\left(t_0\right)} \\ \overline{\mathcal{TC}}_i^{\mathrm{error}}\left(t_1 \mid t_0, t^\star\right) = \dfrac{\mathcal{TC}_i^{\mathrm{error}}\left(t_1 \mid t_0, t^\star\right)}{\left(t_1 - t_0\right) \cdot \mathcal{CE}_i\left(t_0\right)} \\ \overline{\mathcal{TC}}_i^{\mathrm{revision}}\left(t_1 \mid t_0, t^\star\right) = \dfrac{\mathcal{TC}_i^{\mathrm{revision}}\left(t_1 \mid t_0, t^\star\right)}{\left(t^\star - t_1\right) \cdot \mathcal{CE}_i\left(t_0\right)}\end{array}\right.$$

Application to the trend model

Let $\hat{\beta}_{i,0}(t)$ and $\hat{\beta}_{i,1}(t)$ be the intercept and the slope coefficient of the trend model that is estimated at time t. We have:

$$\begin{aligned}
\mathcal{TC}_i^{\mathrm{error}}(t_1 \mid t_0, t^\star) &= \int_{t_0}^{t_1} \left(\mathcal{CE}_i(s) - \left(\hat{\beta}_0(t_0) + \hat{\beta}_{i,1}(t_0)\, s\right)\right) \mathrm{d}s \\
&= -\frac{1}{2}\hat{\beta}_{i,1}(t_0)\left(t_1^2 - t_0^2\right) - \hat{\beta}_{i,0}(t_0)(t_1 - t_0) + \int_{t_0}^{t_1} \mathcal{CE}_i(s)\, \mathrm{d}s
\end{aligned}$$

and:

$$\begin{aligned}
\mathcal{TC}_i^{\mathrm{revision}}(t_1 \mid t_0, t^\star) &= \int_{t_1}^{t^\star} \left(\left(\hat{\beta}_{i,0}(t_1) + \hat{\beta}_{i,1}(t_1)\, s\right) - \left(\hat{\beta}_{i,0}(t_0) + \hat{\beta}_{i,1}(t_0)\, s\right)\right) \\
&= \frac{1}{2}\left(\hat{\beta}_{i,1}(t_1) - \hat{\beta}_1(t_0)\right)\left(t^{\star 2} - t_1^2\right) + \\
&\quad \left(\hat{\beta}_{i,0}(t_1) - \hat{\beta}_{i,0}(t_0)\right)(t^\star - t_1)
\end{aligned}$$

Time contribution

Example 6

- Example 6 is a slight modification of Example 5
- **The company has reduced its carbon emissions from 2007 to 2018 by** 37.5%, **but it has also increased them in the last two years by** 10.4%
- Two scenarios:
  1. Black scenario: $\mathcal{CE}_i(2021) = 41$ MtCO_2e
  2. Green scenario: $\mathcal{CE}_i(2021) = 36$ MtCO_2e

Table 60: Carbon emissions in MtCO_2e

Year	2007	2008	2009	2010	2011	2012	2013	2014
$\mathcal{CE}_i(t)$	57.82	58.36	57.70	55.03	51.73	46.44	47.19	46.18
Year	2015	2016	2017	2018	2019	2020	2021	
Scenario							**Black**	**Green**
$\mathcal{CE}_i(t)$	45.37	40.75	39.40	36.16	38.71	39.91	**41**	**36**

Time contribution

Table 61: Estimation of the rescaled trend model (Example 6)

Scenario	$\hat{\beta}_{i,0}$	$\hat{\beta}_{i,1}$	t_p	$\mathcal{CE}_i(t_p)$	$\tilde{\beta}_{i,0}$
2020	3 637.7316	−1.7832	2020	39.91	3 642.0362
Black	3 276.8078	−1.6038	2021	41.00	3 282.2509
Green	3 578.5078	−1.7538	2021	35.00	3 579.4009

Source: Le Guenedal *et al.* (2022).

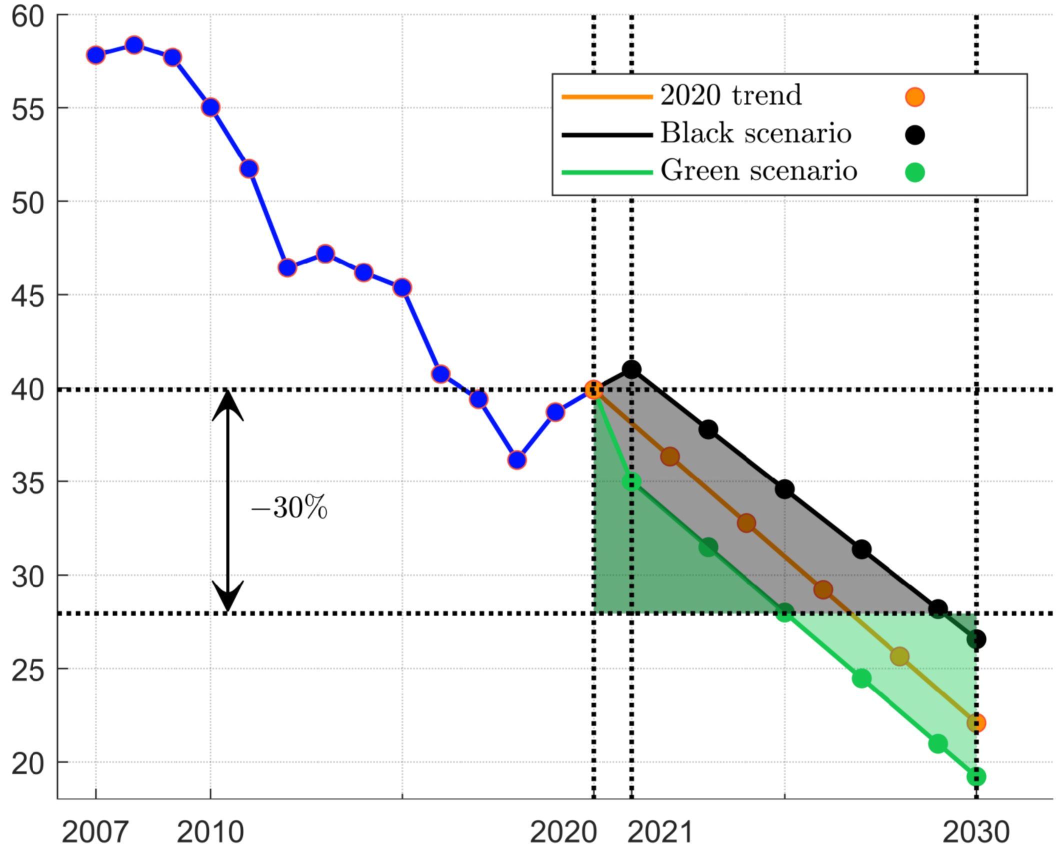
Table 62: Time contribution of 2021 black and green scenarios in $MtCO_2e$

Scenario	$\mathcal{CB}_i(t_0, t_1, t^\star)$	$\mathcal{CB}_i(t_0, t_1, t_1)$	$\mathcal{CB}_i(t_1, t_1, t^\star)$	$\mathcal{CB}_i(t_0, t_0, t^\star)$
2020	30.568	11.081	19.487	30.568
Black	65.132	12.518	52.614	30.568
Green	2.057	9.518	−7.461	30.568
Scenario	$\mathcal{CB}_i(t_0, t_1, t^\star)$	$\mathcal{TC}_i(t_1 \mid t_0, t^\star)$	$\mathcal{TC}_i^{\text{error}}(t_1 \mid t_0, t^\star)$	$\mathcal{TC}_i^{\text{revision}}(t_1 \mid t_0, t^\star)$
Black	65.132	34.563	1.437	33.127
Green	2.057	−28.512	−1.563	−26.948

Source: Le Guenedal *et al.* (2022).

Time contribution

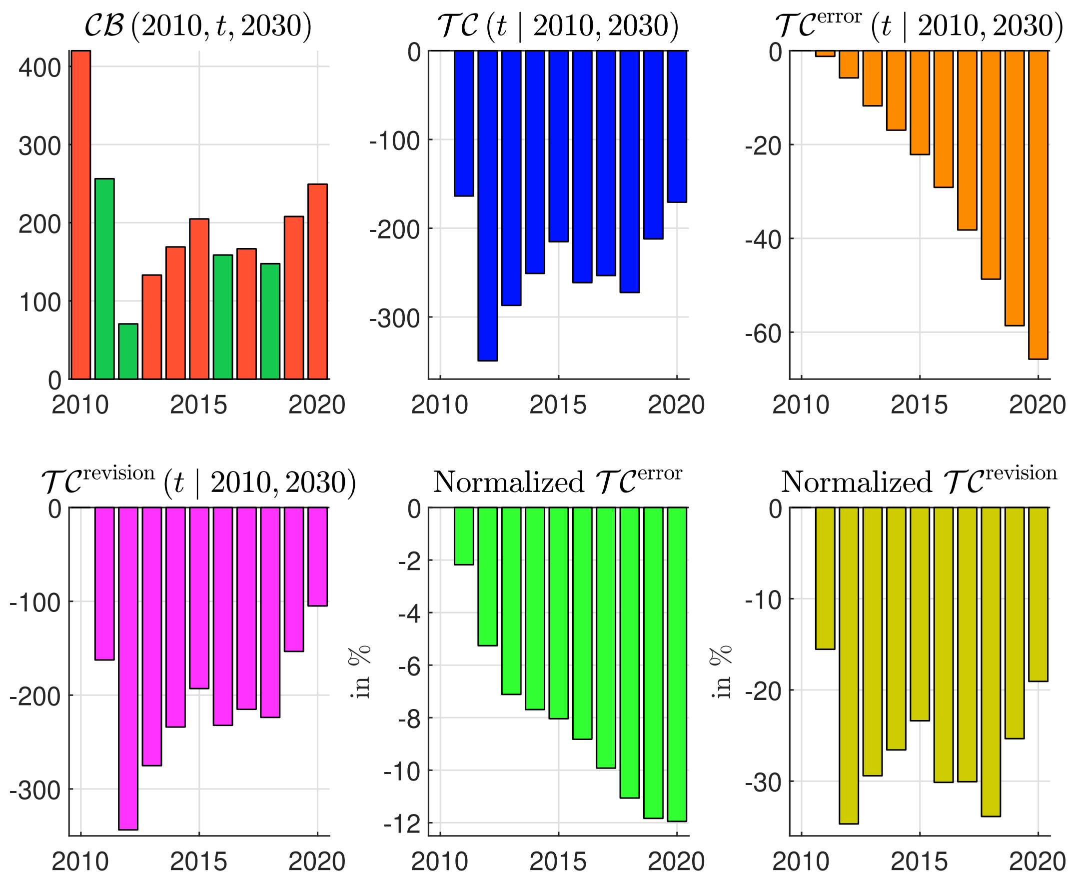
Figure 119: Impact of 2021 scenarios on the carbon budget (Example 6)



Source: Le Guenedal *et al.* (2022).

Time contribution

Figure 120: Dynamic analysis of the carbon budget $\mathcal{CB}_i\,(2010, t, 2030)$ (Example 6)



Source: Le Guenedal *et al.* (2022).

The NZE velocity

- The NZE velocity $\boldsymbol{v}_i\left(t_1, t_2\right)$ is defined as:

$$\boldsymbol{v}_i\left(t_1, t_2\right) := \frac{\Delta \hat{\beta}_{i,1}\left(t_1, t_2\right)}{t_2 - t_1}$$

- This measure is expressed in tCO_2e
- The h-step velocity is defined by $\boldsymbol{v}_i^{(h)}\left(t\right) = \boldsymbol{v}_i\left(t - h, t\right)$
- The one-step velocity measures the change of the slope by adding a new observation: $\boldsymbol{v}_i^{(1)}\left(t\right) = \hat{\beta}_1\left(t\right) - \hat{\beta}_{i,1}\left(t - 1\right)$

The NZE velocity

Table 63: Computation of the h-step velocity (Example 5)

t	$\hat{\beta}_1(t)$	$\boldsymbol{v}_i^{(1)}(t)$	$\boldsymbol{v}_i^{(2)}(t)$	$\boldsymbol{v}_i^{(5)}(t)$
2010	−0.903			
2011	−1.551	−0.648		
2012	−2.270	−0.719	−0.684	
2013	−2.204	0.067	−0.326	
2014	−2.076	0.127	0.097	
2015	−1.932	0.144	0.136	−0.206
2016	−2.006	−0.073	0.035	−0.091
2017	−2.016	−0.010	−0.042	0.051
2018	−2.069	−0.053	−0.032	0.027
2019	−1.949	0.120	0.034	0.026
2020	−1.783	0.166	0.143	0.030

Source: Le Guenedal *et al.* (2022).

The zero-velocity scenario

We have:

$$\boldsymbol{v}_i^{(h)}(t+1) \leq 0 \Leftrightarrow \mathcal{CE}_i(t+1) \leq \mathcal{ZV}_i^{(h)}(t+1)$$

$\Rightarrow \mathcal{ZV}_i^{(h)}(t+1)$ is the value of carbon emissions to obtain a zero velocity. In the case $h=1$, we obtain:

$$\mathcal{ZV}_i^{(1)}(t+1) = \frac{18(n+1)\cdot\widetilde{\mathcal{CE}}_i(t) - 12(n+2)\cdot\overline{\mathcal{CE}}_i(t)}{6(n-1)}$$

The zero-velocity scenario

Table 64: Computation of the zero-velocity scenario $\mathcal{ZV}_i^{(h)}(2021)$ (Example 5)

h	$\mathcal{ZV}_i^{(h)}(2021)$	$\mathcal{R}_i(2020, 2021)$
1	33.82	15.25%
2	27.20	31.85%
3	22.39	43.90%
4	24.51	38.59%
5	24.92	37.57%

Source: Le Guenedal *et al.* (2022).

We recall that $\mathcal{CE}_i(2020) = 39.91$ $\mathrm{MtCO_2e}$

The NZE burn-out scenario

- The burn-out scenario refers to a sudden and violent reduction of carbon emissions in order to satisfy the NZE trajectory
- The NZE burn-out scenario is then the value of the carbon emissions next year such that the gap is equal to zero, meaning that the NZE scenario will be achieved on average
- The burn-out scenario is denoted by $\mathcal{BO}_i\left(t+1, \mathcal{CE}_i^{\mathrm{nze}}\left(t^{\star}\right)\right)$ where t is the last reporting date, $\mathcal{CE}_i^{\mathrm{nze}}\left(t^{\star}\right)$ is the NZE scenario and $t^{\star}$ is the NZE date

The NZE burn-out scenario

- Let $\mathcal{R}_i^{\mathcal{T}arget}(t+1, t^\star)$ be the reduction rate between the date $t+1$ and the NZE date $t^\star$ when we consider the carbon targets of the issuer
- We have:

$$\mathcal{BO}_i^{\mathcal{T}arget}\left(t+1, \mathcal{CE}_i^{\mathrm{nze}}(t^\star)\right) = \frac{\mathcal{CE}_i^{\mathrm{nze}}(t^\star)}{1 - \mathcal{R}_i^{\mathcal{T}arget}(t+1, t^\star)}$$

- If we consider the linear trend model, we have:

$$\mathcal{BO}_i^{\mathcal{T}rend}\left(t+1, \mathcal{CE}_i^{\mathrm{nze}}(t^\star)\right) =$$

$$\left\{\mathcal{CE}_i(t+1) : \hat{\beta}_{i,0}(t+1) + \hat{\beta}_{i,1}(t+1) \cdot t^\star = \mathcal{CE}_i^{\mathrm{nze}}(t^\star)\right\}$$

The NZE burn-out scenario

Table 65: Computation of the burn-out scenario $\mathcal{BO}_i\left(2021, \mathcal{CE}_i^{\mathrm{nze}}\left(2030\right)\right)$ (Example 5)

$\mathcal{CE}_i^{\mathrm{nze}}(2030)$	Target		Trend	
	$\mathcal{BO}_i(2021)$	$\mathcal{R}_i(2020, 2021)$	$\mathcal{BO}_i(2021)$	$\mathcal{R}_i(2020, 2021)$
5.00	5.76	85.58%	6.45	83.84%
10.00	11.51	71.16%	17.17	56.99%
15.00	17.27	56.73%	27.88	30.14%
20.00	23.02	42.31%	38.59	3.30%
25.00	28.78	27.89%	49.31	−23.55%
−30%	32.16	19.42%	55.60	−39.32%

Source: Le Guenedal *et al.* (2022).

The $\mathcal{PAC}$ framework

The $\mathcal{PAC}$ framework

- **P**articipation
- **A**mbition
- **C**redibility

The $\mathcal{PAC}$ framework

Three questions:

- Is the trend of the issuer in line with the net zero emissions scenario? $\Rightarrow$ **P**articipation
- Is the commitment of the issuer to fight climate change ambitious? $\Rightarrow$ **A**mbition
- Is the target setting of this issuer relevant and robust? $\Rightarrow$ **C**redibility

The $\mathcal{PAC}$ framework

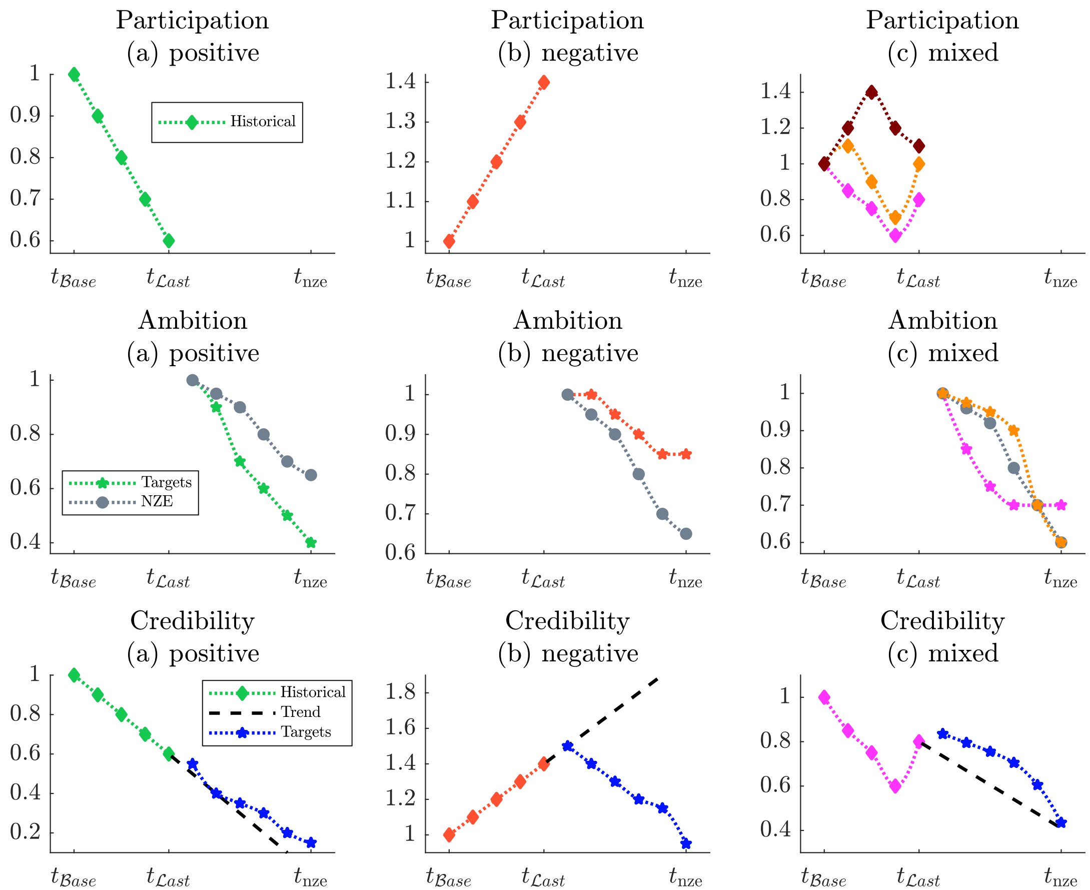
The three pillars depends on the carbon trajectories $\mathcal{CE}_i(t)$, $\mathcal{CE}_i^{\mathcal{T}rend}(t)$, $\mathcal{CE}_i^{\mathcal{T}arget}(t)$ and $\mathcal{CE}_i^{\mathrm{nze}}(t)$ where:

1. $\mathcal{CE}_i(t)$ is the time series of historical carbon emissions
2. $\mathcal{CE}_i^{\mathcal{T}rend}(t)$ and $\mathcal{CE}_i^{\mathcal{T}arget}(t)$ are the estimated carbon emissions deduced from the trend model and the target
3. $\mathcal{CE}_i^{\mathrm{nze}}(t)$ is the market-based NZE scenario

$t_{\mathcal{B}ase}$ is the base date, $t_{\mathcal{L}ast}$ is the last reporting date and t_{nze} is the target date of the NZE scenario

The *PAC* framework

Figure 121: Illustration of the participation, ambition and credibility pillars



Source: Le Guenedal *et al.* (2022).

The $\mathcal{PAC}$ framework

Table 66: The three pillars of an effective NZE strategy

Pillar	Metric	Condition
Participation	Gap	$\mathcal{G}ap_i^{\mathcal{T}rend}(t_{\mathcal{L}ast}) \leq 0$
	Reduction	$\mathcal{R}_i(t_{\mathcal{B}ase}, t_{\mathcal{L}ast}) < 0$
	Time contribution	$\mathcal{TC}_i(t_{\mathcal{L}ast}+1 \mid t_{\mathcal{L}ast}, t_{\mathrm{nze}}) < 0$
	Trend	$\hat{\beta}_{i,1} < 0$ and $\mathbf{R}_i^2 > 50\%$
	Trend	$\mathcal{CE}_i^{\mathcal{T}rend}(t)$ for $t > t_{\mathcal{L}ast}$
	Velocity	$v_i^{(1)}(t_{\mathcal{L}ast}) \leq 0$
Ambition	Budget	$\mathcal{CB}_i^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}}) \leq \mathcal{CB}_{\mathcal{S}ector}^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$
	Budget	$\mathcal{CB}_i^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}}) \leq \mathcal{CB}_i^{\mathcal{T}rend}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$
	Duration	$\tau_i^{\mathcal{T}arget} \leq t_{\mathrm{nze}}$
	Gap	$\mathcal{G}ap_i^{\mathcal{T}arget}(t_{\mathrm{nze}}) \leq 0$
Credibility	Budget	$\mathcal{CB}_i^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}}) > \mathcal{CB}_i^{\mathcal{T}rend}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$
	Burn-out Scenario	$\mathcal{BO}_i(t_{\mathcal{L}ast}+1, \mathcal{CE}_i^{\mathrm{nze}}(t^{\mathrm{nze}})) \geq \varphi_{\mathcal{BO}} \cdot \mathcal{CE}_i(t_{\mathcal{L}ast})$
	Duration	$\tau_i^{\mathcal{T}rend} \leq t_{\mathrm{nze}}$
	Gap	$\mathcal{G}ap_i^{\mathcal{T}rend}(t_{\mathrm{nze}}) \leq 0$
	Gap	$\underline{\mathcal{G}ap_i^{\mathcal{T}rend}}(t_{\mathrm{nze}}) \leq \underline{\mathcal{G}ap_i^{\mathcal{T}arget}}(t_{\mathrm{nze}})$
	Slope	$\mathcal{S}lope_i(t_{\mathrm{nze}}) \geq \mathcal{S}lope_{\mathcal{S}ector}(t_{\mathrm{nze}})$
	Slope	$m_i^{\mathcal{S}lope} \ll 1$
	Trend	$\mathbf{R}_i^2 > 50\%$
	Zero-velocity	$\mathcal{ZV}_i^{(1)}(t_{\mathcal{L}ast}+1) \geq \varphi_{\mathcal{ZV}} \cdot \mathcal{CE}_i(t_{\mathcal{L}ast})$

The $\mathcal{PAC}$ framework

If we compare the carbon budget $\mathcal{CB}_i^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$ using the targets and the carbon budget $\mathcal{CB}_i^{\mathcal{T}rend}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$ using the trend model, we can face two extreme situations:

1. The company is ambitious but not credible if $\mathcal{CB}_i^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}}) \ll \mathcal{CB}_i^{\mathcal{T}rend}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$
2. The company is credible but not ambitious if $\mathcal{CB}_i^{\mathcal{T}arget}(t_{\mathcal{L}ast}, t_{\mathrm{nze}}) \gg \mathcal{CB}_i^{\mathcal{T}rend}(t_{\mathcal{L}ast}, t_{\mathrm{nze}})$

$\Rightarrow$ the pillars can be (negatively) correlated

The $\mathcal{PAC}$ scoring system

In order to analyse the $\mathcal{PAC}$ pillars, we can use a scoring system:

$$\begin{aligned} q_i &= \Phi\left(z_i\right) \\ z_i &= \frac{s_i - \mu\left(s_i\right)}{\sigma\left(s_i\right)} \end{aligned}$$

Examples

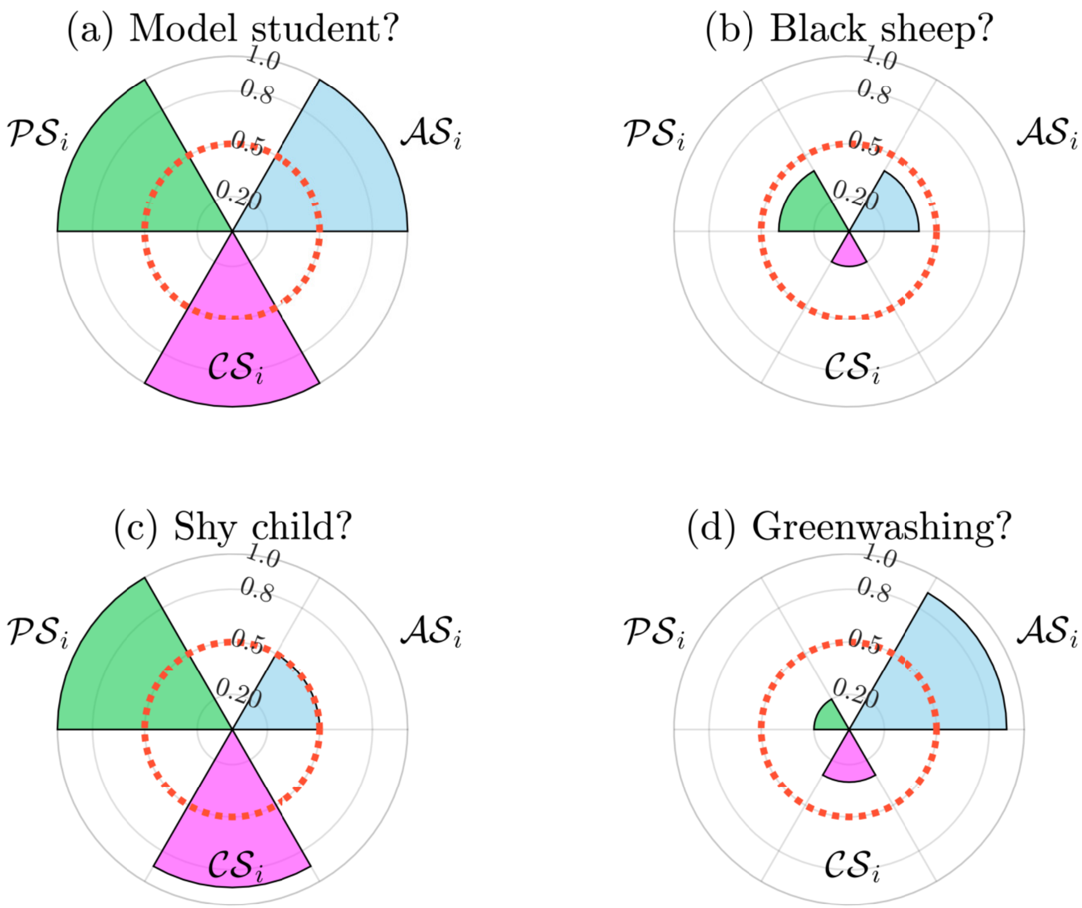
Participation $s_i = -\dfrac{\hat{\beta}_{i,1}}{\mathcal{CE}_i\left(t_{\mathcal{L}ast}\right)}$

Ambition $s_i = \dfrac{\mathcal{CB}_i^{\mathcal{T}rend}\left(t_{\mathcal{L}ast}, t_{\mathrm{nze}}\right) - \mathcal{CB}_i^{\mathcal{T}arget}\left(t_{\mathcal{L}ast}, t_{\mathrm{nze}}\right)}{\mathcal{CE}_i\left(t_{\mathcal{L}ast}\right)}$

Credibility $s_i = \frac{\mathcal{BO}_i\left(t_{\mathcal{L}ast}+1, \mathcal{CE}_i^{\mathrm{nze}}\left(t^{\mathrm{nze}}\right)\right)}{\mathcal{CE}_i\left(t_{\mathcal{L}ast}\right)}$

The $\mathcal{PAC}$ scoring system

Figure 122: The $\mathcal{PAC}$ scoring system



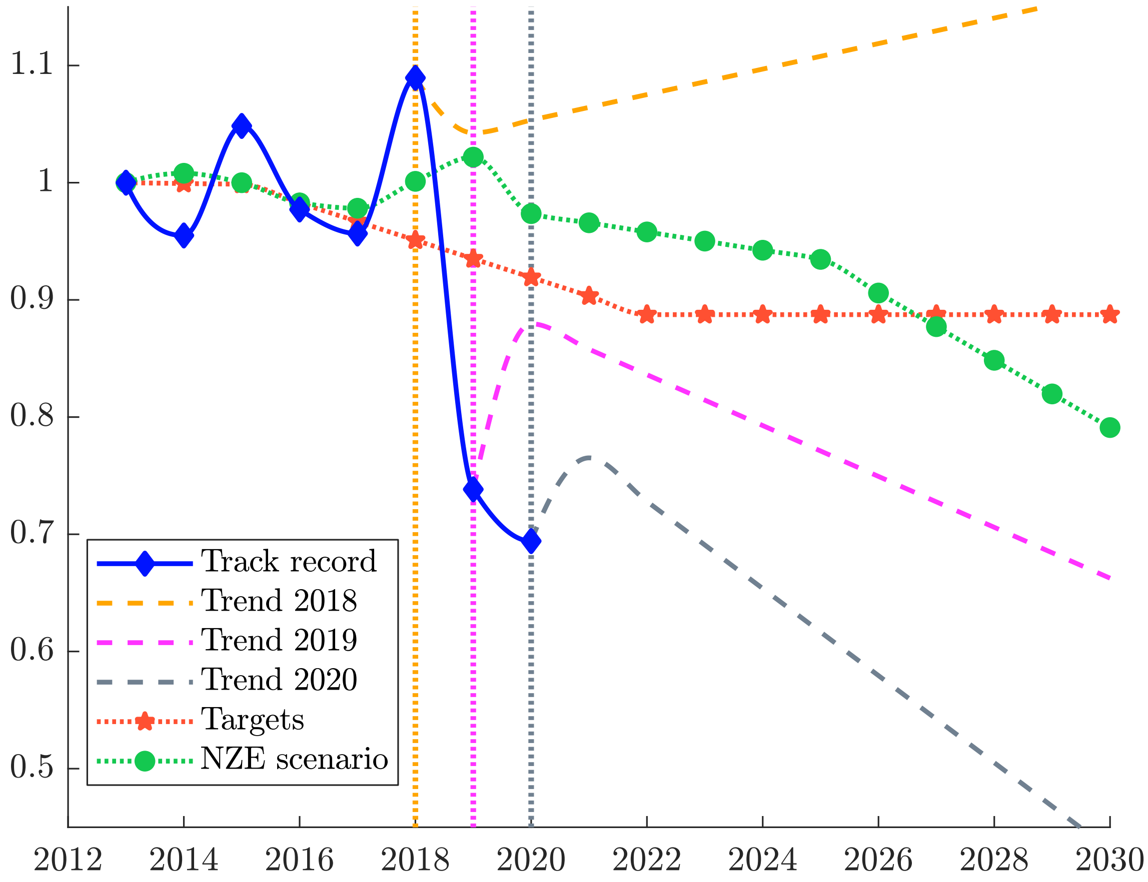
Source: Le Guenedal *et al.* (2022).

A tale of three companies

- Company A is a US based multinational technology conglomerate
  - It has communicated in September 2021 on their ambition and committed to net zero GHG emissions by 2040
- Company B which is one of the major airlines of the US
  - It announced a carbon neutrality ambition in September 2021
  - Its policy seems to require the purchase of carbon offsets
- Company C is an European multinational company which supplies industrial resources and services to various industries
  - It has a clear ambition and has embraced the NZE context
  - It positions its business on the climate change opportunity

A tale of three companies

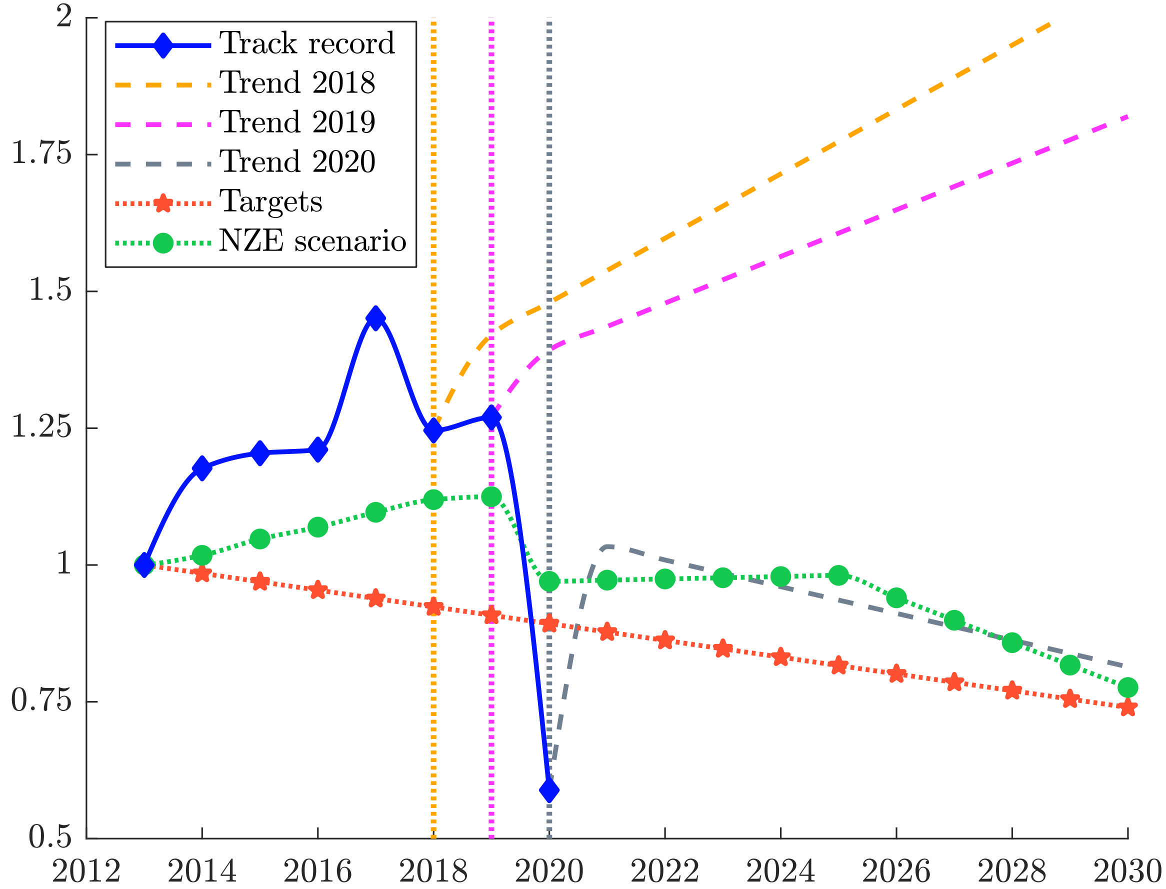
Figure 123: Carbon emissions, trends and targets and NZE scenario (Company A)



Source: CDP database (2020) & Le Guenedal *et al.* (2022).

A tale of three companies

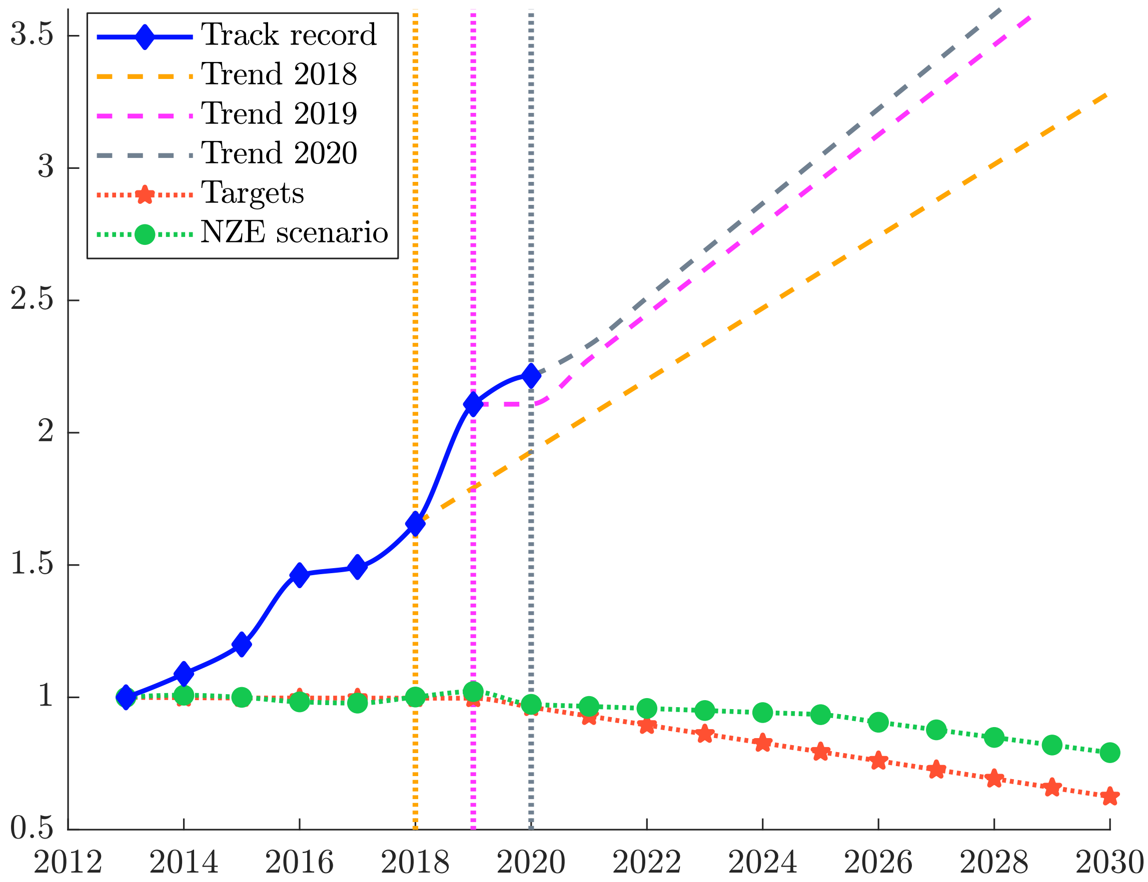
Figure 124: Carbon emissions, trends and targets and NZE scenario (Company B)



Source: CDP database (2020) & Le Guenedal *et al.* (2022).

A tale of three companies

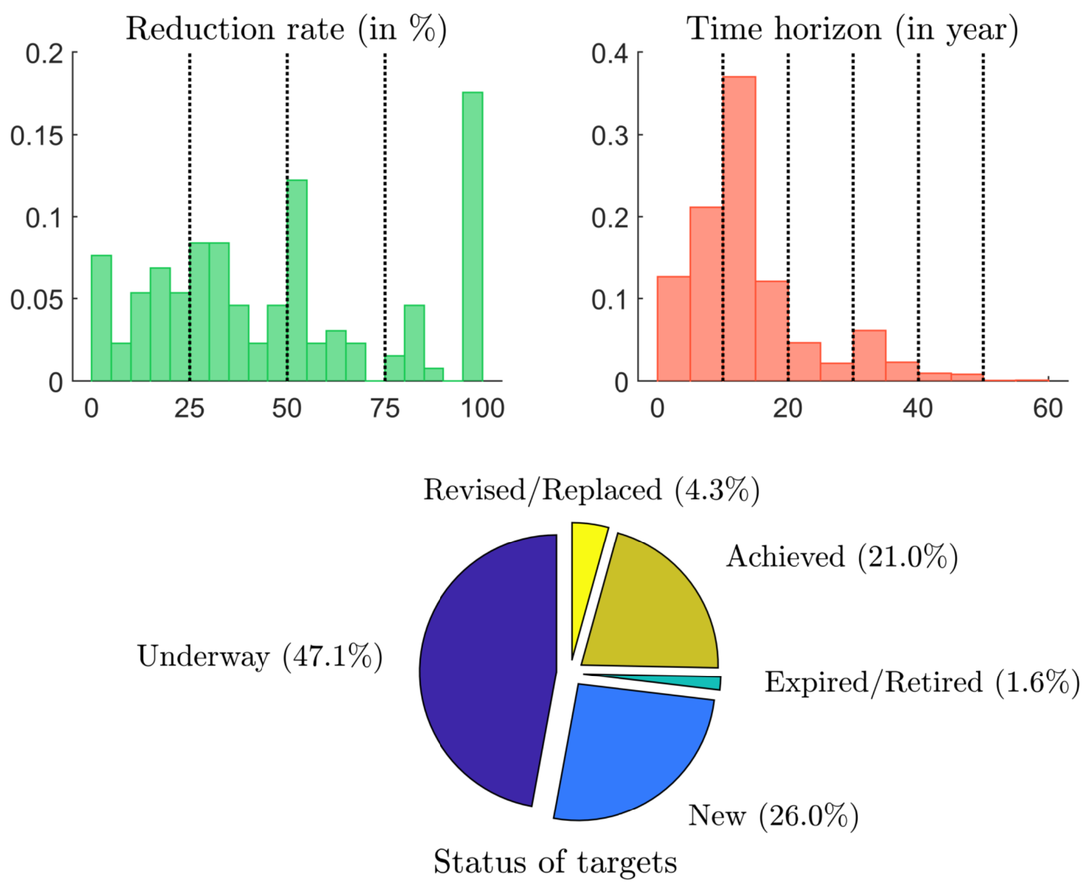
Figure 125: Carbon emissions, trends and targets and NZE scenario (Company C)



Source: CDP database (2020) & Le Guenedal *et al.* (2022).

The CDP database

Figure 126: Status, time horizon and scale of reduction targets



Source: CDP database (2020) & Le Guenedal *et al.* (2022).

The CDP database

Table 67: Coverage of CDP data for the MSCI index universes

IEA sector	All Issuers			EMU			North America			EM Asia		
	P	NP	NR	P	NP	NR	P	NP	NR	P	NP	NR
Electricity	227	57	381	27		3	51	6	21	18	12	85
Industry	1 136	262	1 237	85	7	11	202	29	51	120	40	390
Other	904	264	1 318	71	15	14	196	35	99	80	50	335
Transport	88	21	81	2			18	1	6	4	5	14
Total	2 355	604	3 017	185	22	28	467	71	177	222	107	824
# issuers		5 976			235			715			1 153	
Frequency (in %)	39.4	10.1	50.5	78.7	9.4	11.9	65.3	9.9	24.8	19.3	9.3	71.5

P = public, NP = non-public, NR = non-responder.

Source: CDP database (2021), MSCI indices & Le Guenedal *et al.* (2022).

The study universe

We consider issuers that have:

1. at least one reduction target between 2013 and 2030
2. and a full track record of carbon emissions between 2013 and 2020
3. an ISIN code that match with the IEA and GICS sector classification.

$\Rightarrow$ Finally, we obtain a database of 751 issuers

The study universe

Table 68: Number of issuers by sector

GICS sector	IEA sector				Total
	Electricity	Industry	Other	Transport	
Communication Services			41		41
Consumer Discretionary		52	29		81
Consumer Staples		57	16		73
Energy	23		7	4	34
Financials			135		135
Health Care	4	29	7		40
Industrials	3	74	42	16	135
Information Technology		46	24		70
Materials		63			63
Real Estate		21	2		23
Utilities	56				56
Total	86	342	303	20	751

Source: CDP database (2020) & Le Guenedal *et al.* (2022).

The study universe

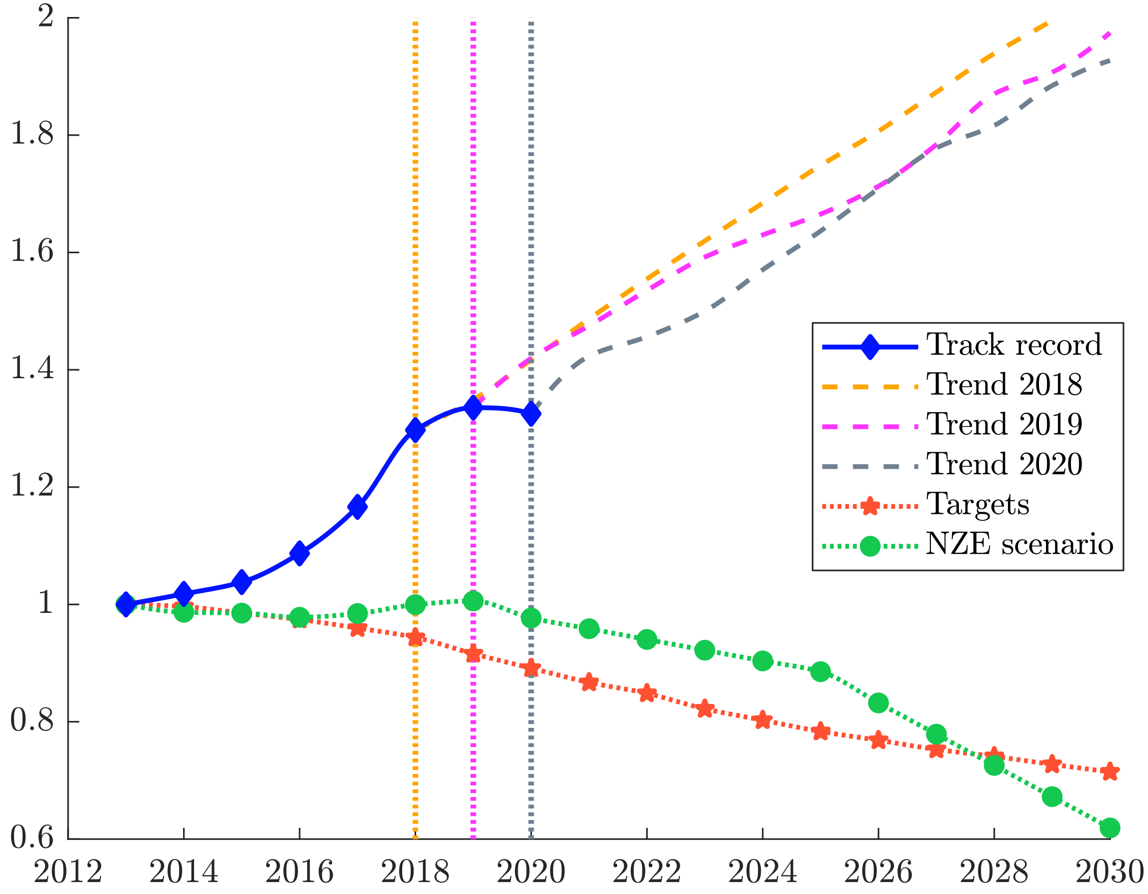
Table 69: Number of issuers by region

Region	IEA sector				Total
	Electricity	Industry	Other	Transport	
DM	66	276	245	19	606
EMU	31	88	71	4	194
Europe-ex-EMU	7	67	60	4	138
North America	26	93	106	9	234
Other DM	2	28	8	2	40
EM	20	66	58	1	145
Total	86	342	303	20	751

Source: CDP database (2020) & Le Guenedal *et al.* (2022).

Global analysis

Figure 127: Carbon emissions, trends and targets and NZE scenario (median analysis)



Source: CDP database (2020) & Le Guenedal *et al.* (2022).

Global analysis

Table 70: Statistics of the normalized slope and velocity (expressed in %)

Slope		$\frac{\hat{\beta}_{i,1}(t_{\mathcal{L}ast})}{\mathcal{CE}_i(2013)}$ $Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	$\frac{\hat{\beta}_{i,1}(t_{\mathcal{L}ast})}{\mathcal{CE}_i(t_{\mathcal{L}ast})}$ $Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	$\#\left\{\hat{\beta}_{i,1} < 0\right\}$
$t_{\mathcal{L}ast}$	2018	−2.44	6.06	41.29	−2.85	4.46	12.93	32.36
	2019	−2.13	6.38	44.23	−2.31	4.18	11.42	29.56
	2020	−2.97	6.16	52.01	−3.82	3.66	10.60	32.62
Velocity		$\frac{v_i^{(1)}(t_{\mathcal{L}ast})}{\mathcal{CE}_i(2013)}$ $Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	$\frac{v_i^{(1)}(t_{\mathcal{L}ast})}{\mathcal{CE}_i(t_{\mathcal{L}ast})}$ $Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	$\#\left\{v_i^{(1)}(t_{\mathcal{L}ast}) < 0\right\}$
$t_{\mathcal{L}ast}$	2019	−4.38	−0.09	2.62	−2.15	−0.37	1.99	51.27
	2020	−6.99	−1.53	1.15	−3.68	−0.99	1.11	65.11

Source: CDP database (2020) & Le Guenedal *et al.* (2022).

Global analysis

Table 71: Statistics of the budget difference

$\Delta\mathcal{CB}_i(2020, 2030)$	$Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	$\#\{<0\}$
$\mathcal{CB}_i^{\mathcal{T}rend}(2020, 2030) - \mathcal{CB}_i^{\mathrm{nze}}(2020, 2030)$	-3.00	5.78	13.45	32.9%
$\mathcal{CB}_i^{\mathcal{T}arget}(2020, 2030) - \mathcal{CB}_i^{\mathrm{nze}}(2020, 2030)$	-1.54	-0.18	0.54	59.9%
$\mathcal{CB}_i^{\mathcal{T}arget}(2020, 2030) - \mathcal{CB}_i^{\mathcal{T}rend}(2020, 2030)$	-14.48	-7.19	2.64	68.9%

Source: CDP database (2020) & Le Guenedal *et al.* (2022).

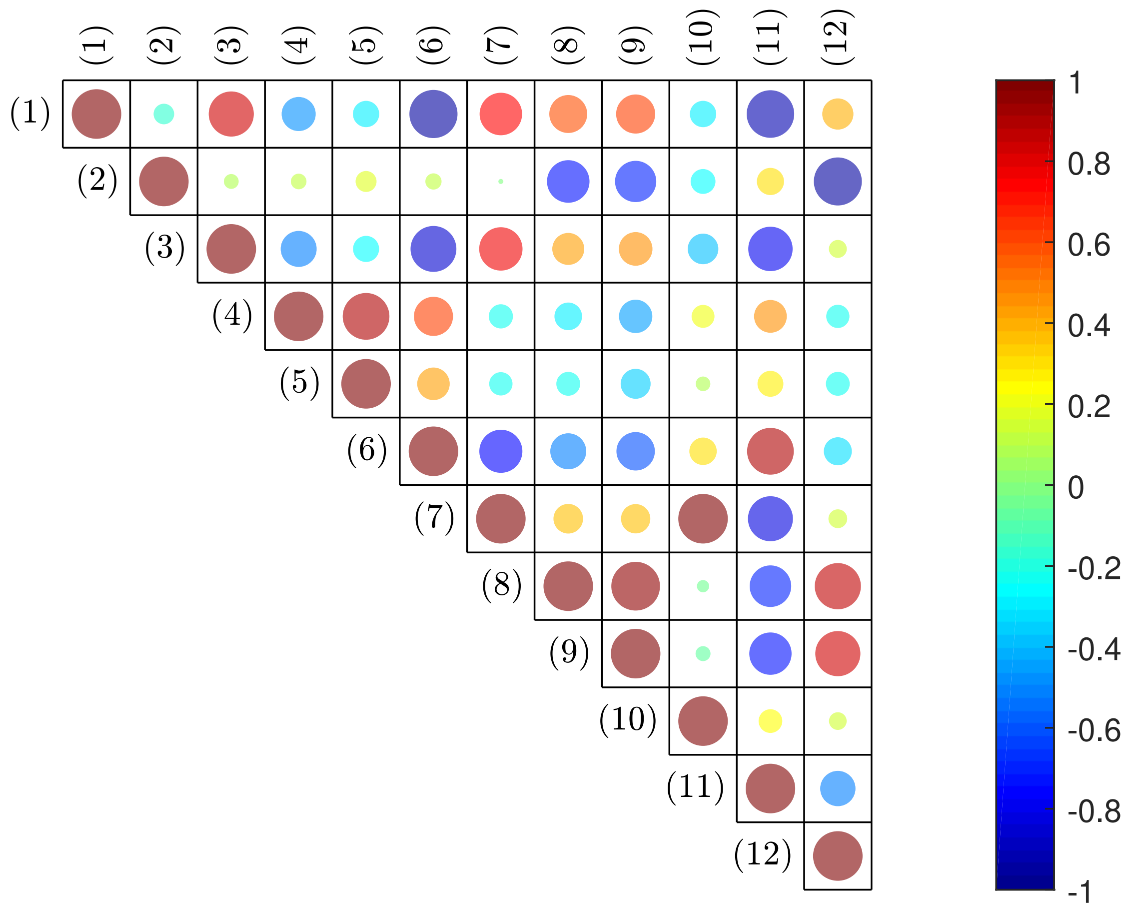
Global analysis

We consider the following NZE metrics:

1. the slope $\hat{\beta}_{i,1}$
2. the velocity $\boldsymbol{v}_i^{(1)}(2020)$
3. the current gap of the trend model $\mathcal{G}ap_i^{\mathcal{T}rend}(2020)$
4. the 2030 gap of the carbon targets $\mathcal{G}ap_i^{\mathcal{T}arget}(2030)$
5. the net budget of the carbon targets $\mathcal{CB}_i^{\mathcal{T}arget}(2020, 2030) - \mathcal{CB}_i^{\mathrm{nze}}(2020, 2030)$
6. the budget difference $\mathcal{CB}_i^{\mathcal{T}arget}(2020, 2030) - \mathcal{CB}_i^{\mathcal{T}rend}(2020, 2030)$
7. the trend duration $\boldsymbol{\tau}_i^{\mathcal{T}rend}$
8. the 2030 gap of the trend model $\mathcal{G}ap_i^{\mathcal{T}rend}(2030)$
9. the gap difference $\mathcal{G}ap_i^{\mathcal{T}rend}(2030) - \mathcal{G}ap_i^{\mathcal{T}arget}(2030)$
10. the (non-normalized) slope multiplier $m_i^{\mathcal{S}lope}$
11. the burn-out scenario $\mathcal{BO}_i(2021, \mathcal{CE}_i^{\mathrm{nze}}(2030))$
12. the zero-velocity scenario $\mathcal{ZV}_i^{(1)}(2021)$

Global analysis

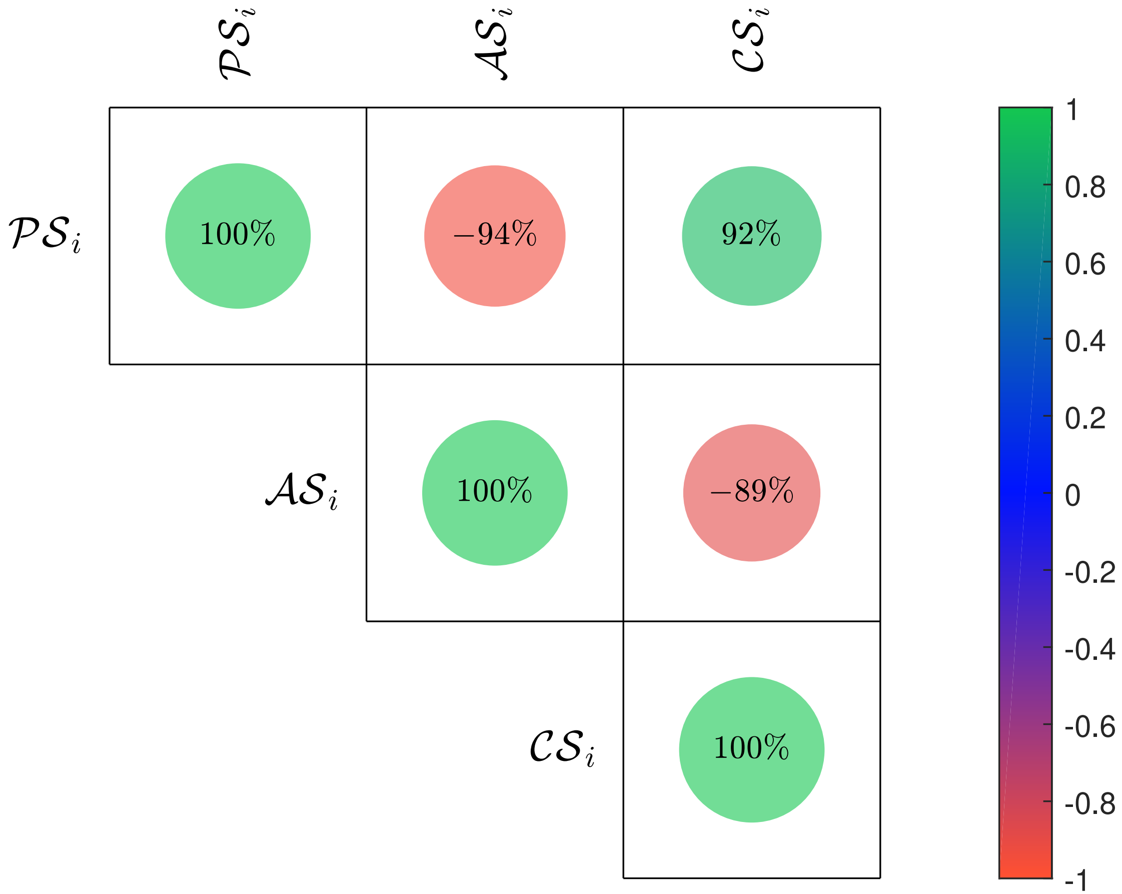
Figure 128: Rank correlation matrix of the $\mathcal{PAC}$ metrics



Source: CDP database (2020) & Le Guenedal *et al.* (2022).

Global analysis

Figure 129: Rank correlation matrix of the $\mathcal{PAC}$ scoring system



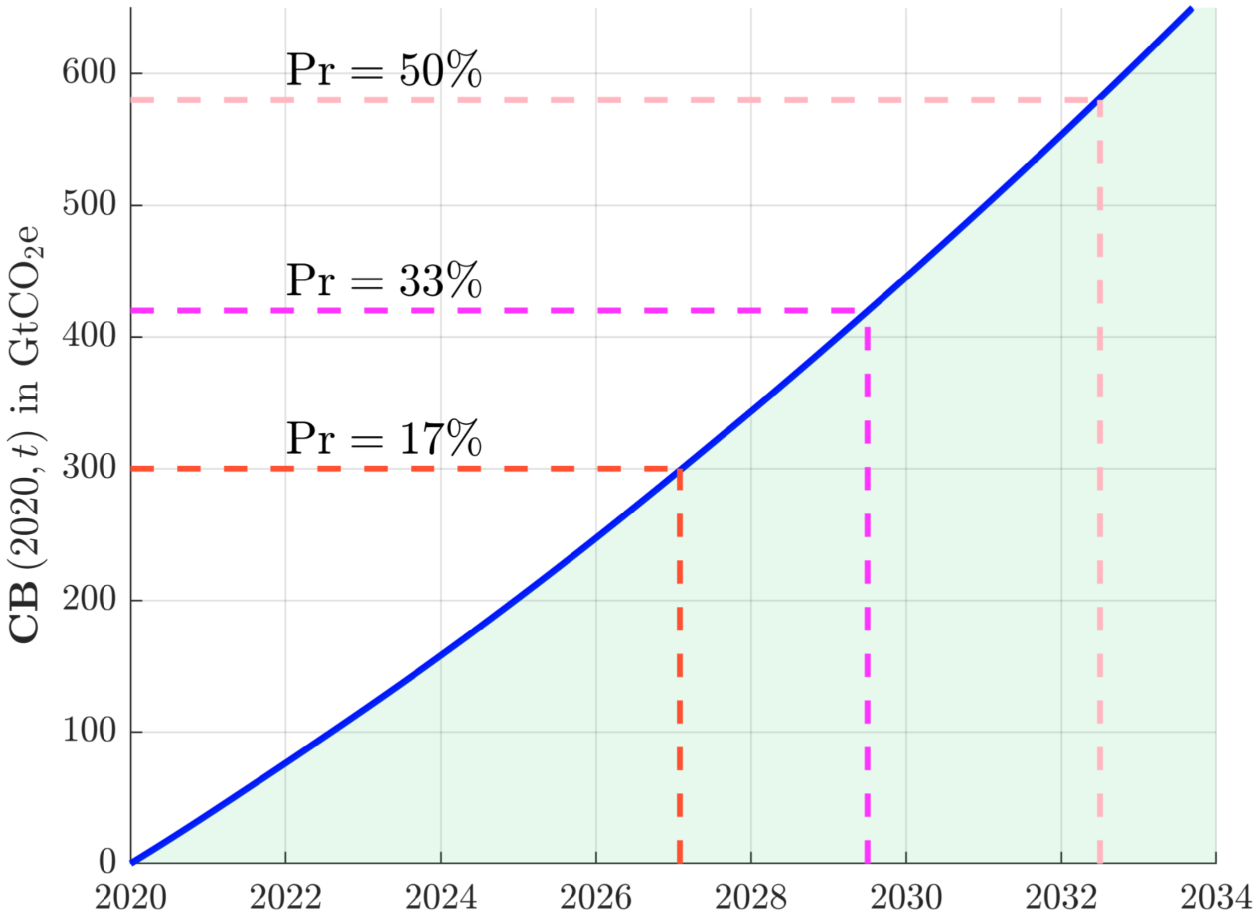
Source: CDP database (2020) & Le Guenedal *et al.* (2022).

Global analysis

"Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 *$GtCO_2e$ for a* 50% *probability of limiting warming to* $1.5°\mathrm{C}$*, and* 420 *$GtCO_2e$ for a* 66% *probability (medium confidence)" (IPCC, 2018).*

Global analysis

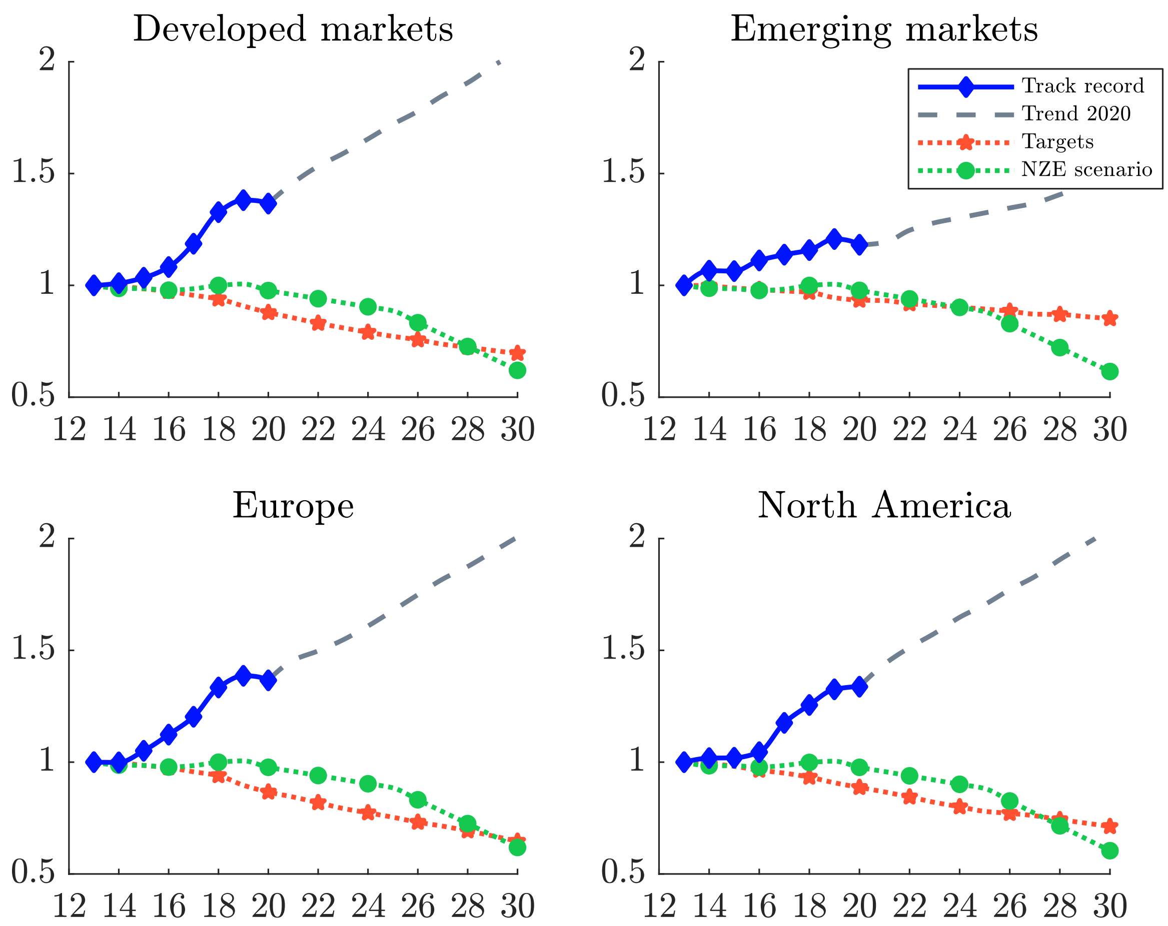
Figure 130: Probability to reach 1.5°C



Source: Le Guenedal *et al.* (2022).

Regional analysis

Figure 131: Carbon emissions, trends and targets and NZE scenario (median analysis)



Regional analysis

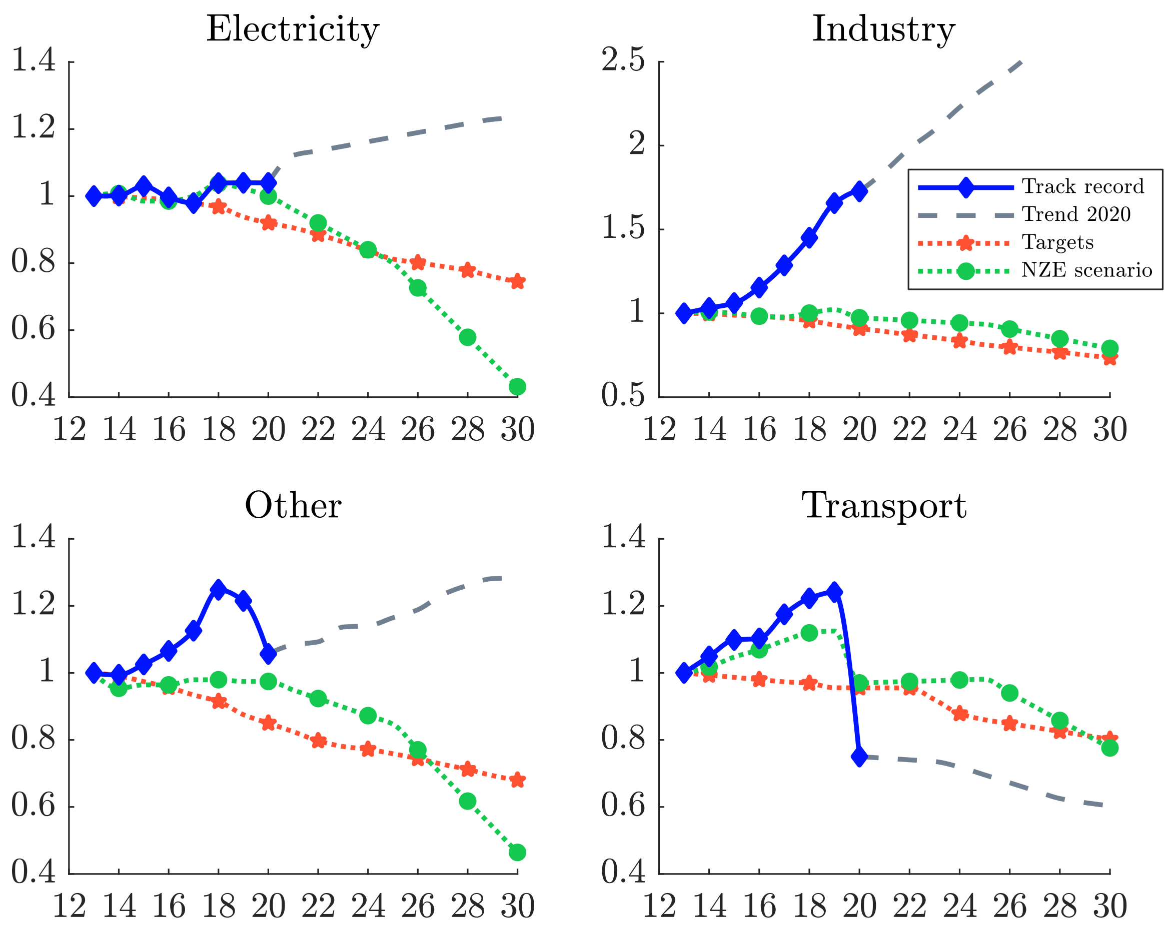
Table 72: Frequencies of targets lower or greater than the trend in 2030

	Lower	Greater
DM	79.21%	20.79%
EM	71.03%	28.97%
Europe	79.17%	20.83%
North America	76.92%	23.08%
EMU	79.90%	20.10%
Asia	67.61%	32.39%
Global	77.63%	22.37%

Source: IEA (2021), CDP database (2020) & Le Guenedal *et al.* (2022).

Sectoral analysis

Figure 132: Carbon emissions, trends and targets and NZE scenario (median analysis)



Application to the MSCI World index

Table 73: Scope $1+2+3$ carbon emissions of the MSCI World index in tCO_2e ($W = \$1$ mn, $h = 1$ year)

Year	Missing	$\mathcal{CE}(x; W)$ (1)	$\mathcal{CE}(x; W)$ (2)	$\mathcal{CE}(x; W)$ (3)	$\mathcal{CI}(x)$ (1)	$\mathcal{CI}(x)$ (2)	$\mathcal{CI}(x)$ (3)
2013	3.63%	389.6	401.0	451.7	346.3	346.3	346.1
2014	3.72%	372.7	383.0	426.5	343.0	341.3	341.2
2015	4.51%	371.4	381.3	417.7	325.9	324.5	324.4
2016	3.85%	325.3	337.9	364.6	340.5	341.4	341.4
2017	2.79%	272.6	277.6	295.1	355.9	352.9	352.9
2018	2.31%	330.4	337.4	359.2	351.4	348.7	348.6
2019	3.67%	267.1	268.4	282.5	315.6	313.8	313.6
2020	4.30%	206.7	210.9	225.2	275.1	272.9	272.6
2021	7.09%	138.1	154.6	181.7	259.9	262.1	262.4

Source: MSCI (2021), Trucost reporting year (2021) & Le Guenedal *et al.* (2022).

Application to the MSCI World index

Table 74: Scope $1+2+3$ carbon emissions of the MSCI World index in $GtCO_2e$ ($h=1$ year)

Year	$\sum_{i=1}^{n} \mathcal{MC}_i$ (in \$ tn)	$\sum_{i=1}^{n} \mathcal{CE}_i$ (1)	(2)	(3)
2013	31.9	12.8	12.8	14.4
2014	33.1	12.8	12.7	14.1
2015	32.3	12.4	12.3	13.5
2016	33.7	11.3	11.4	12.3
2017	40.4	11.4	11.2	11.9
2018	35.8	12.1	12.1	12.8
2019	44.7	12.3	12.0	12.6
2020	51.4	11.2	10.8	11.6
2021	62.4	9.5	9.7	11.3

Source: MSCI (2021), Trucost reporting year (2021) & Le Guenedal *et al.* (2022).

Application to the MSCI World index

"Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 *$GtCO_2e$ for a* 50% *probability of limiting warming to* $1.5^{\circ}\mathrm{C}$, *and* 420 *$GtCO_2e$ for a* 66% *probability (medium confidence)" (IPCC, 2018).*

Application to the MSCI World index

Arithmetic

What is the carbon footprint of the investment industry if:

1. Each investor decreases its carbon footprint by $x\%$;
2. Each investor increases its wealth by $y\%$;

Answer

The carbon emissions change is equal to:

$$\begin{aligned} z &= (1-x)(1+y)-1 \\ &= y-x-xy \end{aligned}$$

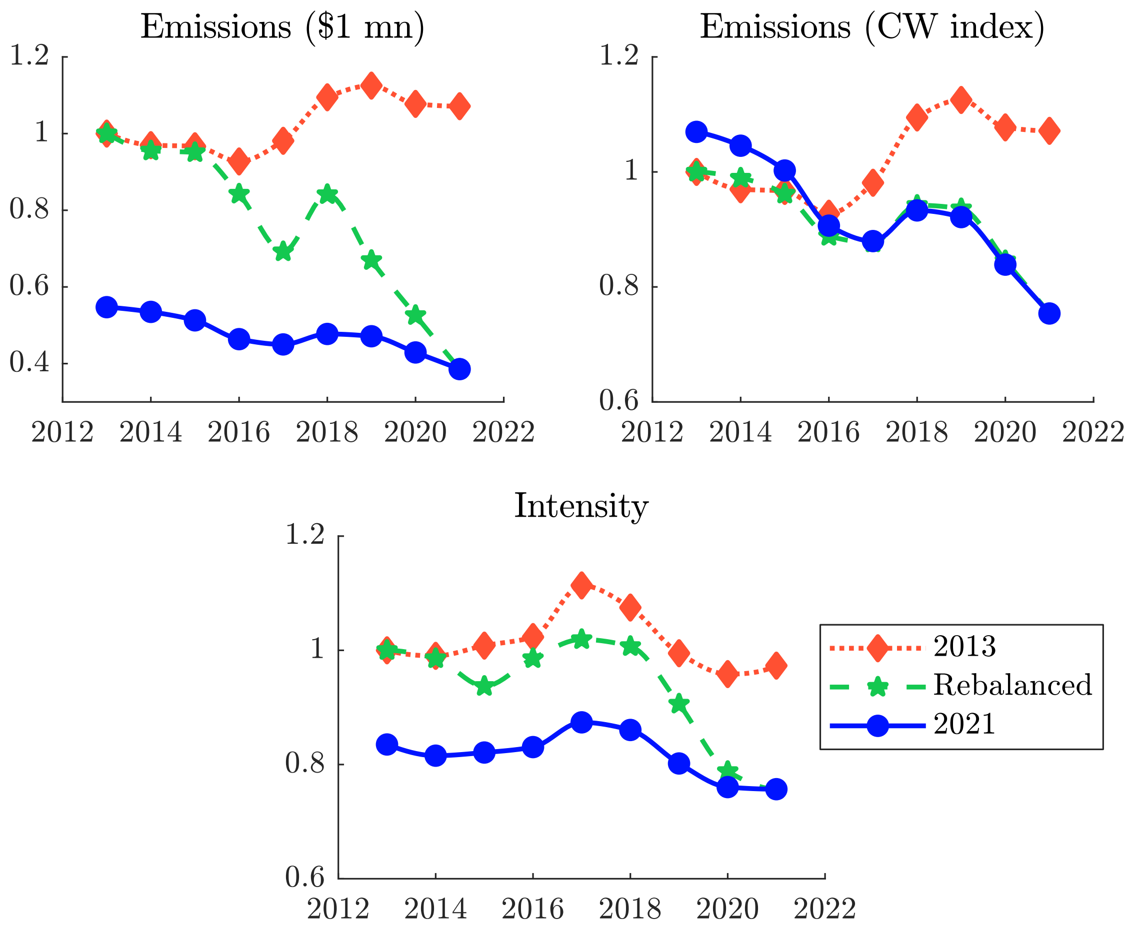
Application to the MSCI World index

Table 75: Carbon emissions change (in %)

		y in %						
		0.0	25.0	50.0	75.0	100.0	200.0	300.0
	0.0	0.0	25.0	50.0	75.0	100.0	200.0	300.0
	10.0	-10.0	12.5	35.0	57.5	80.0	170.0	260.0
	20.0	-20.0	0.0	20.0	40.0	60.0	140.0	220.0
	30.0	-30.0	-12.5	5.0	22.5	40.0	110.0	180.0
	40.0	-40.0	-25.0	-10.0	5.0	20.0	80.0	140.0
x	50.0	-50.0	-37.5	-25.0	-12.5	0.0	50.0	100.0
	60.0	-60.0	-50.0	-40.0	-30.0	-20.0	20.0	60.0
	70.0	-70.0	-62.5	-55.0	-47.5	-40.0	-10.0	20.0
	80.0	-80.0	-75.0	-70.0	-65.0	-60.0	-40.0	-20.0
	90.0	-90.0	-87.5	-85.0	-82.5	-80.0	-70.0	-60.0
	100.0	-100.0	-100.0	-100.0	-100.0	-100.0	-100.0	-100.0

Application to the MSCI World index

Figure 133: Scope 1 + 2 + 3 carbon emissions and intensity



Source: MSCI (2021), Trucost reporting year (2021) & Le Guenedal *et al.* (2022).

Carbon trend of a portfolio

We can show that:

$$\mathcal{CE}(t, x; 1) = \sum_{i=1}^{n} w_i \cdot \mathcal{CE}_i(t)$$

where:

$$w_i = \frac{x_i \cdot \mathcal{FP}_i}{\mathcal{MC}_i}$$

We deduce that:

$$\mathcal{CE}(t, x; 1) = \underbrace{\left(\sum_{i=1}^{n} w_i \beta_{i,0}\right)}_{\beta_0(x)} + \underbrace{\left(\sum_{i=1}^{n} w_i \beta_{i,1}\right)}_{\beta_1(x)} t + \underbrace{\left(\sum_{i=1}^{n} w_i u_i(t)\right)}_{\varepsilon(t)}$$

Application to the MSCI World index

Puzzle

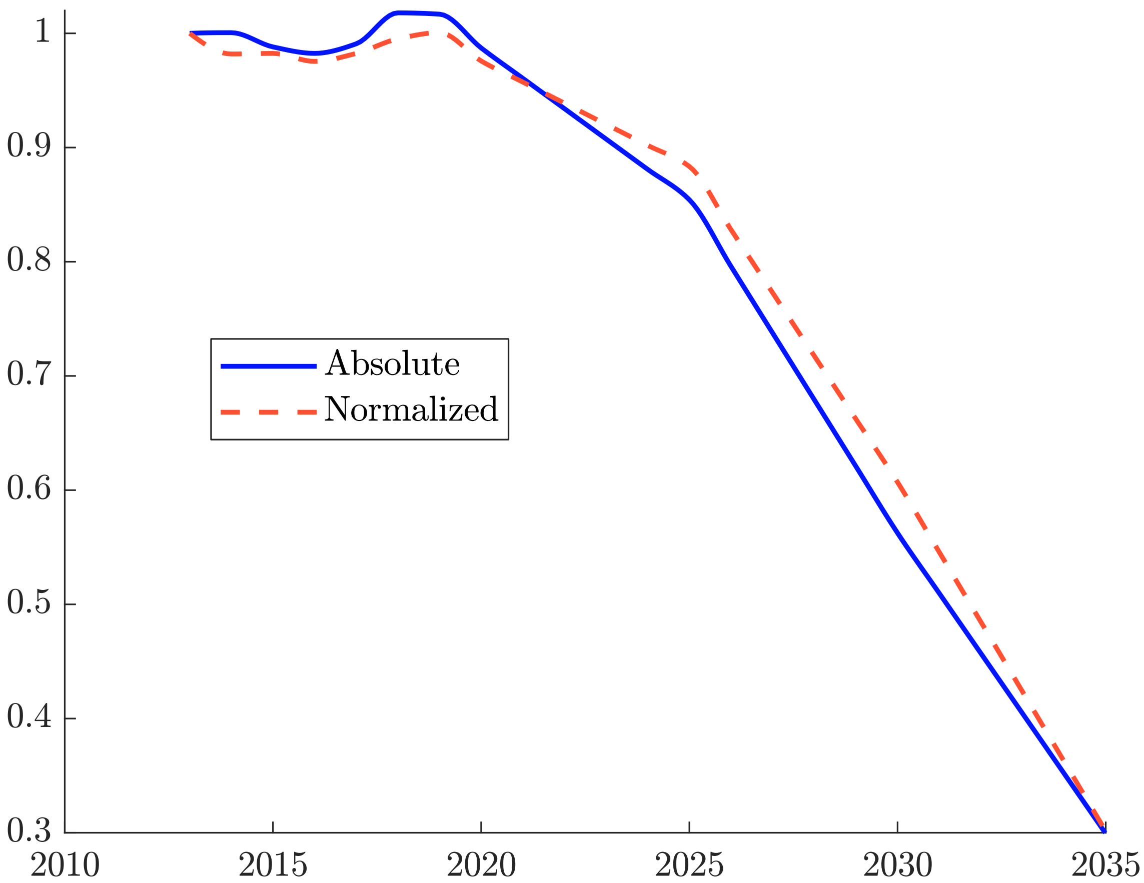
- $\hat{\beta}_1 = -28.80$ tCO_2e/\$ mn
- $\hat{\beta}_1$ (2019) $= -4.69$ tCO_2e/\$ mn
- $\hat{\beta}_1$ (2019) $= -4.07$ tCO_2e/\$ mn
- $\hat{\beta}_1$ (2019) $= -3.24$ tCO_2e/\$ mn

WHY?

- The rebalancing of the index composition explains 80% of the reduction
- The remaining 20% is explained by the reduction of the issuers

Application to the MSCI World index

Figure 134: NZE scenario of the MSCI World index (2021)



Source: IEA (2021), MSCI (2021), Trucost reporting year (2021) & Le Guenedal *et al.* (2022).

NZE alliances

- **NZAOA** Net Zero Asset Owner Alliance
  - `https://www.unepfi.org/net-zero-alliance`
  - 66 signatories with $10 trillion in assets under management
- **NZAMI** Net Zero Asset Managers initiative
  - `https://www.netzeroassetmanagers.org`
  - 236 signatories with $57.5 trillion in assets under management
- **NZBA** Net Zero Banking Alliance
  - `https://www.unepfi.org/net-zero-banking`
  - 100 signatories representing 40 countries and 43% of global banking assets
- **NZIA** Net Zero Insurance Alliance
  - `https://www.unepfi.org/net-zero-insurance`
  - Eight founding members: AXA, Allianz, Aviva, Generali, Munich Re, SCOR, Swiss Re and Zurich Insurance Group
- **GFANZ** Glasgow Financial Alliance for Net Zero
  - `https://www.gfanzero.com`
  - 450 financial firms across 45 countries responsible for assets of over $130 trillion

How to define an NZE policy

With all these alliances, we may think that defining an NZE policy is simple

It is not simple, it is a nightmare!

Too much side effects

How to define an NZE policy

Key elements

- Engagement
  - Shareholder activism (active ownership, exit, media, controversies)
  - Voting policy & resolutions
  - Stewardship
- Capital allocation
  - Financing green solutions
    - Power/electricity sector
    - Renewable energies (wind, solar, etc.)
    - Cleantech & CCS (carbon capture and storage)
    - Green/blue hydrogen
  - Portfolio allocation
    - Strategic asset allocation
    - Portfolio construction
    - Portfolio alignment ($\neq$ portfolio decarbonization)

How to define an NZE policy

Current timing and priorities

Portfolio allocation $\succ$ (Engagement, Green financing)

Right timing and priorities

(Engagement, Green financing) $\succ$ Portfolio allocation

Remark

The three biggest US asset managers are the largest shareholders in 90% of S&P 500 companies

How to define an NZE policy

The magic formula is:

$$\textbf{Cost of Capital} = \textbf{Cost of Equity} + \textbf{Cost of Debt}$$

$\Rightarrow$ The power of finance and capital allocation:

1. Banks
2. Asset owners
3. Asset managers

How to define an NZE policy

- Traditional view of capital allocation:

  Innovations first, then finance the industrialization

- Alternative view of capital allocation:

  Money first, then innovations

Cost of capital = price equilibrium between supply and demand

- Is Supply the Problem?
- Is Demand the Problem?

How to boost supply?

- By creating the demand (new fiduciary role of asset managers)
- By the regulation

$\Rightarrow$ This is always a question about cost of capital

How to define an NZE policy

The example of low-carbon hydrogen solutions:

- Advancing Hydrogen Fund (CEFC)
- CPR Invest – Hydrogen Fund
- GLOBAL X Hydrogen ETF (HYDR)
- Green Hydrogen Fund (EIB)
- Green Hydrogen Fund (Hy24)
- Hydrogen Economy ETF (Legal & General IM)

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Any normalization is an issue: $\mathcal{CI} = \dfrac{\mathcal{CE}}{Y}$

Are we on the right track if:

- the carbon intensity of issuers decreases by 7% p.a. and their revenues increase by 3% p.a.?
- the carbon intensity of countries decreases by 10% p.a. and their gdp increase by 3% p.a.?
- the carbon intensity of the aviation sector decreases by 15% p.a. (in terms of revenue passenger kilometers) and the number of passenger is multiplied by 3 in 2050?
- the carbon intensity of issuers decreases by 12% p.a. and the number of issuers is multiplied by 2 in 2050?

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Static analysis

- Baseline date

$$\mathcal{CI}(t_0) = \frac{\mathcal{CE}(t_0)}{Y(t_0)}$$

- Current date

$$\mathcal{CI}(t) = \frac{\mathcal{CE}(t)}{Y(t)}$$

- We deduce that:

$$\mathcal{CI}(t) = \left(\frac{1 + \upsilon_{\mathcal{CE}}(t)}{1 + \upsilon_Y(t)}\right) \frac{\mathcal{CE}(t_0)}{Y(t_0)} = (1 + \upsilon_{\mathcal{CI}}(t)) \, \mathcal{CI}(t_0)$$

where:

$$\upsilon_{\mathcal{CI}}(t) = \frac{\upsilon_{\mathcal{CE}}(t) - \upsilon_Y(t)}{1 + \upsilon_Y(t)}$$

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Table 76: Values* of $\upsilon_{\mathcal{CI}}(t)$ (in %)

		$\upsilon_{\mathcal{CE}}(t)$						
		−90.0	−75.0	−50.0	−25.0	0.0	25.0	50.0
$\upsilon_Y(t)$	−50.0	−80.0	−50.0	0.0	50.0	100.0	150.0	200.0
	−25.0	−86.7	−66.7	−33.3	0.0	33.3	66.7	100.0
	0.0	−90.0	−75.0	−50.0	−25.0	0.0	25.0	50.0
	25.0	−92.0	−80.0	−60.0	−40.0	−20.0	0.0	20.0
	50.0	−93.3	−83.3	−66.7	−50.0	−33.3	−16.7	0.0
	75.0	−94.3	−85.7	−71.4	−57.1	−42.9	−28.6	−14.3
	90.0	−94.7	−86.8	−73.7	−60.5	−47.4	−34.2	−21.1

(*)If the issuer does not reduce its carbon emissions and increases its revenues (or the normalization variable) by 25%, its carbon intensity is reduced by 20%

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Dynamic analysis

- The carbon budget constraint is $\int_{t_0}^{t} \mathcal{CE}(s)\,\mathrm{d}s \leq \mathcal{CB}^+$. We can show that this constraint is equivalent to:

$$m^{\mathrm{nze}} \cdot (t - t_0) \leq \frac{\mathcal{CB}^+}{\mathcal{CE}(t_0)}$$

  where* $m^{\mathrm{nze}} = 1 + \bar{\upsilon}_{\mathcal{CI}} + \bar{\upsilon}_Y + \bar{\upsilon}_{\mathcal{CI},Y}$
- Interpretation
  - $t - t_0$ is the time period before net zero target date (e.g., 30 years)
  - The ratio $\dfrac{\mathcal{CB}^+}{\mathcal{CE}(t_0)}$ indicates the number of remaining years before reaching the carbon budget if nothing is done (e.g., 20 ans)
  - m^{nze} is the carbon emissions average multiplier (e.g., $m^{\mathrm{nze}} = 0.50$)

(*) Generally, we have $\upsilon_{\mathcal{CI}}(t) < 0$ and $\upsilon_Y(t) > 0$ (implying that $\upsilon_{\mathcal{CI}}(t)\,\upsilon_Y(t) < 0$)

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Proof.

We have:

$$
\begin{aligned}
(*) \quad & = \int_{t_0}^{t} \mathcal{CE}(s)\,\mathrm{d}s \leq \mathcal{CB}^{+} \\
& \Leftrightarrow \int_{t_0}^{t} \left(1 + \upsilon_{\mathcal{CE}}(s)\right) \mathcal{CE}(t_0)\,\mathrm{d}s \leq \mathcal{CB}^{+} \\
& \Leftrightarrow \int_{t_0}^{t} \left(1 + \upsilon_{\mathcal{CI}}(s)\right)\left(1 + \upsilon_{Y}(s)\right)\mathrm{d}s \leq \frac{\mathcal{CB}^{+}}{\mathcal{CE}(t_0)} \\
& \Leftrightarrow \int_{t_0}^{t} \left(1 + \upsilon_{\mathcal{CI}}(s) + \upsilon_{Y}(s) + \upsilon_{\mathcal{CI}}(s)\,\upsilon_{Y}(s)\right)\mathrm{d}s \leq \frac{\mathcal{CB}^{+}}{\mathcal{CE}(t_0)}
\end{aligned}
$$

Using the mean value theorem, we have $\int_{t_0}^{t} \upsilon(s)\,\mathrm{d}s = \bar{\upsilon} \cdot (t - t_0)$. We deduce that:

$$
(*) \Leftrightarrow \left(1 + \bar{\upsilon}_{\mathcal{CI}} + \bar{\upsilon}_{Y} + \bar{\upsilon}_{\mathcal{CI},Y}\right) \cdot (t - t_0) \leq \frac{\mathcal{CB}^{+}}{\mathcal{CE}(t_0)}
$$

∎

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Example: 50% probability to reach net zero by 2050

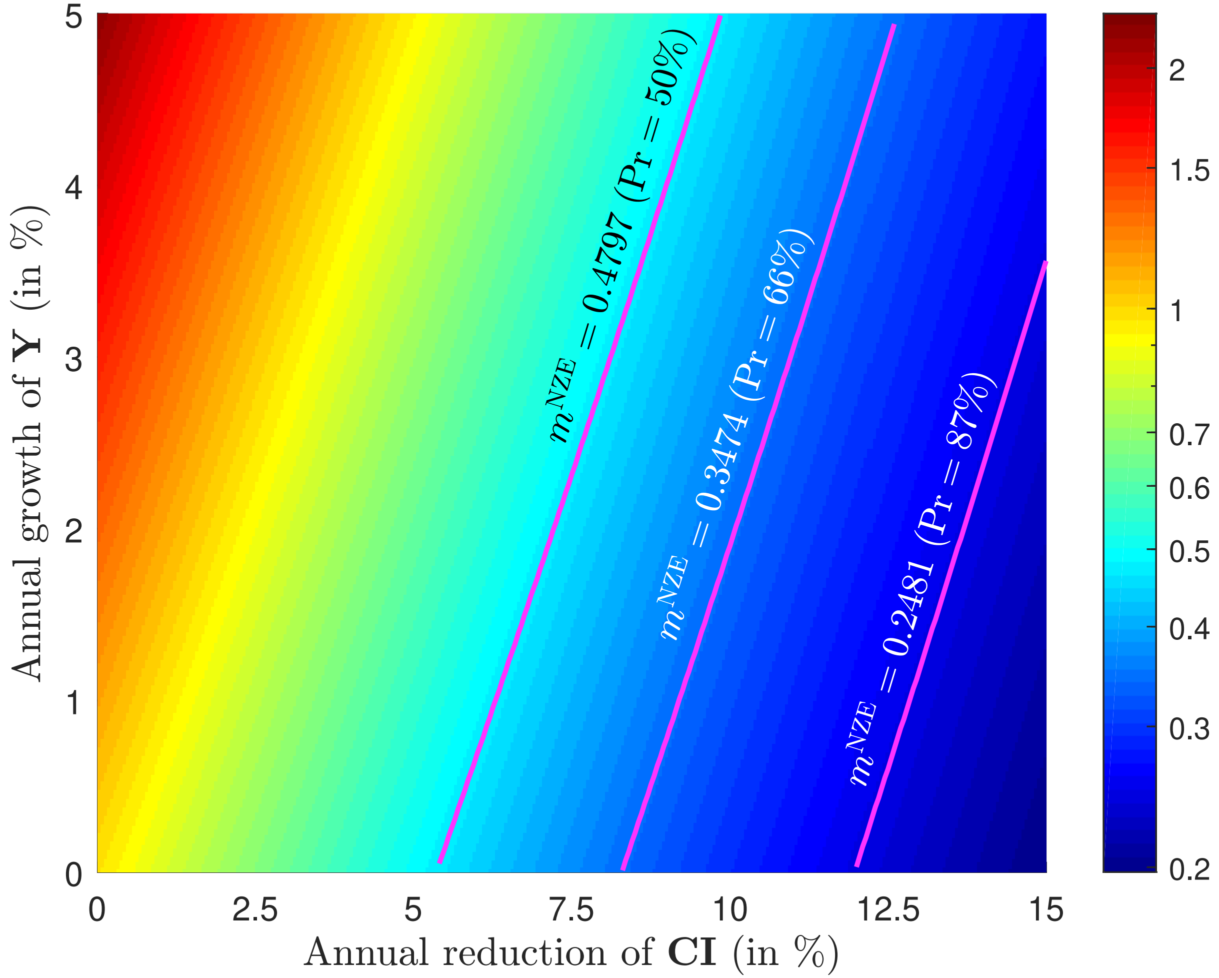
- $t_0 = 2019$
- $\mathcal{CE}(2019) = 36 \text{ GtCO}_2\text{e}$
- $t = 2050$
- $\mathcal{CB}^+ = 580 \text{ GtCO}_2\text{e}$
- $t - t_0 = 31$ years
- $\tau = \dfrac{\mathcal{CB}^+}{\mathcal{CE}(t_0)} = 14.87$ years
- We deduce that:

$$m^{\text{nze}} \leq \frac{14.87}{31} = 0.4797$$

How to define an NZE policy

Absolute carbon emissions vs. carbon intensity

Figure 135: Value of the carbon emissions average multiplier



Paris-aligned benchmarks

The EU Technical Expert Group on sustainable finance (TEG) has created two climate benchmark labels:

1. Climate transition benchmark (CTB)
2. Paris-aligned benchmark (PAB)

Paris-aligned benchmarks

Principles

- A year-on-year self-decarbonization of 7% on average per annum, based on scope 1, 2 and 3 emissions
- A minimum carbon intensity reduction $\mathcal{R}^-$ compared to the investable universe
- A minimum exposure to sectors highly exposed to climate change
- Issuer exclusions (controversial weapons and societal norms violators)
- Minimum green share revenue

CTB

$$\mathcal{R}^- = 30\%$$

PAB

$$\mathcal{R}^- = 50\%$$

Decarbonization pathway

- t_0 is the base date of the climate benchmark
- The minimum reduction $\mathcal{R}(t_0, t)$ of the carbon intensity between the current date t and the base date t_0 is equal to:

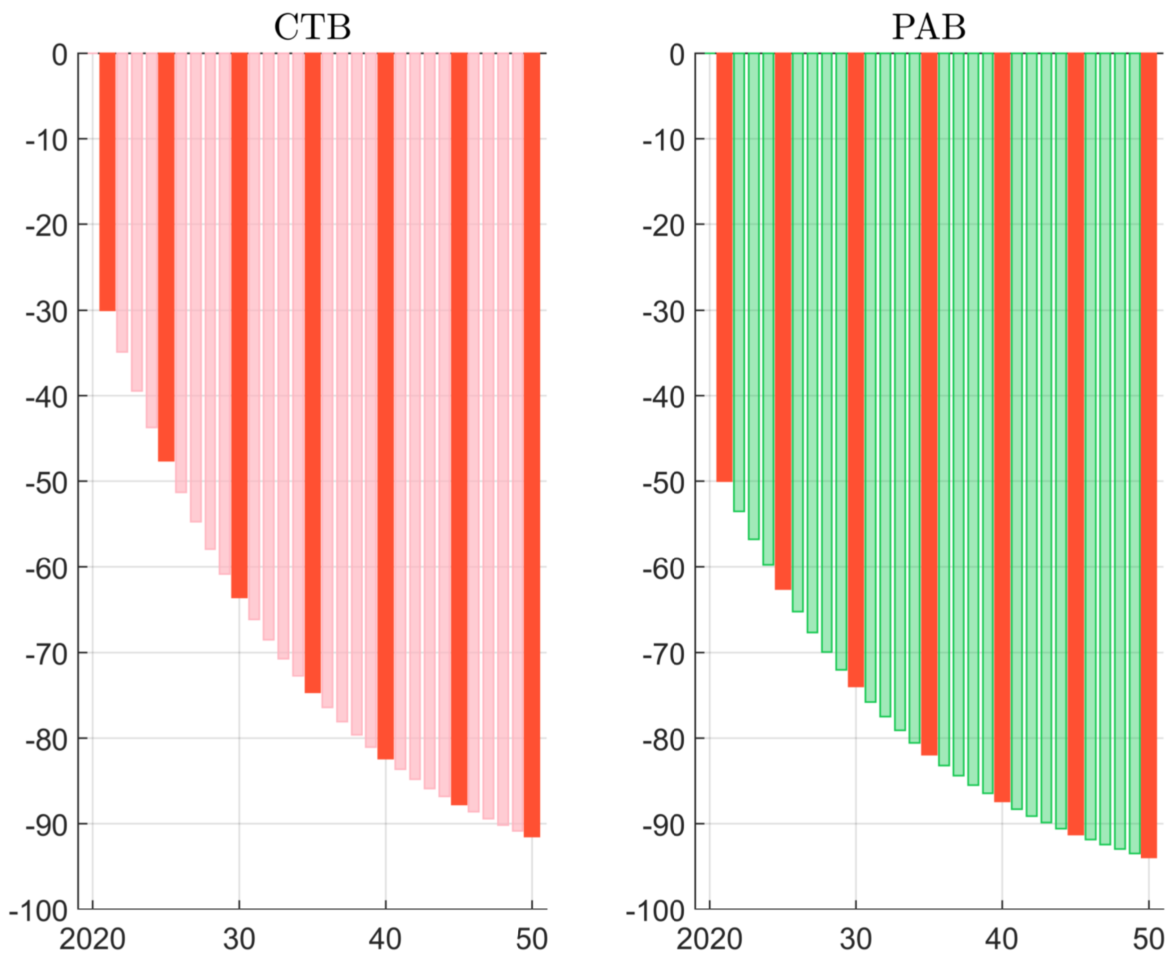
$$\mathcal{R}(t_0, t) = 1 - (1 - 7\%)^{t - t_0} \cdot \left(1 - \mathcal{R}^-\right)$$

- At date t, the CTB and PAB labels impose the following inequality constraint for the portfolio $x(t)$:

$$\mathcal{CI}(x(t)) \leq (1 - \mathcal{R}(t_0, t)) \cdot \mathcal{CI}(b(t_0))$$

Decarbonization pathway

Figure 136: Decarbonization pathway of CTB and PAB labels (base year = 2021)



Climate impact sector

Two types of sectors:

1. High climate impact sectors (HCIS or $\mathcal{CIS}_{\mathcal{H}igh}$)
2. Low climate impact sectors (LCIS or $\mathcal{CIS}_{\mathcal{L}ow}$)

- The HCIS category is made up of sectors that are key to the low-carbon transition
- At each rebalancing date t, we must verify that:

$$\mathcal{CIS}_{\mathcal{H}igh}\left(x\left(t\right)\right) \geq \varphi_{\mathcal{CIS}} \cdot \mathcal{CIS}_{\mathcal{H}igh}\left(b\left(t\right)\right)$$

where $\varphi_{\mathcal{CIS}} = 1$ and $\mathcal{CIS}_{\mathcal{H}igh}\left(x\right) = \sum_{i \in \mathcal{CIS}_{\mathcal{H}igh}} x_i$ is the HCIS weight of Portfolio x

NACE classification of high climate impact sectors

- A. Agriculture, Forestry, and Fishing
- B. Mining and Quarrying
- C. Manufacturing
- D. Electricity, Gas, Steam, and Air Conditioning Supply
- E. Water Supply; Sewerage, Waste Management, and Remediation Activities
- F. Construction
- G. Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
- H. Transportation and Storage
- L. Real Estate Activities

Broad HCIS measure

Mapping between the NACE classes and several sector classification structures (TEG, 2019):

- BICS (Bloomberg)
- GICS (MSCI and S&P)
    - 129 sub-industries out of a total of 185 are classified as high climate impact sectors
    - Only two sectors are classified in low climate impact sectors: Communication Services and Financials
    - Half of the Health Care and Information Technology sub-industries are viewed as high climate impact sectors
- ICB (FTSE)
- TRBC (Refinitiv)

Narrow HCIS measure

Table 77: The narrow measure of high climate impact sectors

NACE		GICS	
Code	Sector	Code	Sector
A	Agriculture, Forestry & Fishing	302020	Food Products
B	Mining & Quarrying	10 151040	Energy Metals & Mining
C	Manufacturing	20	Industrials
D	Electricity, Gas, Steam & Air Conditioning Supply	55	Utilities
E	Water Supply Sewerage, Waste Management & Remediation Activities		
F	Construction	151020	Construction Materials
G	Wholesale & retail trade Repair of Motor Vehicles & Motorcycles	301010	Food & Staples Retailing
H	Transportation & Storage	2030	Transportation
L	Real Estate Activities	60	Real Estate

Source: Le Guenedal and Roncalli (2022).

High climate impact sectors

Table 78: Weights and carbon intensity of high climate impact sectors

Sector	S&P 500 b_s	S&P 500 $\mathcal{CI}_s$	Narrow HCIS b_s	Narrow HCIS $\mathcal{CI}_s$	Broad HCIS b_s	Broad HCIS $\mathcal{CI}_s$
Communication Services	10.89%	80				
Consumer Discretionary	13.57%	190			10.22%	185
Consumer Staples	6.10%	355	2.73%	348	6.10%	355
Energy	2.81%	790	2.81%	790	2.81%	790
Financials	11.13%	67				
Health Care	12.74%	126			8.56%	152
Industrials	7.97%	330	7.97%	330	6.32%	368
Information Technology	27.50%	99			13.30%	139
Materials	2.45%	966	0.44%	850	2.45%	966
Real Estate	2.55%	198	2.55%	198	2.55%	198
Utilities	2.30%	2 669	2.30%	2 669	2.30%	2 669
Total	100.00%	245	18.79%	681	54.59%	380

Source: Le Guenedal and Roncalli (2022).

Optimization problem

We have:

$$\begin{aligned} x^{\star}(t) &= \arg\min_{x(t)} \frac{1}{2}\sigma^2 (x(t) \mid b(t)) + \lambda \tau (x(t) \mid x^{\star}(t-1)) \\ & \text{s.t.} \quad \left\{ \begin{array}{l} \mathbf{1}_n^\top x(t) = 1 \\ x(t) \geq \mathbf{0}_n \\ \mathcal{CI}(x(t)) \leq (1 - \mathcal{R}(t_0, t)) \cdot \mathcal{CI}(b(t_0)) \\ \mathcal{CIS}_{\mathcal{H}igh}(x(t)) \geq \varphi_{\mathcal{CIS}} \cdot \mathcal{CIS}_{\mathcal{H}igh}(b(t)) \\ \left| \sum_{i \in \mathcal{S}ector_j} x_i(t) - \sum_{i \in \mathcal{S}ector_j} b_i(t) \right| \leq \delta_j \end{array} \right. \end{aligned}$$

where $\lambda \geq 0$, $\sigma(x(t) \mid b(t))$ is the tracking error risk:

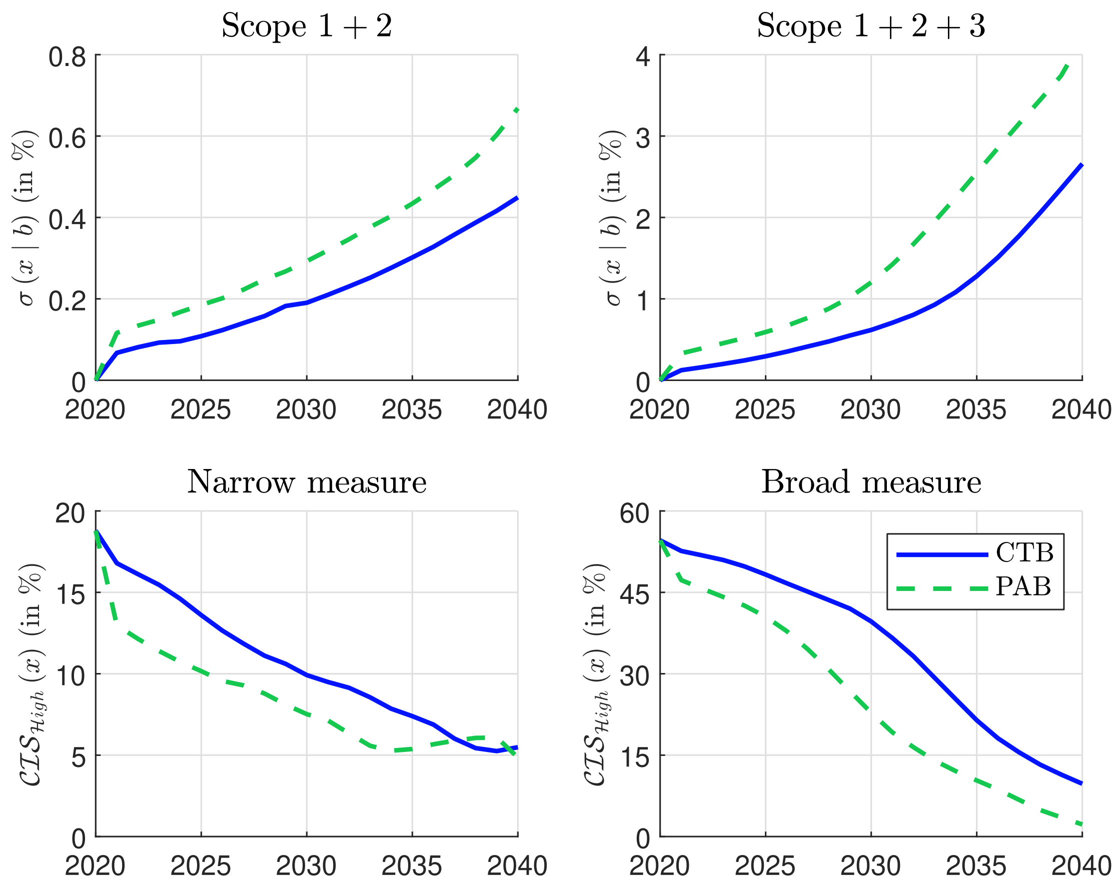
$$\sigma(x(t) \mid b(t)) = \sqrt{(x(t) - b(t))^\top \Sigma(t) (x(t) - b(t))}$$

and $\tau(x(t) \mid x^{\star}(t-1))$ is the one-way turnover of the portfolio between $t-1$ and t:

$$\tau(x(t) \mid x^{\star}(t-1)) = \frac{1}{2} \left\| x(t) - x^{\star}(t-1) \right\|_1$$

Optimization solution

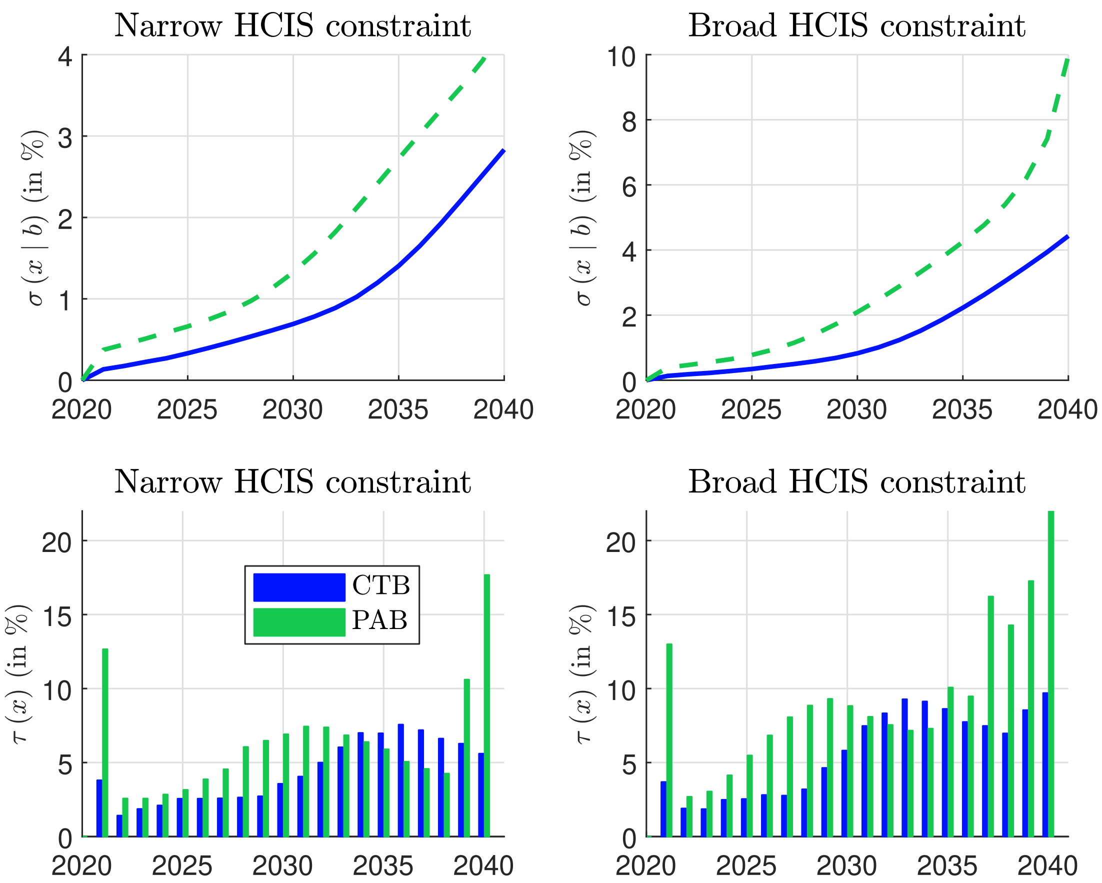
Figure 137: The impact of scope 3 on CTB and PAB labels



Source: Le Guenedal and Roncalli (2022).

Optimization solution

Figure 138: The impact of the HCIS constraint on CTB and PAB labels



Source: Le Guenedal and Roncalli (2022).

Optimization solution

Table 79: Tracking error risk of CTB and PAB labels

Year	CTB			PAB		
	Scope 3	+ Narrow	+ Broad	Scope 3	+ Narrow	+ Broad
2021	0.12%	0.13%	0.13%	0.33%	0.37%	0.39%
2022	0.16%	0.18%	0.19%	0.39%	0.44%	0.47%
2023	0.20%	0.23%	0.23%	0.46%	0.51%	0.56%
2024	0.24%	0.27%	0.28%	0.52%	0.59%	0.65%
2025	0.29%	0.33%	0.35%	0.59%	0.66%	0.78%
2030	0.62%	0.69%	0.83%	1.20%	1.33%	2.09%
2035	1.28%	1.40%	2.23%	2.55%	2.72%	4.25%
2040	2.66%	2.83%	4.43%	4.19%	4.43%	9.97%

Source: Le Guenedal and Roncalli (2022).

Optimization solution

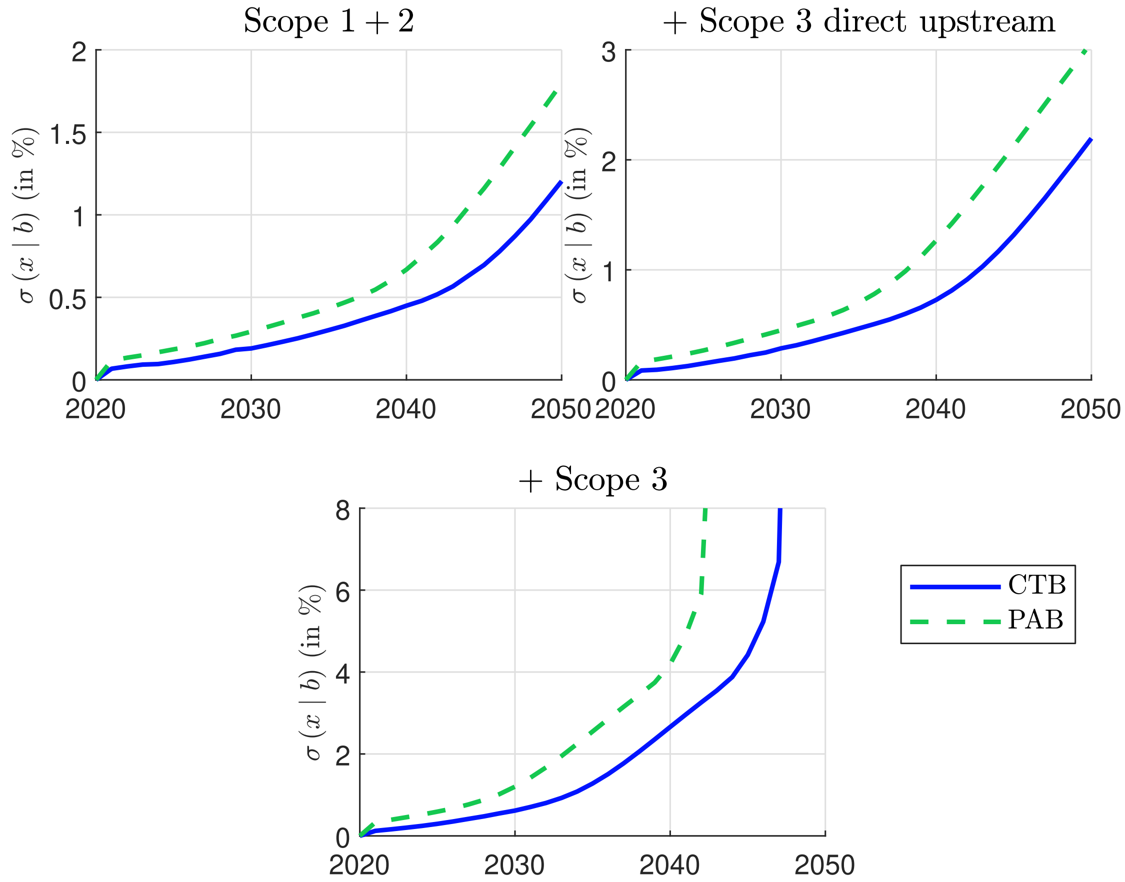
Table 80: Effective number of bets

Year	CTB			PAB		
	Scope 3	+ Narrow	+ Broad	Scope 3	+ Narrow	+ Broad
2020	70.56	70.56	70.56	70.56	70.56	70.56
2021	69.95	70.29	70.15	68.37	69.30	68.78
2022	69.77	70.24	70.53	68.06	68.93	68.30
2023	69.48	70.22	69.88	67.59	68.43	67.95
2024	69.07	69.73	69.68	67.02	68.12	67.11
2025	68.66	69.52	69.08	66.58	67.46	66.75
2030	66.26	67.24	66.42	66.64	68.82	66.85
2035	67.36	69.61	66.15	76.35	76.42	44.72
2040	76.26	75.67	41.45	49.97	42.61	5.48

Source: Le Guenedal and Roncalli (2022).

The scope 3 issue (which scope 3?)

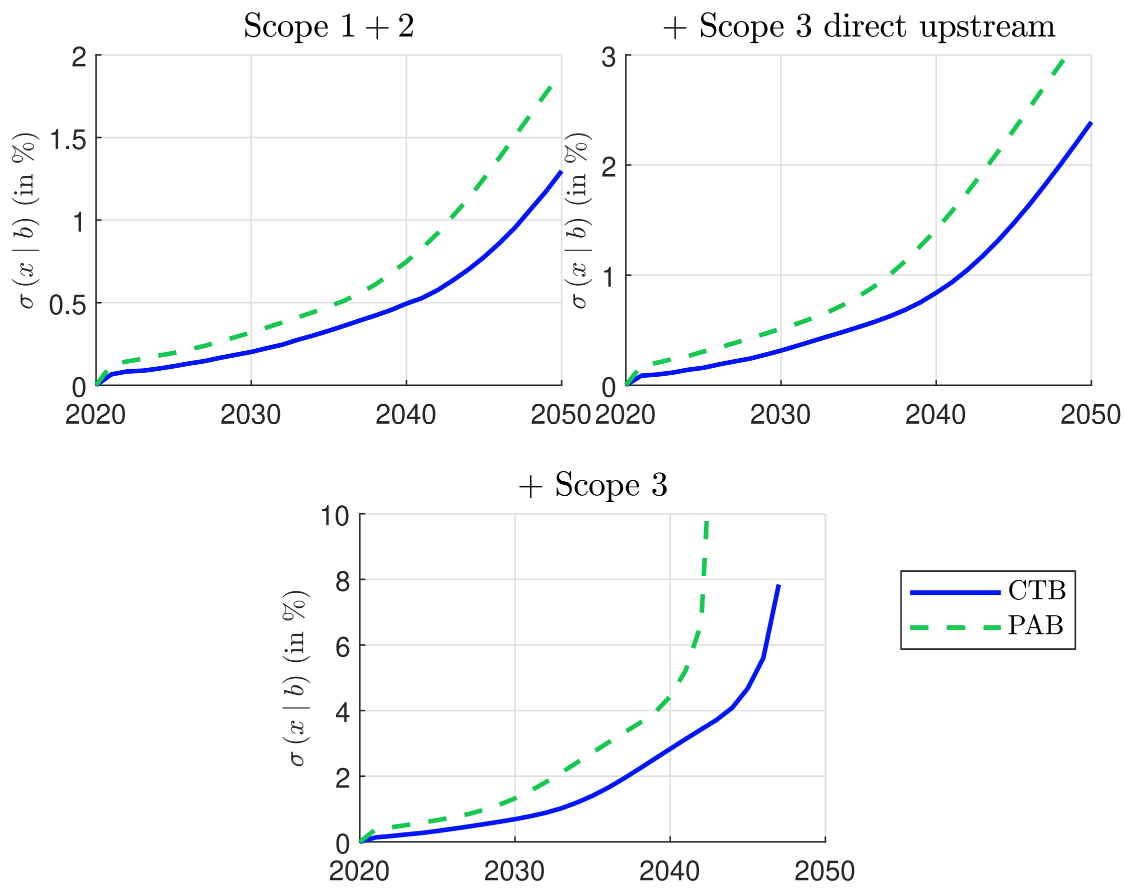
Figure 139: Tracking error of CTB and PAB labels when implementing the decarbonization pathway



Source: Le Guenedal and Roncalli (2022).

The scope 3 issue (which scope 3?)

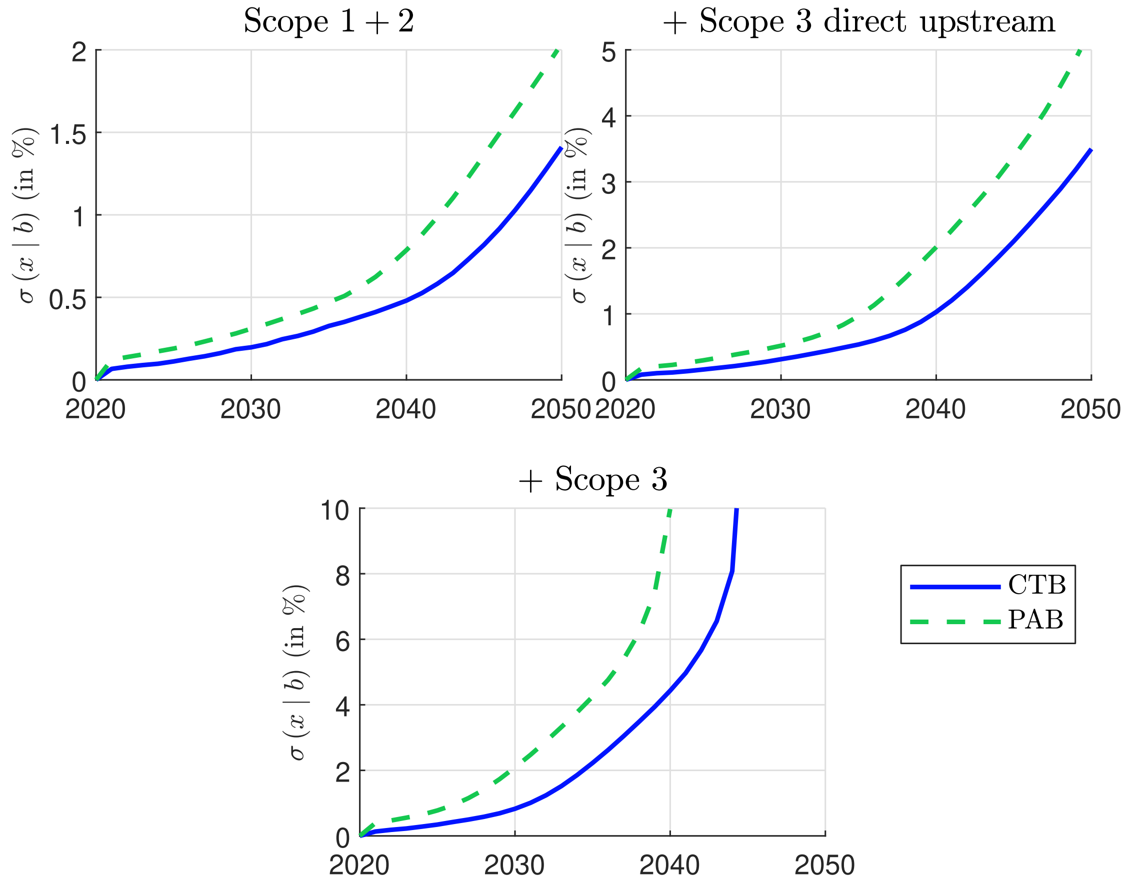
Figure 140: Tracking error of CTB and PAB labels when implementing the decarbonization pathway and the narrow HCIS constraint



Source: Le Guenedal and Roncalli (2022).

The scope 3 issue (which scope 3?)

Figure 141: Tracking error of CTB and PAB labels when implementing the decarbonization pathway and the broad HCIS constraint



Source: Le Guenedal and Roncalli (2022).

Understanding allocation effects

See Barahhou and Roncalli (2022) $\Rightarrow$ additional slides

Top-down approach $\Rightarrow$ bottom-up approach

Preamble

- NZE portfolio alignment cannot be reduced to portfolio decarbonization with a carbon reduction pathway
- NZE portfolio alignment is more difficult than portfolio decarbonization for three reasons:
  1. Reduction rates $\mathcal{R}(t_0, t)$ are very high $\Rightarrow$ Diversification will be highly reduced!
  2. How avoiding to pass the hot potato on to the other investors? $\Rightarrow$ It is easy to decarbonize, but it is difficult to participate to the NZE effort!
  3. Uncertainty about the future trajectories and no turning back $\Rightarrow$ Current mistakes are cumulative

How to manage a portfolio in a highly constrained world in terms of investment universe?

Some risks

Portfolio management risks

- Economy decarbonization $\ll$ Finance decarbonization
- Diversification can be dramatically reduced between/within sectors
- Liquidity issues

Financial risks

- Performance
- Crowding
- How to remain an active manager?

Economic risks

- Who will finance the transition?
- Liability risk(s)

NZE portfolio optimization

The constraints

- We have to introduce the issuer/sector trajectories
- For instance, the carbon intensity constraint of the PAB problem:

$$\mathcal{CI}\left(x\left(t\right)\right) \leq \left(1 - \mathcal{R}\left(t_0, t\right)\right) \cdot \mathcal{CI}\left(b\left(t_0\right)\right)$$

becomes:

$$\widehat{\mathcal{CI}}\left(x\left(t\right)\right) \leq \left(1 - \mathcal{R}\left(t_0, t\right)\right) \cdot \mathcal{CI}\left(b\left(t_0\right)\right)$$

where:

$$\widehat{\mathcal{CI}}\left(x\left(t\right)\right) = \sum_{i=1}^{n} x_i\left(t\right) \cdot \widehat{\mathcal{CI}}_i\left(t\right)$$

- Which estimate measures?
  - Trend trajectory?
  - Target trajectory?
  - NZE trajectory?

NZE portfolio optimization

The constraints

- What is the drawback to use constraints on $\widehat{\mathcal{CI}}(x(t))$ or $\widehat{\mathcal{CE}}(x(t))$?
- The solution does not depend on the intermediate values of $\widehat{\mathcal{CI}}(x(t))$ or $\widehat{\mathcal{CE}}(x(t))$ between t_0 and $t-1$
- A better approach is to consider the carbon budget $\widehat{\mathcal{CB}}(t_0, t)$?

NZE portfolio optimization

The objective function

We consider this simple objective function:

$$
\begin{array}{rcl}
x^{\mathrm{nze}}(t) & = & \arg\min_{x} \dfrac{1}{2}(x-b)^\top \Sigma (x-b) \\
\text{s.t.} & & \left\{\begin{array}{l}
\mathbf{1}_n^\top x = 1 \\
x \geq \mathbf{0}_n \\
\widehat{\mathcal{CI}}(x) \leq (1-\mathcal{R}(t_0,t)) \cdot \mathcal{CI}(b(t_0))
\end{array}\right.
\end{array}
$$

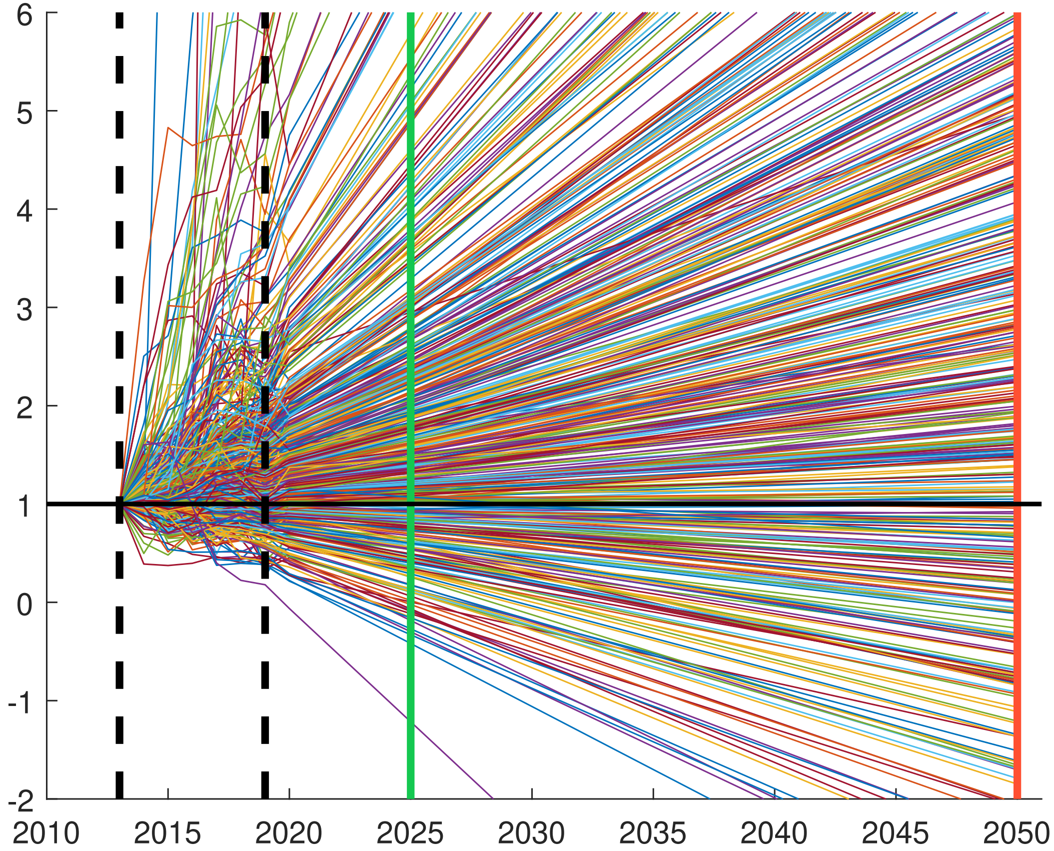
where $\widehat{\mathcal{CI}}(x)$ uses the projected trends:

$$
\widehat{\mathcal{CI}}(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{CI}_i^{Trend}(t)
$$

NZE portfolio optimization

Results with the S&P 500 index

Figure 142: Carbon emissions trends of the S&P 500 constituents



Source: Le Guenedal and Roncalli (2022).

NZE portfolio optimization

Results with the S&P 500 index

We have:

Statistic	$\hat{\beta}_{i,1} \leq 0$	$\hat{\beta}_{i,1} > 0$	$m_i(2050) \geq 2$	$m_i(2050) \geq 5$
Frequency	26.9%	73.1%	59.41%	30.69%

where:

$$m_i(t) = \frac{\mathcal{CI}_i^{Trend}(t)}{\mathcal{CI}_i(2019)}$$

NZE portfolio optimization

Results with the S&P 500 index

We consider:

- The solution $x^{NZE}(t)$
- The solution $x^{\mathrm{DCN}}(t)$ obtained by considering the current carbon intensities $\mathcal{CI}_i(t_0)$ instead of the estimated values $\mathcal{CI}_i^{Trend}(t)$

We compute the active share between the two portfolios:

$$\mathcal{AS}\left(x^{\mathrm{NZE}}(t), x^{\mathrm{DCN}}(t)\right) = \frac{1}{2}\left\|x^{\mathrm{NZE}}(t) - x^{\mathrm{DCN}}(t)\right\|_1$$

Table 81: Active share between NZE and DCN portfolios

Year	$\mathcal{R}(t_0, t)$							
	10%	20%	30%	40%	50%	60%	70%	80%
2025	1.0%	1.3%	2.0%	3.2%	4.4%	7.8%	18.4%	48.9%
2030	1.1%	1.4%	2.7%	4.8%	9.2%	15.3%	28.5%	58.3%
2035	1.1%	1.8%	3.3%	5.9%	11.0%	17.3%	30.6%	60.0%
2040	1.1%	2.0%	3.6%	6.3%	11.5%	18.0%	31.3%	60.6%
2045	1.2%	2.1%	3.8%	6.5%	11.8%	18.3%	31.6%	60.8%
2050	1.2%	2.1%	3.8%	6.7%	11.9%	18.5%	31.7%	60.9%

The no-feasible NZE solution

- The Financials/Industrials solution is not an NZE solution!
- Too much constraints & objectives $\Rightarrow$ No solution!
- The gap between portfolio decarbonization and economy decarbonization must be reduced sooner or later $\Rightarrow$ The asset management industry is at risk!

Course 2021-2022 in ESG and Climate Risks
Lecture 6. Mathematical Methods, Technical Tools and Exercises

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[28] The opinions expressed in this presentation are those of the authors and are not meant to represent the opinions or official positions of Amundi Asset Management.

Computation of the carbon budget

- We consider the following computation:

$$\begin{aligned}\mathcal{CB}_i(t_0, t) &= \int_{t_0}^{t} \left(\mathcal{CE}_i(s) - \mathcal{CE}_i^\star\right) \mathrm{d}s \\ &= \mathcal{I}\left(\mathcal{CE}_i(s), \mathcal{CE}_i^\star; t_0, t\right)\end{aligned}$$

- In the case where $\mathcal{CE}_i^\star$ is not constant, we have:

$$\begin{aligned}\int_{t_0}^{t} \left(\mathcal{CE}_i(s) - \mathcal{CE}_i^\star(s)\right) \mathrm{d}s &= \int_{t_0}^{t} \mathcal{CE}_i(s) \,\mathrm{d}s - \int_{t_0}^{t} \mathcal{CE}_i^\star(s) \,\mathrm{d}s \\ &= \mathcal{I}\left(\mathcal{CE}_i(s), 0; t_0, t\right) - \mathcal{I}\left(\mathcal{CE}_i^\star(s), 0; t_0, t\right)\end{aligned}$$

- We only need a numerical approximation of $\mathcal{I}\left(\mathcal{CE}_i(s), \mathcal{CE}_i^\star; t_0, t\right)$

Numerical solution

- We consider the partition $\{[t_0, t_0 + \Delta t], \ldots, [t - \Delta t, t]\}$ of $[t_0, t]$
- We note:
$$m = \frac{t - t_0}{\Delta t}$$
- In the case of a yearly partition, we have $\Delta t = 1$
- We assume that $t_0 \leq t_{\mathcal{L}ast} \leq t$ where t_0 is the starting date, $t_{\mathcal{L}ast}$ is the last reporting date and t is the ending date

Numerical solution

- The right Riemann approximation is:

$$\begin{aligned}\mathcal{CB}_i(t_0, t) &= \int_{t_0}^{t} \left(\mathcal{CE}_i(s) - \mathcal{CE}_i^{\star}\right) \mathrm{d}s \\ &\approx \sum_{k=1}^{m} \left(\mathcal{CE}_i(t_0 + k\Delta t) - \mathcal{CE}_i^{\star}\right) \cdot \Delta t\end{aligned}$$

- The left Riemann sum is:

$$\mathcal{CB}_i(t_0, t) \approx \sum_{k=0}^{m-1} \left(\mathcal{CE}_i(t_0 + k\Delta t) - \mathcal{CE}_i^{\star}\right) \cdot \Delta t$$

- The midpoint rule is given by:

$$\mathcal{CB}_i(t_0, t) \approx \sum_{k=1}^{m} \left(\mathcal{CE}_i\left(t_0 + \frac{k}{2}\Delta t\right) - \mathcal{CE}_i^{\star}\right) \cdot \Delta t$$

Special cases
Constant linear reduction

We use a constant linear reduction rate:

$$\mathcal{R}_i \left(t_{\mathcal{L}ast}, t\right) = \mathcal{R}_i \cdot \left(t - t_{\mathcal{L}ast}\right)$$

We have:

$$\begin{aligned}
\int_{t_{\mathcal{L}ast}}^{t} \mathcal{R}_i \left(t_{\mathcal{L}ast}, s\right) \,\mathrm{d}s &= \mathcal{R}_i \int_{t_{\mathcal{L}ast}}^{t} \left(s - t_{\mathcal{L}ast}\right) \,\mathrm{d}s \\
&= \mathcal{R}_i \frac{\left(t - t_{\mathcal{L}ast}\right)^2}{2}
\end{aligned}$$

We obtain the following semi-analytical expression:

$$\begin{aligned}
\mathcal{CB}_i \left(t_0, t\right) &= \left(t - t_{\mathcal{L}ast}\right)\left(\mathcal{CE}_i \left(t_{\mathcal{L}ast}\right) - \mathcal{CE}_i^{\star}\right) - \left(t_{\mathcal{L}ast} - t_0\right)\mathcal{CE}_i^{\star} + \\
&\quad \int_{t_0}^{t_{\mathcal{L}ast}} \mathcal{CE}_i \left(s\right) \,\mathrm{d}s - \mathcal{R}_i \frac{\left(t - t_{\mathcal{L}ast}\right)^2}{2} \mathcal{CE}_i \left(t_{\mathcal{L}ast}\right)
\end{aligned}$$

Special cases

Constant compound reduction

We have:

$$\mathcal{CE}_i(t) = (1 - \mathcal{R}_i)^{(t - t_{\mathcal{L}ast})} \cdot \mathcal{CE}_i(t_{\mathcal{L}ast})$$

We deduce that:

$$\begin{aligned}
\int_{t_{\mathcal{L}ast}}^{t} \mathcal{CE}_i(s)\,\mathrm{d}s &= \mathcal{CE}_i(t_{\mathcal{L}ast}) \int_{t_{\mathcal{L}ast}}^{t} (1 - \mathcal{R}_i)^{(s - t_{\mathcal{L}ast})}\,\mathrm{d}s \\
&= \mathcal{CE}_i(t_{\mathcal{L}ast}) \left[\frac{(1 - \mathcal{R}_i)^{(s - t_{\mathcal{L}ast})}}{\ln(1 - \mathcal{R}_i)} \right]_{t_{\mathcal{L}ast}}^{t} \\
&= \frac{(1 - \mathcal{R}_i)^{(t - t_{\mathcal{L}ast})} - 1}{\ln(1 - \mathcal{R}_i)} \mathcal{CE}_i(t_{\mathcal{L}ast})
\end{aligned}$$

Special cases

Constant compound reduction

It follows that:

$$\begin{aligned}
\mathcal{CB}_i(t_0,t) &= -(t-t_0)\cdot\mathcal{CE}_i^{\star}+\int_{t_0}^{t}\mathcal{CE}_i(s)\,\mathrm{d}s \\
&= -(t-t_0)\cdot\mathcal{CE}_i^{\star}+\int_{t_0}^{t_{\mathcal{L}ast}}\mathcal{CE}_i(s)\,\mathrm{d}s+ \\
&\quad \left(\frac{(1-\mathcal{R}_i)^{(t-t_{\mathcal{L}ast})}-1}{\ln(1-\mathcal{R}_i)}\right)\mathcal{CE}_i(t_{\mathcal{L}ast})
\end{aligned}$$

Special cases

Linear function

We assume that:

$$\mathcal{CE}_i(t) = \beta_{i,0} + \beta_{i,1} t$$

It follows that:

$$\begin{aligned}
\mathcal{CB}_i(t_0, t) &= \int_{t_0}^{t} \left(\beta_{i,0} + \beta_{i,1} s - \mathcal{CE}_i^{\star}\right) \mathrm{d}s \\
&= \left[\frac{1}{2}\beta_{i,1} s^2 + \left(\beta_{i,0} - \mathcal{CE}_i^{\star}\right) s\right]_{t_0}^{t} \\
&= \frac{1}{2}\beta_{i,1}\left(t^2 - t_0^2\right) + \left(\beta_{i,0} - \mathcal{CE}_i^{\star}\right)(t - t_0)
\end{aligned}$$

Special cases

Piecewise linear function

We assume that $\mathcal{CE}_i(t)$ is known for $t \in \{t_0, t_1, \ldots, t_m\}$ and $\mathcal{CE}_i(t)$ is linear between two consecutive dates:

$$\mathcal{CE}_i(t) = \mathcal{CE}_i(t_{k-1}) + \frac{\mathcal{CE}_i(t_k) - \mathcal{CE}_i(t_{k-1})}{t_k - t_{k-1}}(t - t_{k-1}) \qquad \text{if } t \in [t_{k-1}, t_k]$$

We also have:

$$\begin{aligned}
\mathcal{CE}_i(t) &= \underbrace{\frac{t_k}{t_k - t_{k-1}}\mathcal{CE}_i(t_{k-1}) - \frac{t_{k-1}}{t_k - t_{k-1}}\mathcal{CE}_i(t_k)}_{\beta_{i,0,k}} + \\
&\quad \underbrace{\frac{\mathcal{CE}_i(t_k) - \mathcal{CE}_i(t_{k-1})}{t_k - t_{k-1}}}_{\beta_{i,1,k}} t \\
&= \beta_{i,0,k} + \beta_{i,1,k} \cdot t
\end{aligned}$$

Special cases

Piecewise linear function

We deduce that:

$$\begin{aligned}\mathcal{CB}_i(t_0,t) &= \sum_{k=1}^{k(t)} \int_{t_{k-1}}^{t_k} \left(\mathcal{CE}_i(s) - \mathcal{CE}_i^\star\right) \mathrm{d}s + \\ & \int_{t_{k(t)}}^{t} \left(\mathcal{CE}_i(s) - \mathcal{CE}_i^\star\right) \mathrm{d}s\end{aligned}$$

where $k(t) = \{\max k : t_k \leq t\}$ and:

$$\begin{aligned}\mathcal{CB}_i(t_0,t) &= \frac{1}{2}\sum_{k=1}^{k(t)} \beta_{i,1,k}\left(t_k^2 - t_{k-1}^2\right) + \sum_{k=1}^{k(t)} \left(\beta_{i,0,k} - \mathcal{CE}_i^\star\right)\left(t_k - t_{k-1}\right) + \\ & \frac{1}{2}\beta_{i,1,k(t)+1}\left(t^2 - t_{k(t)}^2\right) + \left(\beta_{i,0,k(t)+1} - \mathcal{CE}_i^\star\right)\left(t - t_{k(t)}\right)\end{aligned}$$

Special cases

Piecewise linear function

We can simplify the previous expression as follows:

$$\begin{aligned}
\mathcal{CB}_i(t_0, t) &= \frac{1}{2}\sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t_k) - \mathcal{CE}_i(t_{k-1})\right)(t_k + t_{k-1}) + \\
&\quad \sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t_{k-1}) - \mathcal{CE}_i^{\star}\right) t_k - \sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t_k) - \mathcal{CE}_i^{\star}\right) t_{k-1} + \\
&\quad \frac{1}{2}\left(\mathcal{CE}_i(t) - \mathcal{CE}_i\left(t_{k(t)}\right)\right)\left(t + t_{k(t)}\right) + \\
&\quad \left(\mathcal{CE}_i\left(t_{k(t)}\right) - \mathcal{CE}_i^{\star}\right) t - \sum_{k=1}^{k(t)} \left(\mathcal{CE}_i(t) - \mathcal{CE}_i^{\star}\right) t_{k(t)}
\end{aligned}$$

Example

Historical data

We consider the following carbon emissions (expressed in $ktCO_2e$):

t	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
$\mathcal{CE}(t)$	30.3	31.2	34.5	37.5	34.5	38.5	32.0	28.5	23.0	20.0	19.9

The goal is to compute the carbon budget:

$$\mathcal{CB}(2010, 2020) = \int_{2010}^{2020} \mathcal{CE}(t) \,\mathrm{d}t$$

Example
Riemann sums

- The right Riemann sum is equal to:

$$\mathcal{CB}(2010, 2020) = (31.2 + 34.5 + \ldots + 20.0 + 19.9) \times 1 = 299.60$$

- The left Riemann sum is equal to:

$$\mathcal{CB}(2010, 2020) = (30.3 + 31.2 + \ldots + 23.0 + 20.0) \times 1 = 329.90$$

- The midpoint rule is equal to:

$$\mathcal{CB}(2010, 2020) = (30.75 + 32.85 + \ldots + 21.50 + 19.95) \times 1 = 304.80$$

Example

Linear reduction rate

- We have:

$$\mathcal{CE}(2020) = (1 - (2020 - 2010) \times \mathcal{R}) \times \mathcal{CE}(2010)$$

- We deduce that the linear reduction rate between 2010 and 2020 was equal to:

$$\mathcal{R} = \frac{1}{10} \times \left(1 - \frac{\mathcal{CE}(2020)}{\mathcal{CE}(2010)}\right) = 3.4323\%$$

- We obtain:

$$\begin{aligned}\mathcal{CB}(2010, 2020) &= (2020 - 2010) \times \mathcal{CE}(2010) - \\ &\quad \mathcal{R} \times \frac{(2020 - 2010)^2}{2} \times \mathcal{CE}(2010) \\ &= 251.00\end{aligned}$$

Example

Compound reduction rate

- We have:

$$\mathcal{CE}\left(2020\right)=\left(1-\mathcal{R}^{\left(2020-2010\right)}\right)\times\mathcal{CE}\left(2010\right)$$

- We deduce that the compound reduction rate between 2010 and 2020 was equal to:

$$\mathcal{R}=1-\left(\frac{\mathcal{CE}\left(2020\right)}{\mathcal{CE}\left(2010\right)}\right)^{\frac{1}{\left(2020-2010\right)}}=4.1171\%$$

- We obtain:

$$\begin{aligned}\mathcal{CB}\left(2010,2020\right) &= \frac{\left(1-\mathcal{R}\right)^{\left(2020-2010\right)}-1}{\ln\left(1-\mathcal{R}\right)}\times\mathcal{CE}\left(2010\right) \\ &= 247.37\end{aligned}$$

Example

Linear function

- We estimate the linear trend model:

$$\hat{\beta} = \left(X^\top X\right)^{-1} X^\top Y = \begin{pmatrix} 2810.6909 \\ -1.3800 \end{pmatrix}$$

- We deduce that:

$$\mathcal{CE}(t) = 2810.6909 - 1.3800 \times t$$

- It follows that:

$$\begin{aligned} \mathcal{CB}(2010, 2020) &= -\frac{1.38}{2} \times \left(2020^2 - 2010^2\right) + \\ &\quad 2810.6909 \times (2020 - 2010) \\ &= 299.91 \end{aligned}$$

Example

Piecewise linear function

- If we consider that $\mathcal{CE}(t)$ is a piecewise linear function, we obtain:

$$\mathcal{CB}(2010, 2020) = 304.80$$

- This is exactly the value obtained with the midpoint rule!

Trend modeling

Managing ESG and Climate Constraints in Portfolio Optimization

Impact of climate risk on credit risk

Modeling climate risks with jump processes

Geolocation and GPS positioning

Atmospheric measurement

Physical data

Probability distribution of an ESG score

Question 1

We consider an investment universe of 8 issuers with the following ESG scores:

Issuer	#1	#2	#3	#4	#5	#6	#7	#8
E	−2.80	−1.80	−1.75	0.60	0.75	1.30	1.90	2.70
S	−1.70	−1.90	0.75	−1.60	1.85	1.05	0.90	0.70
G	0.30	−0.70	−2.75	2.60	0.45	2.35	2.20	1.70

Probability distribution of an ESG score

Question 1.a

Calculate the ESG score of the issuers if we assume the following weighting scheme: 40% for **E**, 40% for **S** and 20% for **G**.

Probability distribution of an ESG score

- We have:

$$s_i^{(\mathrm{ESG})} = 0.4 \times s_i^{(\mathrm{E})} + 0.4 \times s_i^{(\mathrm{S})} + 0.2 \times s_i^{(\mathrm{G})}$$

- We obtain the following results:

Issuer	#1	#2	#3	#4	#5	#6	#7	#8
$s_i^{(\mathrm{E})}$	−2.80	−1.80	−1.75	0.60	0.75	1.30	1.90	2.70
$s_i^{(\mathrm{S})}$	−1.70	−1.90	0.75	−1.60	1.85	1.05	0.90	0.70
$s_i^{(\mathrm{G})}$	0.30	−0.70	−2.75	2.60	0.45	2.35	2.20	1.70
$s_i^{(\mathrm{ESG})}$	−1.74	−1.62	−0.95	0.12	1.13	1.41	1.56	1.70

Probability distribution of an ESG score

Question 1.b

Calculate the ESG score of the equally-weighted portfolio x_{ew}.

Probability distribution of an ESG score

- We obtain:

$$\begin{aligned} \mathcal{S}^{(\mathrm{ESG})}\left(x_{\mathrm{ew}}\right) &= \sum_{i=1}^{8} x_{\mathrm{ew},i} \times \mathcal{S}_i^{(\mathrm{ESG})} \\ &= 0.2013 \end{aligned}$$

Probability distribution of an ESG score

Question 2

We assume that the ESG scores are *iid* and follow a standard Gaussian distribution:

$$s_i \sim \mathcal{N}(0,1)$$

Probability distribution of an ESG score

Question 2.a

We note $x_{\mathrm{ew}}^{(n)}$ the equally-weighted portfolio composed of n issuers.
Calculate the distribution of the ESG score $\mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right)$ of the portfolio $x_{\mathrm{ew}}^{(n)}$.

Probability distribution of an ESG score

- We have:

$$\begin{aligned} \mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right) &= \sum_{i=1}^{n} x_{\mathrm{ew},i}^{(n)} \times \mathcal{S}_i \\ &= \frac{1}{n}\sum_{i=1}^{n} \mathcal{S}_i \end{aligned}$$

We deduce that $\mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right)$ follows a Gaussian distribution.

Probability distribution of an ESG score

- Its mean is equal to:

$$\mathbb{E}\left[\mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right)\right] = \frac{1}{n}\sum_{i=1}^{n}\mathbb{E}\left[\mathcal{S}_i\right] = 0$$

- Its standard deviation is equal to:

$$\begin{aligned}\sigma\left(\mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right)\right) &= \sqrt{\frac{1}{n^2}\sum_{i=1}^{n}\sigma^2\left(\mathcal{S}_i\right)} \\ &= \frac{1}{\sqrt{n}}\end{aligned}$$

- Finally, we obtain:

$$\mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right) \sim \mathcal{N}\left(0, \frac{1}{n}\right)$$

Probability distribution of an ESG score

Question 2.b

What is the ESG score of a well-diversified portfolio?

Probability distribution of an ESG score

- The behavior of a well-diversified portfolio is close to an equally-weighted portfolio with n sufficiently large. Therefore, the ESG score is close to zero because we have:

$$\lim_{n\to\infty} \mathcal{S}\left(x_{\mathrm{ew}}^{(n)}\right) = 0$$

Probability distribution of an ESG score

Question 2.c

We note $T \sim \mathbf{F}_\alpha$ where $\mathbf{F}_\alpha(t) = t^\alpha$, $t \in [0,1]$ and $\alpha \geq 0$. Draw the graph of the probability density function $f_\alpha(t)$ when α is respectively equal to 0.5, 1.5, 2.5 and 70. What do you notice?

Probability distribution of an ESG score

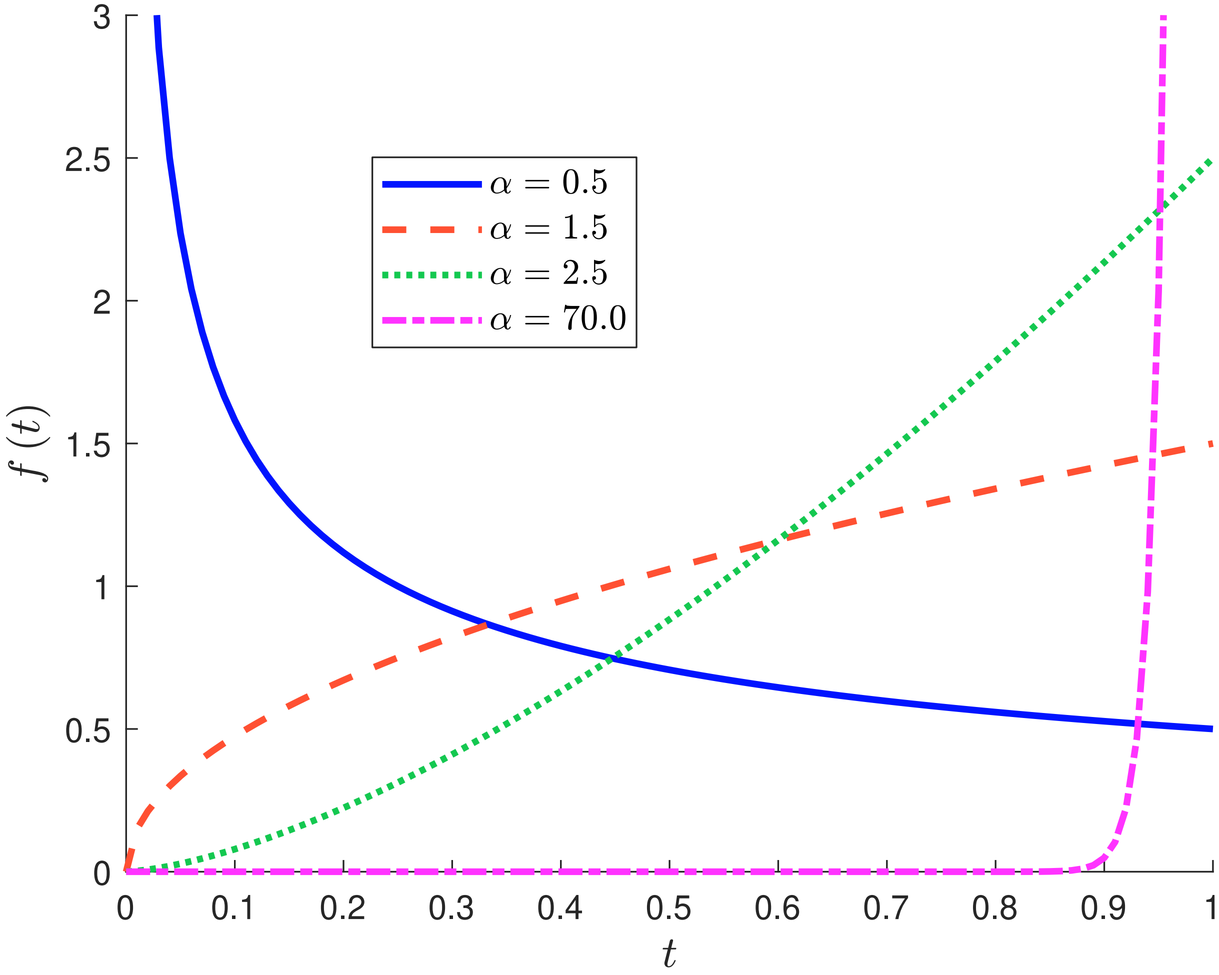


Figure 143: Probability density function $f_\alpha(t)$

Probability distribution of an ESG score

- We have:

$$f_\alpha(t) = \alpha t^{\alpha-1}$$

- We notice that the function $f_\alpha(t)$ tends to the dirac delta function when α tends to infinity:

$$\lim_{\alpha\to\infty} f_\alpha(t) = \delta_1(t) = \begin{cases} 0 & \text{if } t \neq 1 \\ +\infty & \text{if } t = 1 \end{cases}$$

Probability distribution of an ESG score

Question 2.d

We assume that the weights of the portfolio $x = (x_1, \ldots, x_n)$ follow a power-law distribution $\mathbf{F}_\alpha$:

$$x_i \sim c T_i$$

where $T_i \sim \mathbf{F}_\alpha$ are *iid* random variables and c is a normalization constant. Explain how to simulate the portfolio weights $x = (x_1, \ldots, x_n)$. Represent one simulation of the portfolio x for the previous values of α. Comment on these results. Deduce the relationship between the Herfindahl index $\mathcal{H}_\alpha(x)$ of the portfolio weights x and the parameter α.

Remark

We use $n = 50$ in the rest of the exercise.

Probability distribution of an ESG score

- To simulate T_i, we use the property of the probability integral transform:

$$U_i = \mathbf{F}_\alpha \left(T_i \right) \sim \mathcal{U}_{[0,1]}$$

We deduce that:

$$\begin{aligned} T_i &= \mathbf{F}_\alpha^{-1} \left(U_i \right) \\ &= U_i^{1/\alpha} \end{aligned}$$

Probability distribution of an ESG score

The algorithm for simulating the portfolio x is then the following:

1. We simulate n independent uniform random numbers $(u_1, \ldots, u_n)$.
2. We compute the random variates $(t_1, \ldots, t_n)$ where:

$$t_i = u_i^{1/\alpha}$$

3. We calculate the normalization constant:

$$c = \left(\sum_{i=1}^{n} t_i \right)^{-1} = \left(\sum_{i=1}^{n} u_i^{1/\alpha} \right)^{-1}$$

4. We deduce the portfolio weights $x = (x_1, \ldots, x_n)$:

$$x_i = c \cdot t_i = c \cdot u_i^{1/\alpha} = \frac{u_i^{1/\alpha}}{\sum_{j=1}^{n} u_j^{1/\alpha}}$$

Probability distribution of an ESG score

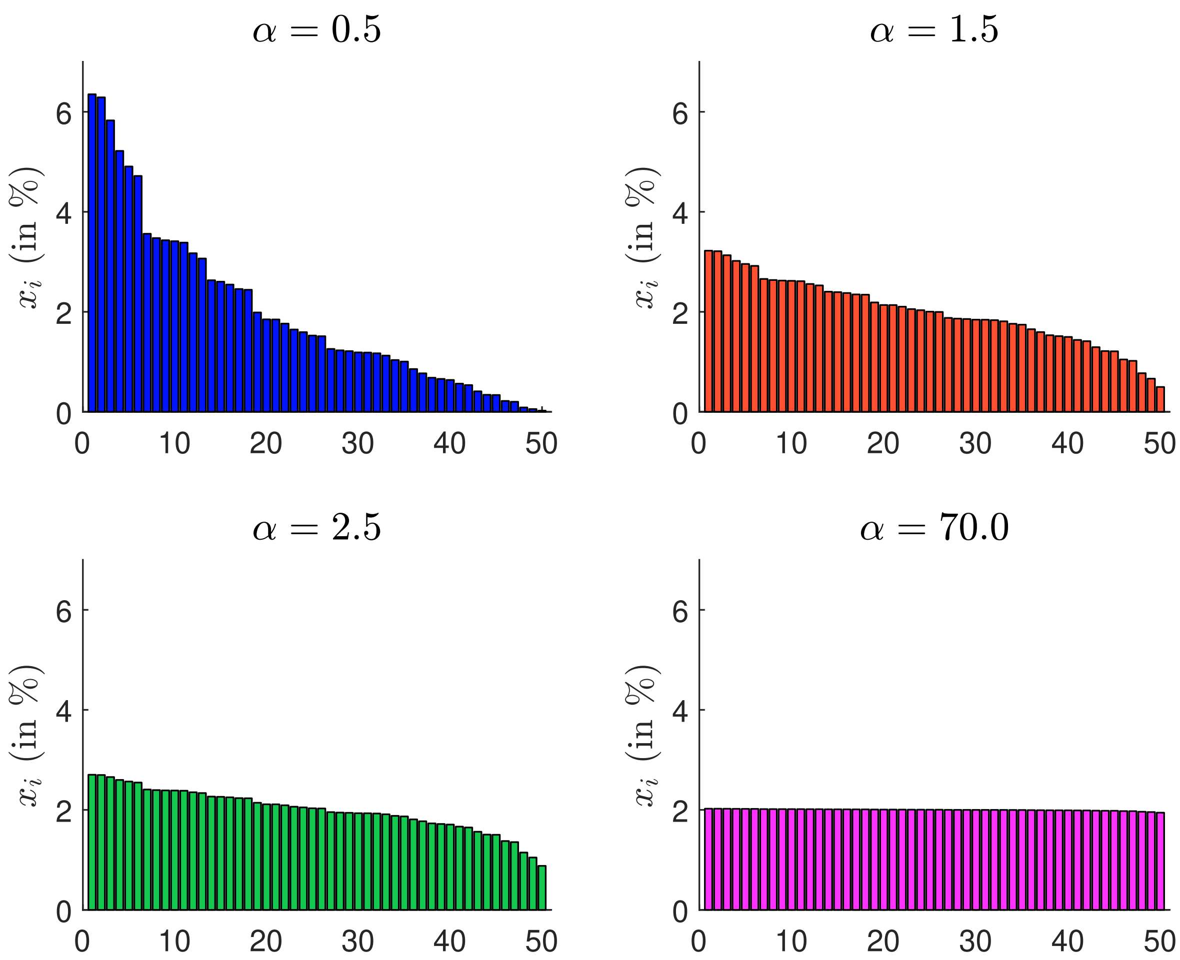


Figure 144: Repartition of the portfolio weights in descending order

Probability distribution of an ESG score

- In Figure 144, we have represented the composition of the portfolio x for the 4 values of α. The weights are ranked in descending order. We deduce that the portfolio x is uniform when $\alpha \rightarrow \infty$. The parameter α controls the concentration of the portfolio. Indeed, when α is small, the portfolio is highly concentrated. It follows that the Herfindahl index $\mathcal{H}_{\alpha}(x)$ of the portfolio weights is a decreasing function of the parameter α.

Probability distribution of an ESG score

Question 2.e

We assume that the weight x_i and the ESG score $\mathcal{S}_i$ of the issuer i are independent. How to simulate the portfolio ESG score $\mathcal{S}(x)$? Using 50 000 replications, estimate the probability distribution function of $\mathcal{S}(x)$ by the Monte Carlo method. Comment on these results.

Probability distribution of an ESG score

- We simulate $x = (x_1, \ldots, x_n)$ using the previous algorithm. The vector of ESG scores $\mathcal{S} = (\mathcal{S}_1, \ldots, \mathcal{S}_n)$ is generated with normally-distributed random variables since we have $\mathcal{S}_i \sim \mathcal{N}(0, 1)$. We deduce that the simulated value of the portfolio ESG score $\mathcal{S}(x)$ is equal to:

$$\mathcal{S}(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{S}_i$$

- We replicate the simulation of $\mathcal{S}(x)$ 50 000 times and draw the corresponding histogram in Figure 145. We also report the fitted Gaussian distribution. We observe that the portfolio ESG score $\mathcal{S}(x)$ is equal to zero on average, and its variance is an increasing function of the portfolio concentration.

Probability distribution of an ESG score

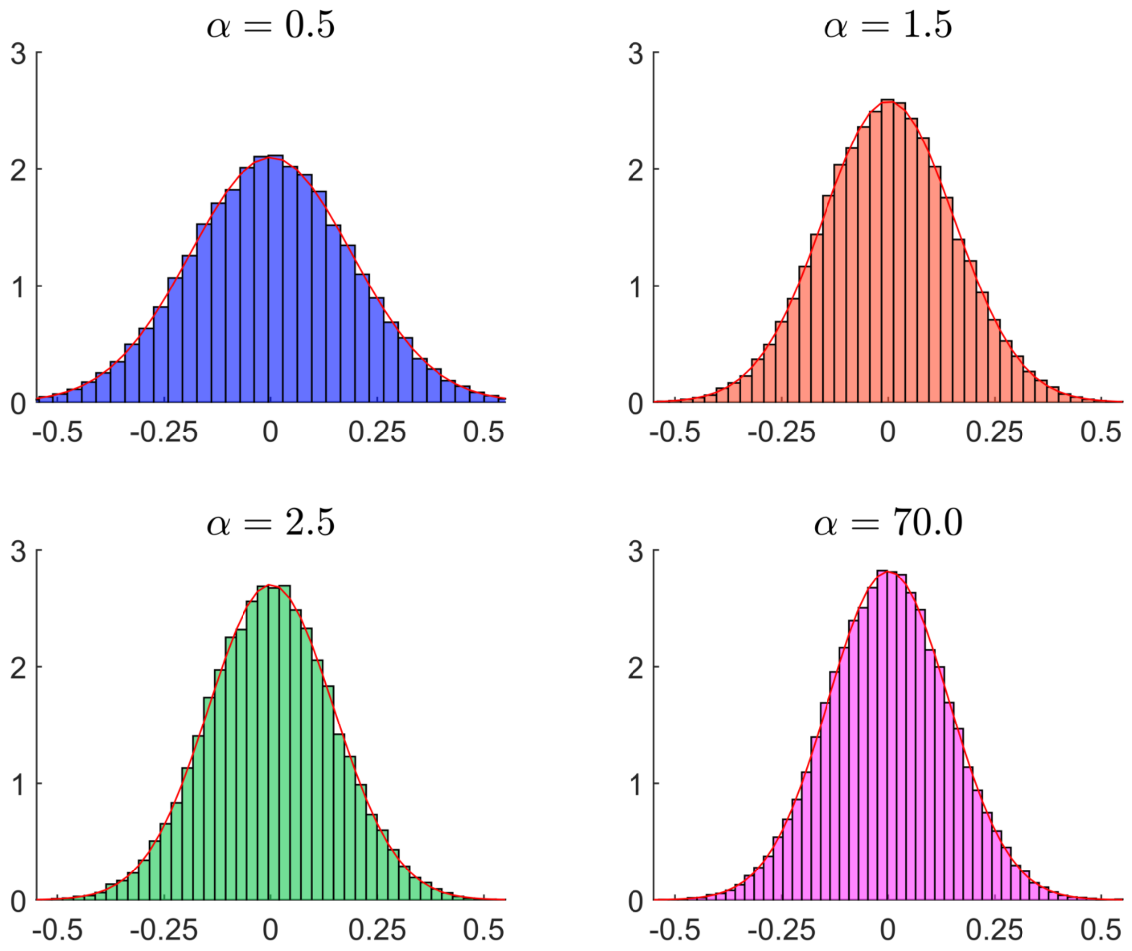


Figure 145: Histogram of the portfolio ESG score $\mathcal{S}(x)$

Probability distribution of an ESG score

Question 2.f

We now assume that the weight x_i and the ESG score $\mathcal{S}_i$ of the issuer i are positively correlated. More precisely, the dependence function between x_i and $\mathcal{S}_i$ is the Normal copula function with parameter ρ. Show that this is also the copula function between T_i and $\mathcal{S}_i$. Deduce an algorithm to simulate $\mathcal{S}(x)$.

Probability distribution of an ESG score

- Since $x_i \sim cT_i$, x_i is an increasing function of T_i. We deduce that the copula function of $(T_i, \mathcal{S}_i)$ is the same as the copula function of $(x_i, \mathcal{S}_i)$.
- To simulate the Normal copula function $\mathbf{C}(u, v)$, we use the transformation algorithm based on the Cholesky decomposition:

$$\left\{ \begin{array}{l} u_i = \Phi\left(g_i'\right) \\ v_i = \Phi\left(\rho g_i' + \sqrt{1-\rho^2} g_i''\right) \end{array} \right.$$

where g_i' and g_i'' are two independent random numbers from the probability distribution $\mathcal{N}(0, 1)$.

Probability distribution of an ESG score

Here is the algorithm to simulate the ESG portfolio score $\mathcal{S}(x)$:

1. We simulate n independent normally-distributed random numbers $g_i'$and g_i'' and we compute (u_i, v_i):

$$\begin{cases} u_i = \Phi\left(g_i'\right) \\ v_i = \Phi\left(\rho g_i' + \sqrt{1-\rho^2} g_i''\right) \end{cases}$$

2. We compute the random variates $(t_1, \ldots, t_n)$ where $t_i = u_i^{1/\alpha}$
3. We deduce the vector of weights $x = (x_1, \ldots, x_n)$:

$$x_i = t_i \Big/ \sum_{j=1}^{n} t_j$$

4. We simulate the vector of scores $\mathcal{S} = (\mathcal{S}_1, \ldots, \mathcal{S}_n)$:

$$\mathcal{S}_i = \Phi^{-1}(v_i) = \rho g_i' + \sqrt{1-\rho^2} g_i''$$

5. We calculate the portfolio score:

$$\mathcal{S}(x) = \sum_{i=1}^{n} x_i \cdot \mathcal{S}_i$$

Probability distribution of an ESG score

Question 2.g

Using 50 000 replications, estimate the probability distribution function of $\mathcal{S}(x)$ by the Monte Carlo method when the correlation parameter ρ is set to 50%. Comment on these results.

Probability distribution of an ESG score

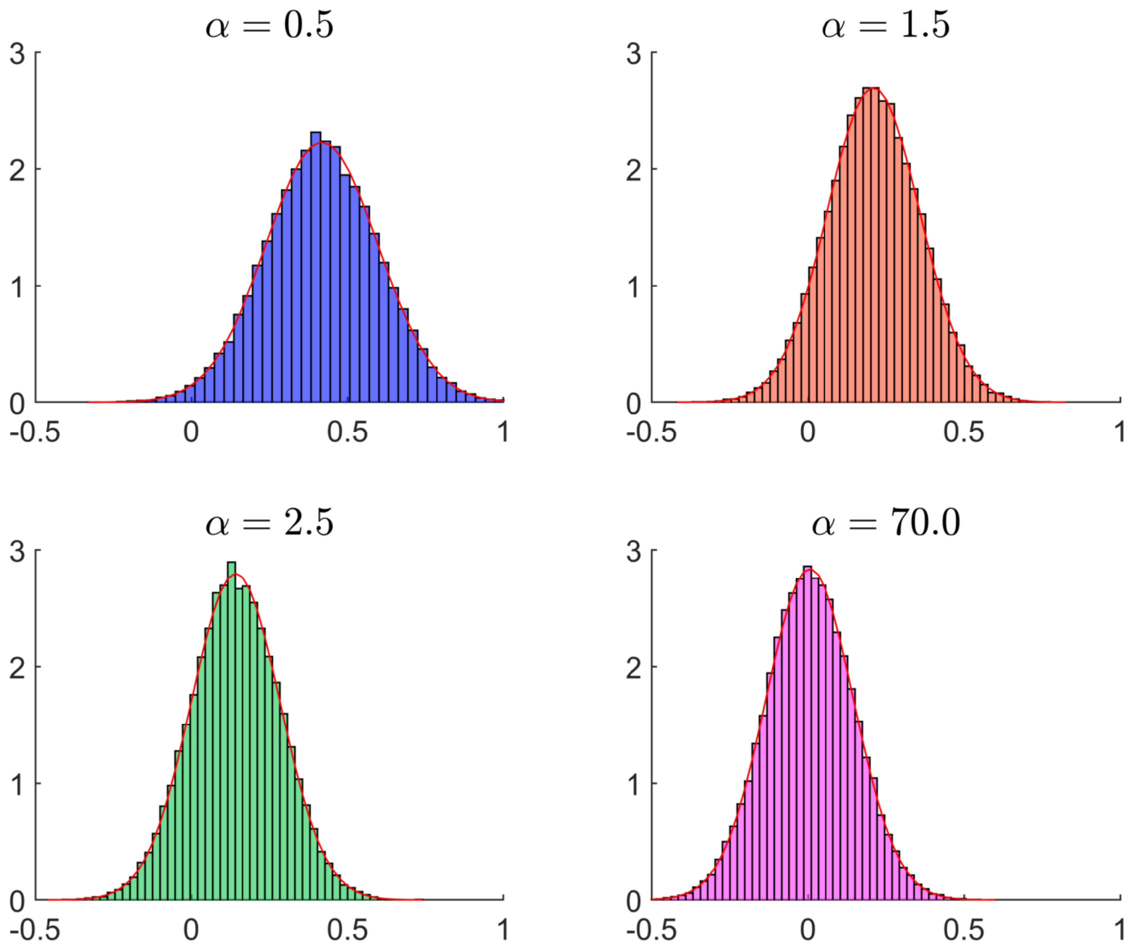


Figure 146: Histogram of the portfolio ESG score $\mathcal{S}(x)$ ($\rho = 50\%$)

Probability distribution of an ESG score

- In the independent case, we found that $\mathbb{E}\left[\mathcal{s}\left(x\right)\right] = 0$. In Figure 146, we notice that $\mathbb{E}\left[\mathcal{s}\left(x\right)\right] \neq 0$ when ρ is equal to 50%. Indeed, we obtain:

$$\mathbb{E}\left[\mathcal{s}\left(x\right)\right] = \begin{cases} 0.418 & \text{if } \alpha = 0.5 \\ 0.210 & \text{if } \alpha = 1.5 \\ 0.142 & \text{if } \alpha = 2.5 \\ 0.006 & \text{if } \alpha = 70.0 \end{cases}$$

Probability distribution of an ESG score

Question 2.h

Estimate the relationship between the correlation parameter ρ and the expected ESG score $\mathbb{E}\left[s\left(x\right)\right]$ of the portfolio x. Comment on these results.

Probability distribution of an ESG score

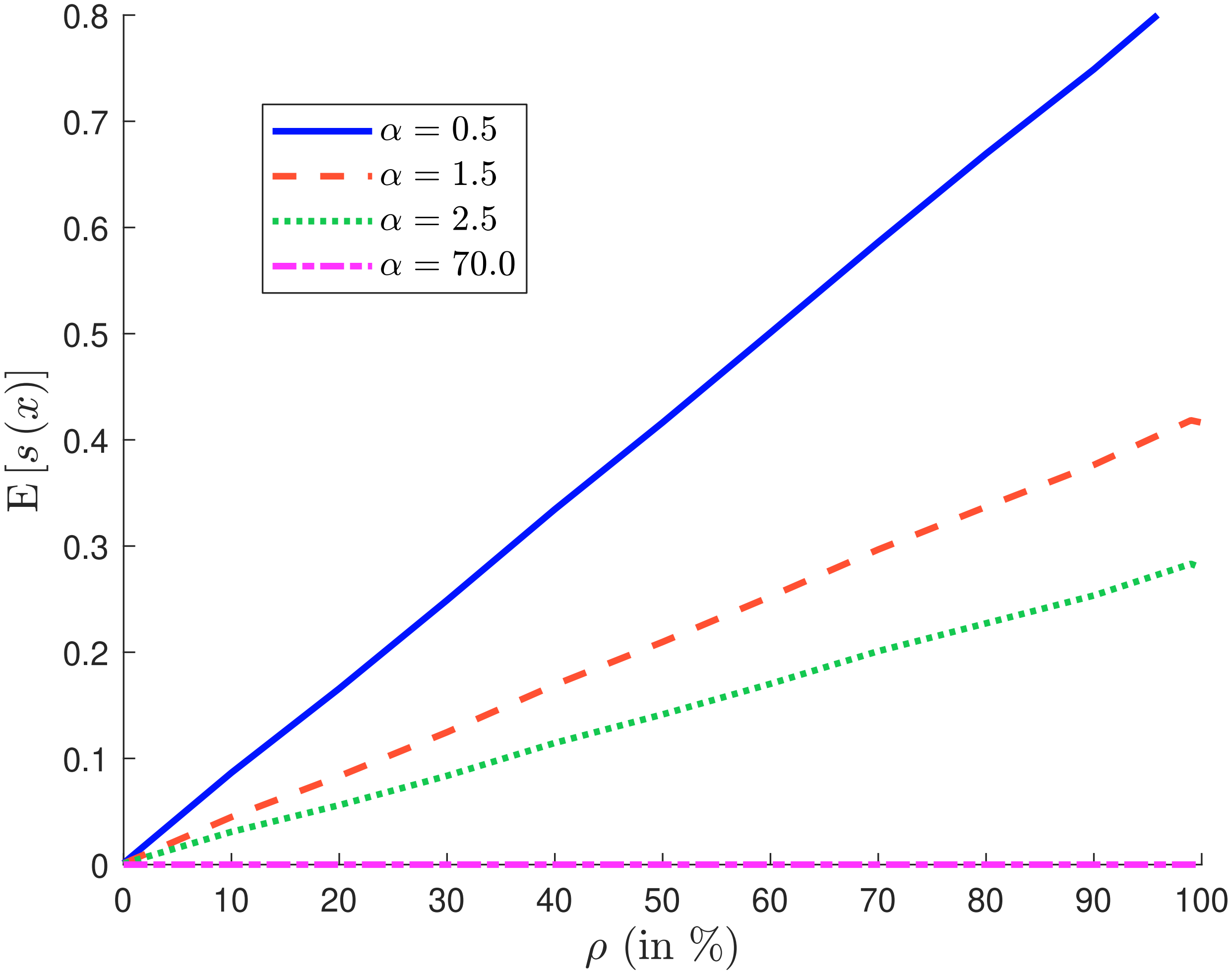


Figure 147: Relationship between ρ and $\mathbb{E}[s(x)]$

Probability distribution of an ESG score

- We notice that there is a positive relationship between ρ and $\mathbb{E}\left[\mathcal{S}\left(x\right)\right]$ and the slope increases with the concentration of the portfolio.

Probability distribution of an ESG score

Question 2.i

How are the previous results related to the size bias of ESG scoring?

Probability distribution of an ESG score

- Big cap companies have more (financial and human) resources to develop an ESG policy than small cap companies.
- Therefore, we observe a positive correlation between the market capitalization and the ESG score of an issuer.
- It follows that ESG portfolios have generally a size bias. For instance, we generally observe that cap-weighted indexes have an ESG score which is greater than the average of ESG scores.
- In the previous questions, we verify that $\mathbb{E}[\mathcal{S}(x)] \geq \mathbb{E}[\mathcal{S}]$ when the Herfindahl index of the portfolio x is high and the correlation between x_i and $\mathcal{S}_i$ is positive.

Probability distribution of an ESG score

Question 3

Let $\mathcal{S}$ be the ESG score of the issuer. We assume that the ESG score follows a standard Gaussian distribution:

$$\mathcal{S} \sim \mathcal{N}(0,1)$$

The ESG score $\mathcal{S}$ is also converted into an ESG rating $\mathcal{R}$, which can take the values **A**, **B**, **C** and **D** — **A** is the best rating and **D** is the worst rating.

Probability distribution of an ESG score

Question 3.a

We assume that the breakpoints of the rating system are -1.5, 0 and $+1.5$. Compute the frequencies of the ratings.

Probability distribution of an ESG score

- We have:

$$\begin{aligned}\Pr\{\mathcal{R}=\mathbf{A}\} &= \Pr\{\mathcal{s}\geq 1.5\} \\ &= 1-\Phi(1.5) \\ &= 6.68\%\end{aligned}$$

and:

$$\begin{aligned}\Pr\{\mathcal{R}=\mathbf{B}\} &= \Pr\{0\leq \mathcal{s} < 1.5\} \\ &= \Phi(1.5)-\Phi(0) \\ &= 43.32\%\end{aligned}$$

- Since the Gaussian distribution is symmetric around 0, we also have:

$$\Pr\{\mathcal{R}=\mathbf{C}\} = \Pr\{\mathcal{R}=\mathbf{B}\} = 43.32\%$$

and:

$$\Pr\{\mathcal{R}=\mathbf{D}\} = \Pr\{\mathcal{R}=\mathbf{A}\} = 6.68\%$$

Probability distribution of an ESG score

- The mapping function is:

$$\mathcal{M}_{\text{appring}}(\mathcal{s}) = \begin{cases} \textbf{A} & \text{if } \mathcal{s} < -1.5 \\ \textbf{B} & \text{if } -1.5 \leq \mathcal{s} < 0 \\ \textbf{C} & \text{if } 0 \leq \mathcal{s} < 1.5 \\ \textbf{D} & \text{if } \mathcal{s} \geq 1.5 \end{cases}$$

Probability distribution of an ESG score

Question 3.b

We would like to build a rating system such that each category has the same frequency. Find the mapping function.

Probability distribution of an ESG score

- We have:

$$\Pr\{\mathcal{R}(t) = \mathbf{A}\} = \Pr\{\mathcal{R}(t) = \mathbf{B}\} = \Pr\{\mathcal{R}(t) = \mathbf{C}\} = \Pr\{\mathcal{R}(t) = \mathbf{D}\}$$

and:

$$\Pr\{\mathcal{R}(t) = \mathbf{A}\} + \Pr\{\mathcal{R}(t) = \mathbf{B}\} + \Pr\{\mathcal{R}(t) = \mathbf{C}\} + \Pr\{\mathcal{R}(t) = \mathbf{D}\} = 1$$

We deduce that:

$$\Pr\{\mathcal{R}(t) = \mathbf{A}\} = \frac{1}{4} = 25\%$$

and $\Pr\{\mathcal{R}(t) = \mathbf{B}\} = \Pr\{\mathcal{R}(t) = \mathbf{C}\} = \Pr\{\mathcal{R}(t) = \mathbf{D}\} = 25\%$.

- We want to find the breakpoints (s_1, s_2, s_3) such that:

$$\left\{\begin{array}{l} \Pr\{s < s_1\} = 25\% \\ \Pr\{s_1 \leq s < s_2\} = 25\% \\ \Pr\{s_2 \leq s < s_3\} = 25\% \\ \Pr\{s \geq s_3\} = 25\% \end{array}\right.$$

Probability distribution of an ESG score

- We deduce that:

$$\begin{cases} s_1 = \Phi^{-1}(0.25) = -0.6745 \\ s_2 = \Phi^{-1}(0.50) = 0 \\ s_3 = \Phi^{-1}(0.75) = +0.6745 \end{cases}$$

- The mapping function is:

$$\mathcal{M}_{\text{appring}}(\mathcal{s}) = \begin{cases} \mathbf{A} & \text{if } \mathcal{s} < -0.6745 \\ \mathbf{B} & \text{if } -0.6745 \leq \mathcal{s} < 0 \\ \mathbf{C} & \text{if } 0 \leq \mathcal{s} < 0.6745 \\ \mathbf{D} & \text{if } \mathcal{s} \geq 0.6745 \end{cases}$$

Probability distribution of an ESG score

Question 3.c

We would like to build a rating system such that the frequency of the median ratings **B** and **C** is 40% and the frequency of the extreme ratings **A** and **D** is 10%. Find the mapping function.

Probability distribution of an ESG score

- We have:

$$\left\{\begin{array}{l} s_1 = \Phi^{-1}(0.10) = -1.2816 \\ s_2 = \Phi^{-1}(0.50) = 0 \\ s_3 = \Phi^{-1}(0.90) = +1.2816 \end{array}\right.$$

- The mapping function is:

$$\mathcal{M}_{\text{appring}}(\mathcal{s}) = \left\{\begin{array}{ll} \textbf{A} & \text{if } \mathcal{s} < -1.2816 \\ \textbf{B} & \text{if } -1.2816 \leq \mathcal{s} < 0 \\ \textbf{C} & \text{if } 0 \leq \mathcal{s} < 1.2816 \\ \textbf{D} & \text{if } \mathcal{s} \geq 1.2816 \end{array}\right.$$

Probability distribution of an ESG score

Question 4

Let $s(t)$ be the ESG score of the issuer at time t. The ESG scoring system is evaluated every month. The index time t corresponds to the current month, whereas the previous month is $t-1$. We assume that:

- The ESG score at time $t-1$ follows a standard Gaussian distribution:

$$s(t-1) \sim \mathcal{N}(0,1)$$

- The variation of the ESG score is Gaussian between two months:

$$\Delta s(t) = s(t) - s(t-1) \sim \mathcal{N}\left(0,\sigma^2\right)$$

- The ESG score $s(t-1)$ and the variation $\Delta s(t)$ are independent.

Probability distribution of an ESG score

Question 4

The ESG score $\mathcal{S}(t)$ is converted into an ESG rating $\mathcal{R}(t)$, which can take following grades:

$$\mathcal{R}_1 \prec \mathcal{R}_2 \prec \cdots \prec \mathcal{R}_k \prec \cdots \prec \mathcal{R}_{K-1} \prec \mathcal{R}_K$$

We assume that the breakpoints of the rating system are $(s_1, s_2, \ldots, s_{K-1})$. We also note $s_0 = -\infty$ and $s_K = +\infty$.

Probability distribution of an ESG score

Question 4.a

Compute the bivariate probability distribution of the random vector $\left(s\left(t-1\right), \Delta s\left(t\right)\right)$.

Probability distribution of an ESG score

- The joint distribution of $(s(t-1), \Delta s(t))$ is:

$$\begin{pmatrix} s(t-1) \\ \Delta s(t) \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & \sigma^2 \end{pmatrix}\right)$$

Probability distribution of an ESG score

Question 4.b

Compute the bivariate distribution of the random vector $(s(t-1), s(t))$.

Probability distribution of an ESG score

- Since we have:

$$s(t) = s(t-1) + \Delta s(t)$$

we deduce that:

$$\begin{pmatrix} s(t-1) \\ s(t) \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} s(t-1) \\ \Delta s(t) \end{pmatrix}$$

We conclude that $(s(t-1), s(t))$ is a Gaussian random vector.

Probability distribution of an ESG score

- We have:

$$\mathrm{var}\left(s\left(t\right)\right) = 1 + \sigma^2$$

and:

$$\begin{aligned}
\mathrm{cov}\left(s\left(t-1\right), s\left(t\right)\right) &= \mathbb{E}\left[s\left(t-1\right) \cdot s\left(t\right)\right] \\
&= \mathbb{E}\left[s^2\left(t-1\right) + s\left(t-1\right) \cdot \Delta s\left(t\right)\right] \\
&= 1
\end{aligned}$$

Probability distribution of an ESG score

- It follows that:

$$\begin{pmatrix} \mathcal{s}(t-1) \\ \mathcal{s}(t) \end{pmatrix} \sim \mathcal{N}(\mathbf{0}_2, \Sigma_\sigma)$$

where Σ_σ is the covariance matrix:

$$\Sigma_\sigma = \begin{pmatrix} 1 & 1 \\ 1 & 1+\sigma^2 \end{pmatrix}$$

Probability distribution of an ESG score

Question 4.c

Compute the probability $p_k = \Pr\left\{\mathcal{R}\left(t-1\right) = \mathcal{R}_k\right\}$.

Probability distribution of an ESG score

- We have:

$$\begin{aligned}\Pr\left\{\mathcal{R}\left(t-1\right)=\mathcal{R}_k\right\} &= \Pr\left\{s_{k-1}\leq \mathcal{s}\left(t-1\right)<s_k\right\} \\ &= \Phi\left(s_k\right)-\Phi\left(s_{k-1}\right)\end{aligned}$$

Probability distribution of an ESG score

Question 4.d

Compute the joint probability $\Pr\left\{\mathcal{R}\left(t\right)=\mathcal{R}_k,\mathcal{R}\left(t-1\right)=\mathcal{R}_j\right\}$.

Probability distribution of an ESG score

- We have:

$$\begin{aligned}(*) &= \Pr\left\{\mathcal{R}(t) = \mathcal{R}_k, \mathcal{R}(t-1) = \mathcal{R}_j\right\} \\ &= \Pr\left\{s_{k-1} \leq \mathcal{s}(t) < s_k, s_{j-1} \leq \mathcal{s}(t-1) < s_j\right\} \\ &= \Phi_2\left(s_j, s_k; \Sigma_\sigma\right) - \Phi_2\left(s_{j-1}, s_k; \Sigma_\sigma\right) - \\ &\quad \Phi_2\left(s_j, s_{k-1}; \Sigma_\sigma\right) + \Phi_2\left(s_{j-1}, s_{k-1}; \Sigma_\sigma\right)\end{aligned}$$

where $\Phi_2\left(x, y; \Sigma_\sigma\right)$ is the bivariate Normal cdf with covariance matrix Σ_σ.

Probability distribution of an ESG score

Question 4.e

Compute the transition probability
$p_{j,k} = \Pr\left\{\mathcal{R}\left(t\right) = \mathcal{R}_k \mid \mathcal{R}\left(t-1\right) = \mathcal{R}_j\right\}$.

Probability distribution of an ESG score

- We have:

$$
\begin{aligned}
p_{j,k} &= \Pr\left\{\mathcal{R}(t) = \mathcal{R}_k \mid \mathcal{R}(t-1) = \mathcal{R}_j\right\} \\
&= \frac{\Pr\left\{\mathcal{R}(t) = \mathcal{R}_k, \mathcal{R}(t-1) = \mathcal{R}_j\right\}}{\Pr\left\{\mathcal{R}(t-1) = \mathcal{R}_j\right\}} \\
&= \frac{\Phi_2\left(s_j, s_k; \Sigma_\sigma\right) + \Phi_2\left(s_{j-1}, s_{k-1}; \Sigma_\sigma\right)}{\Phi\left(s_j\right) - \Phi\left(s_{j-1}\right)} - \\
&\quad \frac{\Phi_2\left(s_{j-1}, s_k; \Sigma_\sigma\right) + \Phi_2\left(s_j, s_{k-1}; \Sigma_\sigma\right)}{\Phi\left(s_j\right) - \Phi\left(s_{j-1}\right)}
\end{aligned}
$$

Probability distribution of an ESG score

Question 4.f

Compute the monthly turnover $\mathcal{T}\left(\mathcal{R}_k\right)$ of the ESG rating $\mathcal{R}_k$.

Probability distribution of an ESG score

- We have:

$$\begin{aligned}\mathcal{T}\left(\mathcal{R}_k\right) &= \Pr\left\{\mathcal{R}\left(t\right) \neq \mathcal{R}_k \mid \mathcal{R}\left(t-1\right) = \mathcal{R}_k\right\} \\ &= 1 - \Pr\left\{\mathcal{R}\left(t\right) = \mathcal{R}_k \mid \mathcal{R}\left(t-1\right) = \mathcal{R}_k\right\} \\ &= 1 - p_{k,k}\end{aligned}$$

Probability distribution of an ESG score

Question 4.g

Compute the monthly turnover $\mathcal{T}\left(\mathcal{R}_1, \ldots, \mathcal{R}_K\right)$ of the ESG rating system.

Probability distribution of an ESG score

- We have:

$$\begin{aligned}\mathcal{T}\left(\mathcal{R}_1,\ldots,\mathcal{R}_K\right) &= \sum_{k=1}^{K}\Pr\left\{\mathcal{R}\left(t-1\right)=\mathcal{R}_k\right\}\cdot\mathcal{T}\left(\mathcal{R}_k\right) \\ &= \sum_{k=1}^{K}\Pr\left\{\mathcal{R}\left(t\right)\neq\mathcal{R}_k,\mathcal{R}\left(t-1\right)=\mathcal{R}_k\right\}\end{aligned}$$

Probability distribution of an ESG score

Question 4.h

For each rating system given in Questions 3.a, 3.b and 3.c, determine the corresponding ESG migration matrix and the monthly turnover of the rating system if we assume that σ is equal to 10%. What is the best ESG rating system if we would like to control the turnover of ESG ratings?

Probability distribution of an ESG score

Table 82: ESG rating migration matrix (Question 3.a)

Rating	s_k	p_k	Transition probability $p_{j,k}$				$\mathcal{T}(\mathcal{R}_k)$
D		6.68%	92.96%	7.04%	0.00%	0.00%	7.04%
	-1.50						
C		43.32%	1.31%	95.03%	3.66%	0.00%	4.97%
	0.00						
B		43.32%	0.00%	3.66%	95.03%	1.31%	4.97%
	1.50						
A		6.68%	0.00%	0.00%	7.04%	92.96%	7.04%
$\mathcal{T}(\mathcal{R}_1,\ldots,\mathcal{R}_K)$							5.25%

Probability distribution of an ESG score

Table 83: ESG rating migration matrix (Question 3.b)

Rating	s_k	p_k	Transition probability $p_{j,k}$				$\mathcal{T}(\mathcal{R}_k)$
D		25.00%	95.15%	4.85%	0.00%	0.00%	4.85%
C	-0.67	25.00%	5.27%	88.38%	6.35%	0.00%	11.62%
B	0.00	25.00%	0.00%	6.35%	88.38%	5.27%	11.62%
A	0.67	25.00%	0.00%	0.00%	4.85%	95.15%	4.85%
$\mathcal{T}(\mathcal{R}_1,\ldots,\mathcal{R}_K)$							8.23%

Probability distribution of an ESG score

Table 84: ESG rating migration matrix (Question 3.c)

Rating	s_k	p_k	Transition probability $p_{j,k}$				$\mathcal{T}(\mathcal{R}_k)$
D		10.00%	93.54%	6.46%	0.00%	0.00%	6.46%
	-1.28						
C		40.00%	1.89%	94.14%	3.97%	0.00%	5.86%
	0.00						
B		40.00%	0.00%	3.97%	94.14%	1.89%	5.86%
	1.28						
A		10.00%	0.00%	0.00%	6.46%	93.54%	6.46%
$\mathcal{T}(\mathcal{R}_1,\ldots,\mathcal{R}_K)$							5.98%

Probability distribution of an ESG score

The ESG rating system defined in Question 3.a is the best rating system if we would like to reduce the monthly turnover of ESG ratings.

Probability distribution of an ESG score

Question 4.i

Draw the relationship between the parameter σ and the turnover $\mathcal{T}(\mathcal{R}_1, \ldots, \mathcal{R}_K)$ for the three ESG rating systems.

Probability distribution of an ESG score

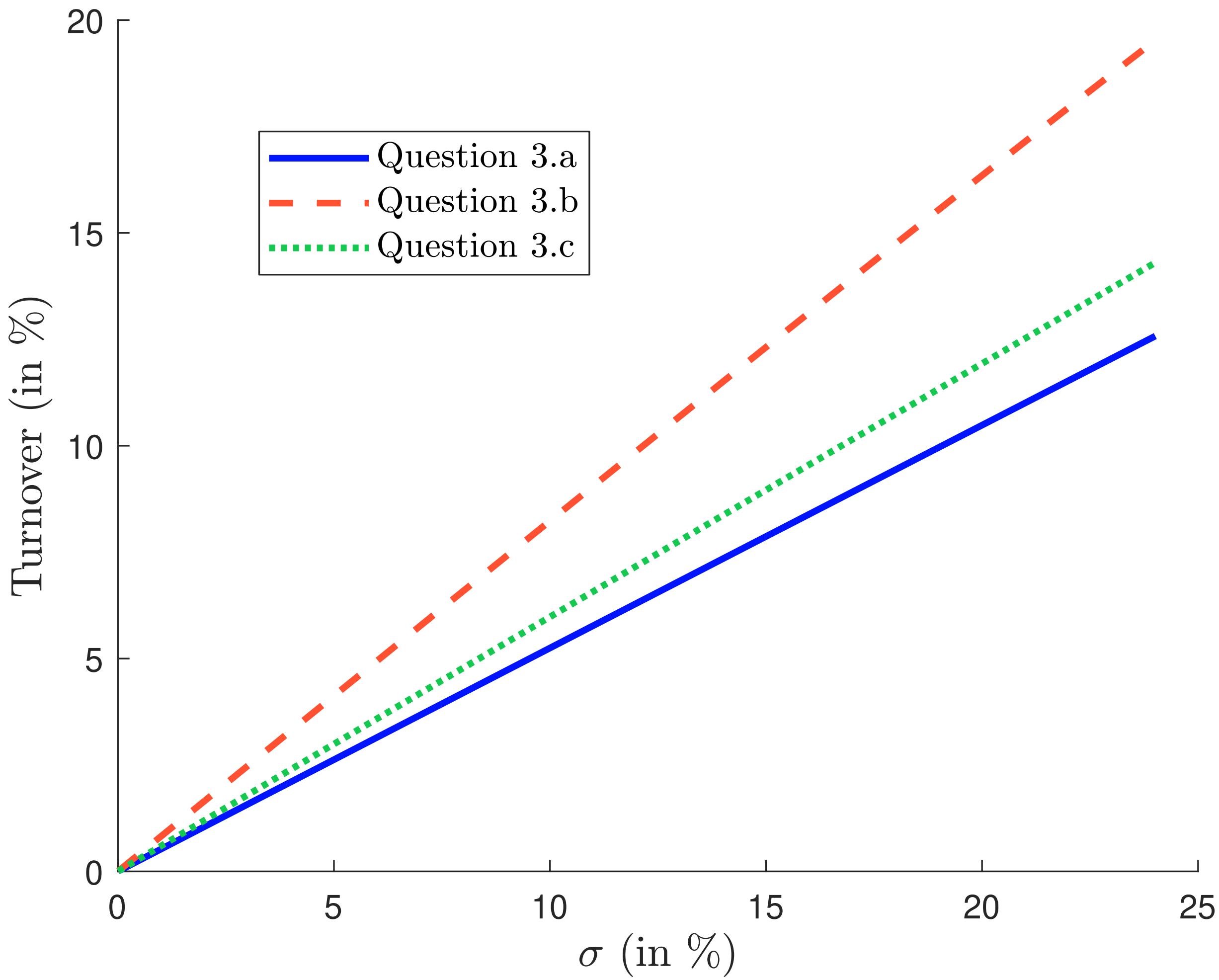


Figure 148: Relationship between σ and $\mathcal{T}(\mathcal{R}_1, \ldots, \mathcal{R}_K)$

Probability distribution of an ESG score

Question 4.j

We consider a uniform ESG rating system where:

$$\Pr\left\{\mathcal{R}(t-1) = \mathcal{R}_k\right\} = \frac{1}{K}$$

Draw the relationship between the number of notches K and the turnover $\mathcal{T}(\mathcal{R}_1, \ldots, \mathcal{R}_K)$ when the parameter σ takes the values 5%, 10% and 25%.

Probability distribution of an ESG score

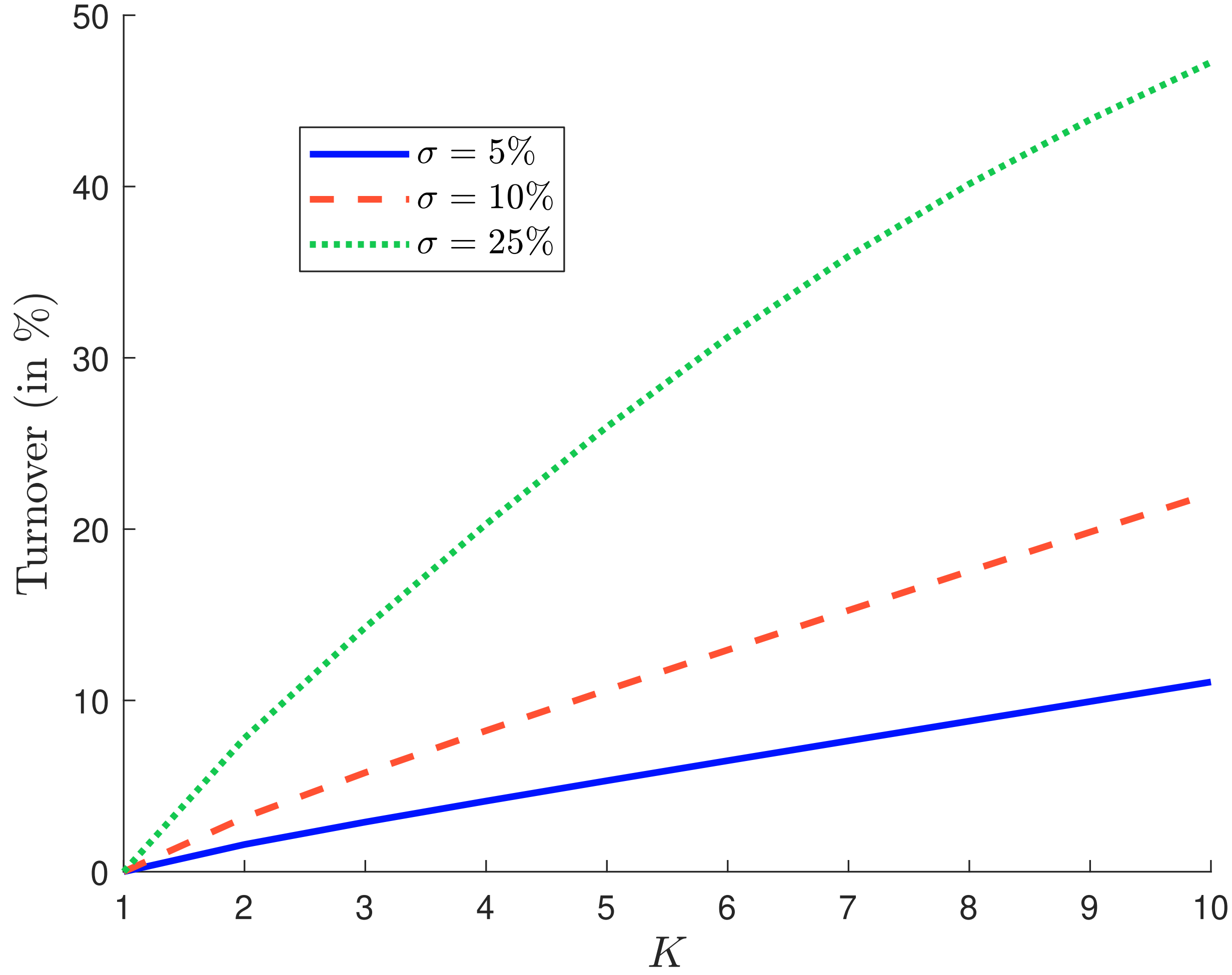


Figure 149: Relationship between K and $\mathcal{T}(\mathcal{R}_1, \ldots, \mathcal{R}_K)$

Probability distribution of an ESG score

Question 4.k

Why is an ESG rating system different than a credit rating system? What do you conclude from the previous analysis? What is the issue of ESG exclusion policy and negative screening?

Probability distribution of an ESG score

- An ESG rating system is mainly quantitative and highly depends on the mapping function. This is not the case of a credit rating system, which is mainly qualitative and discretionary.
- This explains that the turnover of an ESG rating system is higher than the turnover of a credit rating system.
- The stabilization of the ESG rating system implies to reduce the turnover $\mathcal{T}(\mathcal{R}_1, \ldots, \mathcal{R}_K)$, which depends on:
  1. The number of notches[29] K;
  2. The volatility σ of score changes
  3. The design of the ESG rating system $(s_1, \ldots, s_{K-1})$
- The turnover $\mathcal{T}(\mathcal{R}_1, \ldots, \mathcal{R}_K)$ has a big impact on an ESG exclusion (or negative screening) policy, because it creates noisy short-term entry/exit positions that do not necessarily correspond to a decrease or increase of the long-term ESG risks.

[29] This is why ESG rating systems have less notches than credit rating systems

Enhanced ESG score & tracking error control

Exercise

We consider a capitalization-weighted equity index, which is composed of 8 stocks. Their weights, volatilities and ESG scores are the following:

Stock	#1	#2	#3	#4	#5	#6	#7	#8
CW weight	0.23	0.19	0.17	0.13	0.09	0.08	0.06	0.05
Volatility	0.22	0.20	0.25	0.18	0.35	0.23	0.13	0.29
ESG score	−1.20	0.80	2.75	1.60	−2.75	−1.30	0.90	−1.70

The correlation matrix is given by:

$$\rho = \begin{pmatrix}
100\% & & & & & & & \\
80\% & 100\% & & & & & & \\
70\% & 75\% & 100\% & & & & & \\
60\% & 65\% & 80\% & 100\% & & & & \\
70\% & 50\% & 70\% & 85\% & 100\% & & & \\
50\% & 60\% & 70\% & 80\% & 60\% & 100\% & & \\
70\% & 50\% & 70\% & 75\% & 80\% & 50\% & 100\% & \\
60\% & 65\% & 70\% & 75\% & 65\% & 70\% & 80\% & 100\%
\end{pmatrix}$$

Enhanced ESG score & tracking error control

Question 1

Calculate the ESG score of the benchmark.

Enhanced ESG score & tracking error control

- We note b_i and $\mathcal{S}_i$ the weight in the benchmark and the ESG score of Stock i
- The ESG score of the benchmark is equal to:

$$\mathcal{S}(b) = \sum_{i=1}^{8} b_i \cdot \mathcal{S}_i = 0.1690$$

Enhanced ESG score & tracking error control

Question 2

We consider the EW and ERC portfolios. Calculate the ESG score of these two portfolios. Define the ESG excess score with respect to the benchmark. Comment on these results.

Enhanced ESG score & tracking error control

- The composition of the EW portfolio is $x_i = 12.5\%$ and we have:

$$\mathcal{S}\left(x_{\mathrm{ew}}\right) = \sum_{i=1}^{8} \frac{\mathcal{S}_i}{8} = -0.1125$$

- The composition of the ERC portfolio is $x_1 = 12.42\%$, $x_2 = 14.03\%$, $x_3 = 10.17\%$, $x_4 = 13.79\%$, $x_5 = 7.59\%$, $x_6 = 12.34\%$, $x_7 = 20.61\%$ and $x_8 = 9.06\%$. We have:

$$\mathcal{S}\left(x_{\mathrm{erc}}\right) = \sum_{i=1}^{8} x_i \cdot \mathcal{S}_i = 0.1259$$

Enhanced ESG score & tracking error control

- The ESG excess score with respect to the benchmark is:

$$\mathcal{S}(x \mid b) = \mathcal{S}(x) - \mathcal{S}(b)$$

We have:

$$\begin{aligned} \mathcal{S}(x_{\mathrm{ew}} \mid b) &= -0.1125 - 0.1690 = -0.2815 \\ \mathcal{S}(x_{\mathrm{erc}} \mid b) &= 0.1259 - 0.1690 = -0.0431 \end{aligned}$$

- The two portfolios are riskier than the benchmark portfolio in terms of ESG risk

Enhanced ESG score & tracking error control

Question 3

Write the γ-problem of the ESG optimized portfolio when the goal is to improve the ESG score of the benchmark and control at the same time the tracking error volatility. Give the QP objective function.

Enhanced ESG score & tracking error control

- We have:

$$\begin{aligned} x^\star & = & \arg\min \frac{1}{2}\sigma^2\left(x \mid b\right) - \gamma \mathcal{S}\left(x \mid b\right) \\ & \text{u.c.} & \left\{ \begin{array}{l} \mathbf{1}_n^\top x = 1 \\ \mathbf{0}_n \leq x \leq \mathbf{1}_n \\ x \in \Omega \end{array} \right. \end{aligned}$$

- Since $\sigma^2\left(x \mid b\right) = \left(x - b\right)^\top \Sigma \left(x - b\right)$ and $\mathcal{S}\left(x \mid b\right) = \left(x - b\right)^\top \mathcal{S}$, we deduce that the QP objective function is:

$$x^\star = \arg\min \frac{1}{2} x^\top \Sigma x - x^\top \left(\gamma \mathcal{S} + \Sigma b\right)$$

Enhanced ESG score & tracking error control

Question 4

Draw the efficient frontier between the tracking error volatility and the ESG excess score[a].

[a] We notice that $\gamma \in [0, 1.2\%]$ is sufficient for drawing the efficient frontier.

Enhanced ESG score & tracking error control

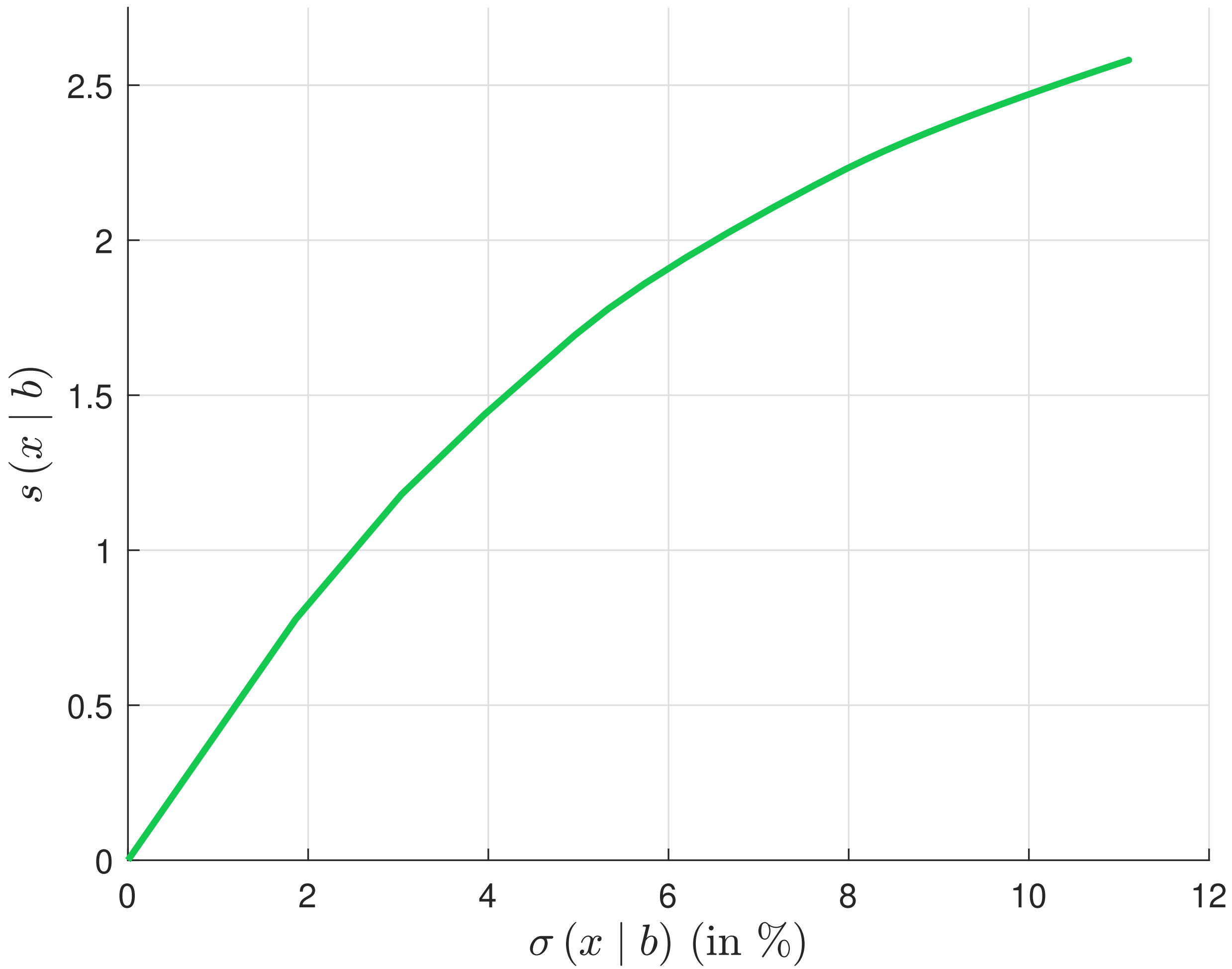


Figure 150: ESG efficient frontier

Enhanced ESG score & tracking error control

Question 5

Using the bisection algorithm, find the optimal portfolio if we would like to improve the ESG score of the benchmark by 0.5. Give the optimal value of γ. Compute the tracking error volatility $\sigma(x \mid b)$.

Enhanced ESG score & tracking error control

- The solution is equal to:

Stock	s_i	b_i	$x_i^\star$
#1	−1.200	23.000	25.029
#2	0.800	19.000	14.251
#3	2.750	17.000	21.947
#4	1.600	13.000	27.305
#5	−2.750	9.000	3.718
#6	−1.300	8.000	1.339
#7	0.900	6.000	1.675
#8	−1.700	5.000	4.736

- The optimal value of γ is 0.02768%
- The tracking error volatility is equal to 1.17636%

Enhanced ESG score & tracking error control

Question 6

Same question if we would like to improve the ESG score of the benchmark by 1.0.

Enhanced ESG score & tracking error control

- The solution is equal to:

Stock	s_i	b_i	$x_i^\star$
#1	-1.200	23.000	21.699
#2	0.800	19.000	12.443
#3	2.750	17.000	28.739
#4	1.600	13.000	33.555
#5	-2.750	9.000	0.002
#6	-1.300	8.000	0.000
#7	0.900	6.000	2.433
#8	-1.700	5.000	1.129

- The optimal value of γ is 0.07276%
- The tracking error volatility is equal to 2.48574%

Enhanced ESG score & tracking error control

Question 7

We impose that the portfolio weights can not be greater than 30%. Find the optimal portfolio if we would like to improve the ESG score of the benchmark by 1.0.

Enhanced ESG score & tracking error control

- The solution is equal to:

Stock	s_i	b_i	$x_i^\star$
#1	−1.200	23.000	20.116
#2	0.800	19.000	14.082
#3	2.750	17.000	29.481
#4	1.600	13.000	30.000
#5	−2.750	9.000	0.644
#6	−1.300	8.000	0.000
#7	0.900	6.000	4.662
#8	−1.700	5.000	1.015

- The optimal value of γ is 0.07355%
- The tracking error volatility is equal to 2.50317%

Enhanced ESG score & tracking error control

Question 8

Comment on these results.

Enhanced ESG score & tracking error control

- We notice that the evolution of the weights is not necessarily monotonous with respect to the ESG excess score $\mathcal{S}(x \mid b)$. For instance, if we target an improvement of 0.5, the weight of Stock #1 increases ($23\% \Rightarrow 25.029\%$). If we target an improvement of 1.0, the the weight of Stock #1 decreases ($25.029\% \Rightarrow 21.699\%$)
- Generally, the optimiser reduces the weight of stocks with low ESG scores and increases the weight of stocks with high ESG scores
- Nevertheless, the weight differences are not ranked in the same order than the ESG scores. For instance, if we target an improvement of 0.5, the largest variation is observed for Stock #4, which has an ESG score of 1.6. This is not the largest ESG score, since Stock #3 has an ESG score of 2.75
- This is due to the structure of the covariance matrix (Stock #3 is riskier than Stock #4)

Tilted portfolios with ESG and carbon intensity constraints

Exercise

We consider the CAPM model:

$$R_i - r = \beta_i \cdot (R_m - r) + \varepsilon_i$$

where R_i is the return of Asset i, R_m is the return of the market portfolio, r is the risk free asset, β_i is the beta of Asset i with respect to the market portfolio and ε_i is the idiosyncratic risk. We assume that $R_m \perp \varepsilon_i$ and $\varepsilon_i \perp \varepsilon_j$. We note σ_m the volatility of the market portfolio and $\tilde{\sigma}_i$ the idiosyncratic volatility. We consider a universe of 5 assets:

Asset i	1	2	3	4	5
β_i	0.30	0.50	0.90	1.30	2.00
$\tilde{\sigma}_i$	15%	16%	10%	11%	12%

and $\sigma_m = 20\%$. The risk free return is set to 1% and we assume that the expected return of the market portfolio is equal to $\mu_m = 6\%$.

Tilted portfolios with ESG and carbon intensity constraints

Question 1

We assume that the CAPM is valid.

Tilted portfolios with ESG and carbon intensity constraints

Question 1.a

Calculate the vector μ of expected returns.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$\begin{aligned}
\mu &= \mathbb{E}[R_i] \\
&= r + \beta_i \cdot (\mu_m - r) \\
&= \begin{pmatrix} 2.50 \\ 3.50 \\ 5.50 \\ 7.50 \\ 11.00 \end{pmatrix} \quad \text{(in \%)}
\end{aligned}$$

Tilted portfolios with ESG and carbon intensity constraints

Question 1.b

Compute the covariance matrix Σ.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$\begin{aligned}
\Sigma &= \operatorname{cov}(R) \\
&= \beta\beta^\top \sigma_m^2 + \operatorname{diag}\left(\tilde{\sigma}_1^2, \ldots, \tilde{\sigma}_5^2\right) \\
&= \begin{pmatrix}
261.00 & 60.00 & 108.00 & 156.00 & 240.00 \\
60.00 & 356.00 & 180.00 & 260.00 & 400.00 \\
108.00 & 180.00 & 424.00 & 468.00 & 720.00 \\
156.00 & 260.00 & 468.00 & 797.00 & 1040.00 \\
240.00 & 400.00 & 720.00 & 1040.00 & 1744.00
\end{pmatrix} \times 10^{-4}
\end{aligned}$$

Tilted portfolios with ESG and carbon intensity constraints

Question 1.c

Deduce the volatility σ_i of the assets and find the correlation matrix $C = (\rho_{i,j})$ between asset returns.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$
\begin{aligned}
\sigma_i &= \sqrt{\Sigma_{i,i}} \\
&= \sqrt{\beta_i^2 \sigma_m^2 + \tilde{\sigma}_i^2} \\
&= \begin{pmatrix} 16.16 \\ 18.87 \\ 20.59 \\ 28.23 \\ 41.76 \end{pmatrix} \quad \text{(in \%)}
\end{aligned}
$$

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$\rho_{i,j} = \frac{\operatorname{cov}(R_i, R_j)}{\sigma(R_i) \cdot \sigma(R_j)} = \frac{\Sigma_{i,j}}{\sqrt{\Sigma_{i,i}} \cdot \sqrt{\Sigma_{i,i}}} \frac{\beta_i \beta_j \sigma_m^2}{\sqrt{\beta_i^2 \sigma_m^2 + \tilde{\sigma}_i^2} \cdot \sqrt{\beta_j^2 \sigma_m^2 + \tilde{\sigma}_i^2}}$$

and:

$$C = \begin{pmatrix} 100.00 & 19.68 & 32.47 & 34.20 & 35.57 \\ 19.68 & 100.00 & 46.33 & 48.81 & 50.76 \\ 32.47 & 46.33 & 100.00 & 80.51 & 83.73 \\ 34.20 & 48.81 & 80.51 & 100.00 & 88.21 \\ 35.57 & 50.76 & 83.73 & 88.21 & 100.00 \end{pmatrix} \quad \text{(in \%)}$$

Tilted portfolios with ESG and carbon intensity constraints

Question 2

We assume that:

Asset i	1	2	3	4	5
μ_i	3%	4%	5%	7%	10%
$\mathcal{S}_i^{\mathrm{esg}}$	1.10	2.70	-0.90	-2.20	0.40
$\mathcal{CI}_i$	50	170	490	180	320
b_i	20%	20%	20%	20%	20%

where μ_i, $\mathcal{S}_i^{\mathrm{esg}}$, $\mathcal{CI}_i$ and b_i are respectively the expected return, the ESG score[a], the carbon intensity in $tCO_2e/\$$ mn and the benchmark weight of Asset i. The covariance matrix is given by the CAPM model and corresponds to the one calculated in Question 1.b. In what follows, we consider **long-only** portfolios.

[a]It corresponds to a z-score between -3 (worst score) and $+3$ (best score).

Tilted portfolios with ESG and carbon intensity constraints

Question 2.a

Compute the ESG score $\mathcal{S}^{\mathrm{esg}}(b)$ and the carbon intensity $\mathcal{CI}(b)$ of the benchmark b.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$\begin{aligned} \mathcal{S}^{\mathrm{esg}}(b) &= \sum_{i=1}^{5} b_i \cdot \mathcal{S}_i^{\mathrm{esg}} \\ &= b^\top \mathcal{S}^{\mathrm{esg}} \\ &= 0.22 \end{aligned}$$

- We have:

$$\begin{aligned} \mathcal{CI}(b) &= \sum_{i=1}^{5} b_i \cdot \mathcal{CI}_i \\ &= b^\top \mathcal{CI} \\ &= 242 \end{aligned}$$

Tilted portfolios with ESG and carbon intensity constraints

Question 2.b

The current portfolio of the fund manager is equal to:

$$x = \begin{pmatrix} 10\% \\ 10\% \\ 30\% \\ 30\% \\ 20\% \end{pmatrix}$$

Compute the excess expected return $\mu(x \mid b)$, the tracking error volatility $\sigma(x \mid b)$, the ESG score $\mathcal{S}^{\mathrm{esg}}(x)$ and the carbon intensity $\mathcal{CI}(x)$ of the portfolio x. Deduce its information ratio $\mathrm{IR}(x \mid b)$. Comment on these results.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$\mu(x \mid b) = (x - b)^\top \mu = 50 \text{ bps}$$

and:

$$\sigma(x \mid b) = \sqrt{(x - b)^\top \Sigma (x - b)} = 3.85\%$$

- We deduce that:

$$\mathrm{IR}(x \mid b) = \frac{\mu(x \mid b)}{\sigma(x \mid b)} = \frac{0.50}{3.85} = 0.13$$

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$\mathcal{S}^{\mathrm{esg}}(x) = \sum_{i=1}^{5} x_i \cdot \mathcal{S}_i^{\mathrm{esg}} = -0.47 \ll \mathcal{S}^{\mathrm{esg}}(b) = 0.22$$

  and:

$$\mathcal{CI}(x) = \sum_{i=1}^{5} x_i \cdot \mathcal{CI}_i = 287 \gg \mathcal{CI}(b) = 242$$

- x is a good portfolio from the viewpoint of financial analysis since it has a positive information ratio. Nevertheless, it is a bad portfolio from the viewpoint of extra-financial analysis if we compare it with the benchmark. Indeed, it has a lower ESG score and a higher carbon intensity.

Tilted portfolios with ESG and carbon intensity constraints

Question 2.c

We would like to tilt the benchmark b in order to improve its expected return. Formulate the γ-problem of portfolio optimization in the presence of a benchmark. Find the corresponding QP problem. We note $x^\star(\gamma)$ the optimized portfolio. Draw the efficient frontier betwen the tracking error volatility $\sigma(x^\star(\gamma) \mid b)$ and the excess expected return $\mu(x^\star(\gamma) \mid b)$.

Question 2.d

Draw the relationship between $\sigma(x^\star(\gamma) \mid b)$ and $\mathcal{S}^{\mathrm{esg}}(x^\star(\gamma))$. Comment on these results.

Question 2.e

Draw the relationship between $\sigma(x^\star(\gamma) \mid b)$ and $\mathcal{CI}(x^\star(\gamma))$. Comment on these results.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$
\begin{aligned}
x^{\star}(\gamma) &= \arg\min \frac{1}{2}\sigma^{2}(x \mid b) - \gamma\mu(x \mid b) \\
\text{u.c.} & \left\{
\begin{array}{l}
\mathbf{1}_n^{\top} x = 1 \\
\mathbf{0}_n \leq x \leq \mathbf{1}_n \\
x \in \Omega
\end{array}
\right.
\end{aligned}
$$

- Since $\sigma^{2}(x \mid b) = (x - b)^{\top} \Sigma (x - b)$ and $\mu(x \mid b) = (x - b)^{\top} \mu$, we deduce that the QP objective function is:

$$
x^{\star}(\gamma) = \arg\min \frac{1}{2} x^{\top} \Sigma x - x^{\top} (\gamma\mu + \Sigma b)
$$

Tilted portfolios with ESG and carbon intensity constraints

- We recall that the formulation of a standard QP problem is:

$$
\begin{aligned}
x^{\star} &= \arg\min \frac{1}{2} x^{\top} Q x - x^{\top} R \\
\text{u.c.} &\quad \left\{
\begin{array}{l}
Ax = B \\
Cx \leq D \\
x^{-} \leq x \leq x^{+}
\end{array}
\right.
\end{aligned}
$$

- We have the following QP correspondences:

$$
\begin{aligned}
Q &= \Sigma \\
R &= \gamma \mu + \Sigma b \\
A &= \mathbf{1}_n^{\top} \\
B &= 1 \\
x^{-} &= \mathbf{0}_n \\
x^{+} &= \mathbf{1}_n
\end{aligned}
$$

Tilted portfolios with ESG and carbon intensity constraints

- We compute $x^{\star}(\gamma)$ for several values of $\gamma \in [0, 10]$.
- For a given optimized portfolio $x^{\star}(\gamma)$, we compute:

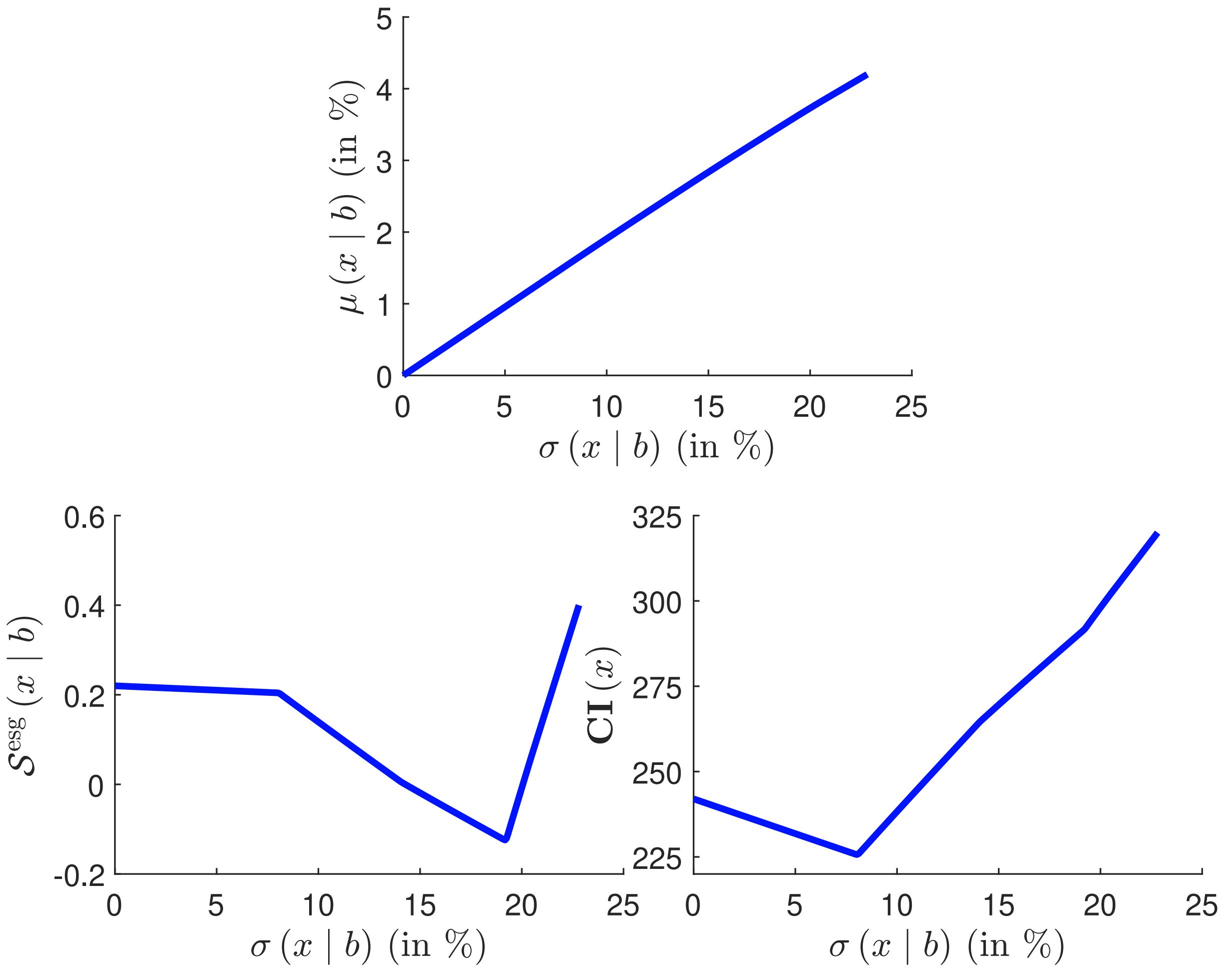
$$\mathcal{S}^{\mathrm{esg}}(x^{\star}(\gamma)) = \sum_{i=1}^{5} x_i^{\star}(\gamma) \cdot \mathcal{S}_i^{\mathrm{esg}}$$

and:

$$\mathcal{CI}(x^{\star}(\gamma)) = \sum_{i=1}^{5} x_i^{\star}(\gamma) \cdot \mathcal{CI}_i$$

Tilted portfolios with ESG and carbon intensity constraints

Figure 151: The efficient frontier of optimal portfolios



Tilted portfolios with ESG and carbon intensity constraints

- We do not observe a monotonous function between the tracking error volatility and the ESG score or the carbon intensity.
- When the tracking error volatility is low, the ESG score decreases weakly but we obtain a better carbon intensity.
- When the tracking error volatility is high, the ESG score is improved but the carbon intensity is degraded.

Tilted portfolios with ESG and carbon intensity constraints

Question 2.f

Find the optimal portfolio $x^{\star}$ if we target an ex-ante tracking error volatility of 5%. Give the optimal value of γ, the expected excess return $\mu\left(x^{\star} \mid b\right)$ and the information ratio $\mathrm{IR}\left(x^{\star} \mid b\right)$. Compute also the ESG score $\mathcal{S}^{\mathrm{esg}}\left(x^{\star}\right)$ and the carbon intensity $\boldsymbol{\mathcal{CI}}\left(x^{\star}\right)$ of the optimal portfolio $x^{\star}$.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$x^{\star} = \begin{pmatrix} 14.66 \\ 18.66 \\ 7.60 \\ 23.96 \\ 35.13 \end{pmatrix} \quad \text{(in \%)}$$

- The optimal value of γ is equal to 26.16%.

Tilted portfolios with ESG and carbon intensity constraints

- We obtain $\mu(x^\star \mid b) = 96$ bps, $\sigma(x^\star \mid b) = 5\%$ and $\mathrm{IR}(x^\star \mid b) = 19\%$.
- We have $\mathcal{S}^{\mathrm{esg}}(x^\star) = 0.21$ and $\mathcal{S}^{\mathrm{esg}}(x^\star \mid b) = -0.01 < 0$. We obtain a lower ESG score, but it is close to zero.
- We have $\mathcal{CI}(x^\star) = 231.81$ and $\mathcal{CI}(x^\star \mid b) = -10.19 < 0$. We have improved the carbon intensity of the benchmark.

Tilted portfolios with ESG and carbon intensity constraints

Question 3

We now assume that $\mu = \mathbf{0}_5$.

Tilted portfolios with ESG and carbon intensity constraints

Question 3.a

We would like to reduce the carbon intensity of the benchmark portfolio by 20%. Give the QP formulation of the optimization problem. Compute the optimal portfolio $x^\star$ such that it has the lowest tracking error volatility $\sigma(x \mid b)$. Give the values of $\sigma(x^\star \mid b)$, $\mathcal{S}^{\mathrm{esg}}(x^\star)$, $\mathcal{S}^{\mathrm{esg}}(x^\star \mid b)$, $\mathcal{CI}(x^\star)$, $\mathcal{CI}(x^\star \mid b)$ and the reduction rate $\mathcal{R}(x^\star \mid b)$ of the carbon intensity. Comment on these results.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$
\begin{aligned}
x^{\star}(\gamma) & = \arg\min \frac{1}{2}\sigma^2(x \mid b) \\
& \text{u.c.} \quad \left\{
\begin{array}{l}
\mathbf{1}_n^\top x = 1 \\
\mathbf{0}_n \leq x \leq \mathbf{1}_n \\
\mathcal{CI}(x) \leq (1 - \mathcal{R}) \cdot \mathcal{CI}(b)
\end{array}
\right.
\end{aligned}
$$

where $\mathcal{R} = 20\%$.

Tilted portfolios with ESG and carbon intensity constraints

- We recall that the formulation of a standard QP problem is:

$$\begin{aligned} x^\star &= \arg\min \frac{1}{2} x^\top Q x - x^\top R \\ &\text{u.c.} \left\{ \begin{array}{l} Ax = B \\ Cx \leq D \\ x^- \leq x \leq x^+ \end{array} \right. \end{aligned}$$

- We have the following QP correspondences:

$$\begin{array}{ll} Q = \Sigma & C = \boldsymbol{\mathcal{CI}}^\top \\ R = \Sigma b & D = \boldsymbol{\mathcal{CI}}^+ = (1 - \boldsymbol{\mathcal{R}}) \cdot \left(b^\top \boldsymbol{\mathcal{CI}} \right) \\ A = \mathbf{1}_n^\top & x^- = \mathbf{0}_n \\ B = 1 & x^+ = \mathbf{1}_n \end{array}$$

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$x^{\star} = \begin{pmatrix} 25.21 \\ 21.93 \\ 6.36 \\ 25.90 \\ 20.60 \end{pmatrix} \quad \text{(in \%)}$$

- We obtain $\sigma\left(x^{\star} \mid b\right) = 1.74\%$, $\mathcal{S}^{\mathrm{esg}}\left(x^{\star}\right) = 0.32$, $\mathcal{S}^{\mathrm{esg}}\left(x^{\star} \mid b\right) = 0.10$, $\mathcal{CI}\left(x^{\star}\right) = 193.60$, $\mathcal{CI}\left(x^{\star} \mid b\right) = -48.40$ and $\mathcal{R}\left(x^{\star} \mid b\right) = 20\%$.
- We obtain a better ESG score with an improvement of the carbon intensity.

Tilted portfolios with ESG and carbon intensity constraints

Question 3.b

We would like to improve the ESG score of the benchmark portfolio by $+0.50$. Give the QP formulation of the optimization problem. Compute the optimal portfolio $x^{\star}$ such that it has the lowest tracking error volatility $\sigma(x \mid b)$. Give the values of $\sigma(x^{\star} \mid b)$, $\mathcal{S}^{\text{esg}}(x^{\star})$, $\mathcal{S}^{\text{esg}}(x^{\star} \mid b)$, $\mathcal{CI}(x^{\star})$, $\mathcal{CI}(x^{\star} \mid b)$ and the reduction rate $\mathcal{R}(x^{\star} \mid b)$ of the carbon intensity. Comment on these results.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$
\begin{aligned}
x^{\star}(\gamma) &= \arg\min \frac{1}{2}\sigma^{2}(x \mid b) \\
\text{u.c.} & \quad \left\{
\begin{array}{l}
\mathbf{1}_n^\top x = 1 \\
\mathbf{0}_n \leq x \leq \mathbf{1}_n \\
\mathcal{S}^{\mathrm{esg}}(x) \geq \mathcal{S}^{\mathrm{esg}}(b) + 0.5
\end{array}
\right.
\end{aligned}
$$

Tilted portfolios with ESG and carbon intensity constraints

- We recall that the formulation of a standard QP problem is:

$$
\begin{aligned}
x^{\star} & = & \arg\min \frac{1}{2} x^{\top} Q x - x^{\top} R \\
& & \text{u.c.} \left\{ \begin{array}{l} Ax = B \\ Cx \leq D \\ x^{-} \leq x \leq x^{+} \end{array} \right.
\end{aligned}
$$

- We have the following QP correspondences:

$$
\begin{array}{ll}
Q = \Sigma & C = \left(-\mathcal{S}^{\mathrm{esg}}\right)^{\top} \\
R = \Sigma b & D = -\left(b^{\top} \mathcal{S}^{\mathrm{esg}} + 0.5\right) \\
A = \mathbf{1}_n^{\top} & x^{-} = \mathbf{0}_n \\
B = 1 & x^{+} = \mathbf{1}_n
\end{array}
$$

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$x^{\star} = \begin{pmatrix} 22.36 \\ 26.70 \\ 14.71 \\ 9.98 \\ 26.24 \end{pmatrix} \quad \text{(in \%)}$$

- We obtain $\sigma\left(x^{\star} \mid b\right) = 1.84\%$, $\mathcal{S}^{\mathrm{esg}}\left(x^{\star}\right) = 0.72$, $\mathcal{S}^{\mathrm{esg}}\left(x^{\star} \mid b\right) = 0.50$, $\mathcal{CI}\left(x^{\star}\right) = 230.61$, $\mathcal{CI}\left(x^{\star} \mid b\right) = -11.39$ and $\mathcal{R}\left(x^{\star} \mid b\right) = 4.71\%$.
- We obtain a better carbon intensity with an improvement of the ESG score. Nevertheless, the reduction of the carbon intensity is low and less than 5%.

Tilted portfolios with ESG and carbon intensity constraints

Question 3.c

Same question if we mix the two constraints.

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$
\begin{aligned}
x^{\star}(\gamma) &= \arg\min \frac{1}{2}\sigma^2(x \mid b) \\
& \text{u.c.} \quad \left\{
\begin{array}{l}
\mathbf{1}_n^\top x = 1 \\
\mathbf{0}_n \leq x \leq \mathbf{1}_n \\
\mathcal{S}^{\mathrm{esg}}(x) \geq \mathcal{S}^{\mathrm{esg}}(b) + 0.5 \\
\boldsymbol{\mathcal{CI}}(x) \leq (1 - \boldsymbol{\mathcal{R}}) \cdot \boldsymbol{\mathcal{CI}}(b)
\end{array}
\right.
\end{aligned}
$$

Tilted portfolios with ESG and carbon intensity constraints

- We recall that the formulation of a standard QP problem is:

$$\begin{aligned} x^{\star} &= \arg\min \frac{1}{2} x^{\top} Q x - x^{\top} R \\ \text{u.c.} & \left\{ \begin{array}{l} Ax = B \\ Cx \leq D \\ x^{-} \leq x \leq x^{+} \end{array} \right. \end{aligned}$$

- We have the following QP correspondences:

$$\begin{array}{ll} Q = \Sigma & C = \left[\begin{array}{c} \mathcal{CI}^{\top} \\ \left(-\mathcal{S}^{\mathrm{esg}}\right)^{\top} \end{array} \right] \\ R = \Sigma b & D = \left[\begin{array}{c} (1 - 20\%) \cdot \left(b^{\top} \mathcal{CI}\right) \\ -\left(b^{\top} \mathcal{S}^{\mathrm{esg}} + 0.5\right) \end{array} \right] \\ A = \mathbf{1}_n^{\top} & x^{-} = \mathbf{0}_n \\ B = 1 & x^{+} = \mathbf{1}_n \end{array}$$

Tilted portfolios with ESG and carbon intensity constraints

- We have:

$$x^{\star} = \begin{pmatrix} 26.16 \\ 27.13 \\ 4.64 \\ 16.41 \\ 25.67 \end{pmatrix} \quad \text{(in \%)}$$

- We obtain $\sigma(x^{\star} \mid b) = 2.29\%$, $\mathcal{S}^{\mathrm{esg}}(x^{\star}) = 0.72$, $\mathcal{S}^{\mathrm{esg}}(x^{\star} \mid b) = 0.50$, $\mathcal{CI}(x^{\star}) = 193.60$, $\mathcal{CI}(x^{\star} \mid b) = -48.40$ and $\mathcal{R}(x^{\star} \mid b) = 20\%$.
- It is possible to target the two objectives, but the tracking error volatility increases and is greater than 2%.

Net Zero Alignment Portfolio