Investment Institute

WORKING PAPER 167 | MARCH 2025

Climate-Related Financial Stress-Testing and Scenarios Valuation: Application to the MSCI World Index

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Abstract

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We apply transition scenarios from the global multi-region multi-sector energy-economic MIT EPPA model to assess a large sample of issuers at the company level. We model the evolution of revenues and earnings for companies in the MSCI World Index under several scenarios of global emission mitigation (1.5°C, below 2°C, below 2°C delayed, and 1.5°C with limited availability of carbon dioxide removal technologies), comparing these to current trends. We analyze direct emission mitigation costs, indirect costs from the supply chain, capital expenditures, and cash flow trajectories, and their influence on other economic variables.

We find that a radical shift from the baseline to the 2°C scenario would imply spot losses of up to 8.7% of the index using our discounted cash-flow approach. While the energy sector bears the largest burden of emission mitigation activities, some companies in the utilities sector would benefit from the transition. The credit risk implied by scaling these models at the company level suggests a widespread effect on transition across most sectors and country, depending on the distribution of their revenues.

The global impact on the credit spreads is limited from 2024 onwards. However, local credit spreads, modeled at the company level for every company of the MSCI World Index, could be substantially impacted. For example, the 90th percentiles of additional cost of debt induced by transition are 1% and 2.3% respectively in 2030 and 2040 in the 1.5°C with limited access to carbon dioxide removal technologies scenario.

Keywords: IAM, Transition Risk, Net-Zero, Asset Pricing, Climate Stress-testing.

JEL classification: **G12, G18, Q41, Q51**.

Acknowledgement

The authors are very grateful to Rami Mery, Matthieu Keip, Aaron Mcdougall, Mathieu Jouanneau, Alexis Sciau, Benjamin Duval, Tegwen Le Berthe, Theophile Tixier, Meghal Arora, Olga Streltchenko, Mahmood Alaghmandan, Thierry Roncalli, Takaya Sekine and Jiali Xu for helpful comments.

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Key Findings

1. **Transition Scenarios Modeling**
    - Our research paper uses the MIT EPPA model to project the evolution of revenues and earnings for companies in the MSCI World Index under various global emission mitigation scenarios, including 1.5°C, below 2°C, below 2°C delayed, and 1.5°C with limited carbon dioxide removal technologies.
    - The analysis considers several cost and investment factors, such as direct emission mitigation costs, indirect costs from the supply chain, capital expenditures, and projected cash-flow trajectories.
2. **Impact on Stock Returns**
    - A sharp policy shift towards more ambitious climate targets (e.g., from a baseline to a 1.5°C with limited access to carbon dioxide removal technologies scenario) could result in spot losses of up to 15.5% of the MSCI World Index value.
3. **Sectoral Breakdown**
    - The energy sector bears the highest cost burden for emission mitigation with shocks as big as -76% on their free cash flows in average in the below 2°C delayed scenario.
    - Companies in the utilities sector could generate positive relative returns, particularly under scenarios with constrained access to carbon dioxide removal technologies, as low-carbon power becomes comparatively more valuable.
4. **Shocks on Credit Risk**
    - The transition effects at the firm level on credit risk is widespread, though it varies by firm revenue share and sector. At the global index level, the impacts on credit spreads are relatively modest by 2024.
    - Each sector has its own story with the 90th percentile of the additional cost of debt (credit spreads) for the materials sector being of 60 basis point by 2030 and 1.6% by 2040 in the 1.5°C scenario with limited access to carbon dioxide removal technologies.
5. **Business Model Adaptation**
    - The findings highlight that companies' ability to adapt or present business models resilient to or supportive of the transition will be crucial in mitigating adverse financial impacts under stringent climate targets.

1 Introduction

Regulators and central banks have increasingly emphasized the need for financial institutions to build robust stress-testing frameworks to gauge their exposure to both transition and physical risks associated with climate change (ESMA, 2022). This study centers on the transition risks, offering a method to assess transition risks for carbon-intensive industries at the company level. The core objective is to explore the benefits and challenges of applying scenarios from integrated assessment models (IAMs) to asset management practices, specifically highlighting the pathways through which climate transition scenarios may impact financial statements and influence valuation models relevant to operational decision-making.

Transition risks arise from the economy's movement towards lower carbon emissions, where industries face regulatory changes and evolving market demands to more sustainable products. These risks can lead to stranded assets, where assets lose their value due to changes in technology, regulation, or market conditions but are primarily driven by policies designed to curtail greenhouse gas (GHG) emissions, thereby contributing to climate mitigation efforts. For example, an industrial firm reliant on carbon-heavy processes could incur lower profits (or even losses) if regulatory measures intensify. A coal-fired power plant may become a stranded asset if a carbon fee makes it uneconomic to operate, or a competition from renewable energy sources. Businesses may also face legal and reputational risks in the form of penalties, lawsuits or damage to their brand reputation. Similarly, a car manufacturer may experience declining sales if consumer preferences shift toward environmentally sustainable products.

Transition risk assessments generally use scenario analysis as a foundation, where scenario development typically relies on integrated assessment models (IAMs). Initiatives suggesting firm-level emission reduction targets frequently employ IAMs' science-based CO_2 trajectories, as found in IPCC frameworks (IPCC, 2022) or International Energy Agency projections (IEA, 2022). While these global trajectories offer a baseline for mitigation efforts, they lack the granularity to capture individual company characteristics. This paper contributes to the existing body of work (see the litterature review of Bouchet and Le Guenedal (2020)) by providing an approach for using IAMs in transition risk assessments and linking these insights to company-level impacts. The study applies the MIT Economic Projection and Policy Analysis (EPPA) model to examine transition scenarios' effects on a representative group of companies, presenting results through scenario narratives aligned with the Network for Greening the Financial System (NGFS, Boirard *et al.*, 2022) scenarios.

Evaluating the effects of climate-related risks on both the real economy and the financial system is crucial due to potential systemic consequences. Studies on transition risk suggest exposures around 10% on average (2 Investing Initiative, 2018; Aubert *et al.*, 2019; Bouchet & Le Guenedal, 2020; EIOPA, 2018; Schotten *et al.*, 2016; Vermeulen *et al.*, 2018, 2019; Weyzig *et al.*, 2014), meaning they are at risk of losing 10% of their earnings on average to transition shocks. Research has increasingly focused on indirect effects, such as cascading impacts across supply chains (Adenot *et al.*, 2022; Cahen-Fourot *et al.*, 2019; Desnos *et al.*, 2023; Mardones & Mena, 2020) and potential contagion of financial losses. This shift in focus has spurred the development of various stress-testing methods. Early climate stress-test models for the banking sector, like Battiston *et al.* (2017), have been extended in recent work, including by Roncoroni *et al.* (2021).[1] Several climate stress-testing frameworks have emerged for the financial and banking sectors (Allen *et al.*, 2020; Alogoskoufis *et al.*, 2021; Dunz *et al.*, 2021; Gourdel and Sydow, 2021; Grippa, Mann, *et al.*, 2020; Nguyen *et al.*, 2020; Reinders *et al.*, 2020). However, the majority of these frameworks are primarily focused on banking needs, leaving a void in methodologies specifically crafted for asset managers. A recent effort to address this gap is the value-at-risk stress-testing method for investment portfolios introduced by Desnos *et al.* (2023), which facilitates forward-looking risk evaluation in the face of transition uncertainties.

This paper generalizes the findings from Le Guenedal *et al.* (2023) by applying and extending the methodologies to a whole investment universe (MSCI World Index). We enhanced the sectoral activity allocation allowing to have the most precise breakdown of company revenues by sector and country using a semi-automatic decision tree process based on (i) embeddings (a correspondence is being made between EPPA sectors and RBICS sectors), (ii) energy mix and (iii) European Taxonomy metrics. The geographic exposure is also accounted for based on a similar process. Modeling of free-cash flows and default probabilities have been enhanced by offering parametric approaches allowing to account for inflation and capital expenditure costs. In all, we provide a transparent stress-testing framework for general purpose that has the capacity to adapt to any scenario settings and carbon-reduction mechanisms (such as border taxes, e.g. Chen *et al.*, 2023, subsidies, etc.).

We base our approach on the study by Le Guenedal *et al.* (2023) which projected climate-relevant variables from the Bank of Canada's study on transition risks (Chen *et al.*, 2022b). This paper introduces a framework to model impacts at the company level for equity using discounted cash flows. The approach aligns with the methodology developed by the European Central Bank (Alogoskoufis *et al.*, 2021; Emambakhsh *et al.*, 2023) for the credit space. For our projection of prices, outputs, GHG emissions, direct and indirect costs, we use the MIT's Economic Projection and Policy Analysis (EPPA) applied for the Bank of Canada scenarios[2] that are consistent with scenario storylines proposed by the Network for Greening the Financial System (NGFS). The 2023 MIT Global Change Outlook that assesses [3] the future of the Earth's energy, managed resources (including water, agriculture and land), and climate, as well as prospects for achieving the Paris Agreement's short-term targets (as defined by Nationally Determined Contributions, or NDCs) and long-term goals of keeping the increase in the average global temperature below 2°C or even stabilizing at 1.5°C. In this paper, we use these updated projections and adjust them to be in line with the NGFS narratives regarding orderly and disorderly transition pathways.

The paper is structured as follows. Section 2 presents the methodology and the integrated assessment model used, presents the storyline scenarios and details the steps to downscale the output of macroeconomic model to the company level. We also present the financial valuation approaches to estimate the impact on equity and bonds securities. Section 3 presents the results for the companies in the MSCI World Index and Section 4 concludes.

[1] These studies prioritize financial interconnectedness over real economy dependencies, such as materials, resources, or fuel flows. The level of interconnectedness being modeled by the pass-through parameter which represents the proportion of a direct shock being transmitted to the rest of the economy.

[2] Available at: https://www.bankofcanada.ca/2022/01/climate-transition-scenario-data/.

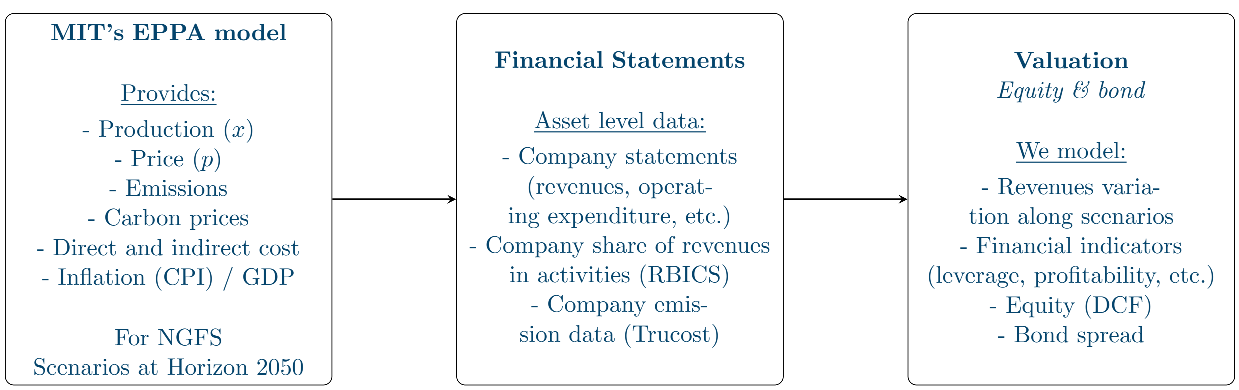
[3] Available at: https://globalchange.mit.edu/publications/signature/2023-global-change-outlook.

2 Top-down stress-testing methodology

The framework of the scenario based stress-test introduced in Le Guenedal *et al.* (2023) can be decomposed in three major blocks (see Figure 1). First, the scenarios are designed with Integrated Assessment Models (IAMs). While many IAMs can produce the global scenarios, the Economic Projection and Policy Analysis (EPPA) model presents several major advantages in the context of stress-testing: (*i*) it provides sector and country granularity, (*ii*) it can be applied to assess different types of policies, such as emissions constraints, carbon prices, border adjustments, subsidies, fuel standards, and others (*iii*) it explicitly calculates sectoral revenues, direct and indirect costs per sectors and countries (Chen *et al.*, 2022a, 2023); (*iv*) it considers advanced energy and industrial technologies and (*v*) it integrates the data from the global trade analysis project (GTAP) that represents sectoral international trade flows (Chen *et al.*, 2022b).[4]

In the second component, we incorporate sectoral projected variations, and adjust them to the company level using both structural and autoregressive (AR) models. These autoregressive projections can be influenced by either macroeconomic factors such as CPI, VAT, GDP, etc., or company-specific factors like carbon intensity (defined in equation 9). The third component focuses on pricing how stock value and default is likely to be impacted by transition risk. We integrate more detailed company-specific financial data, including cost of debt, equity, and corporate tax rates, etc. As discussed in the paper, we have the flexibility to extend specific data integration.

Figure 1: MIT's Economic Projection and Policy Analysis based Stress-testing framework



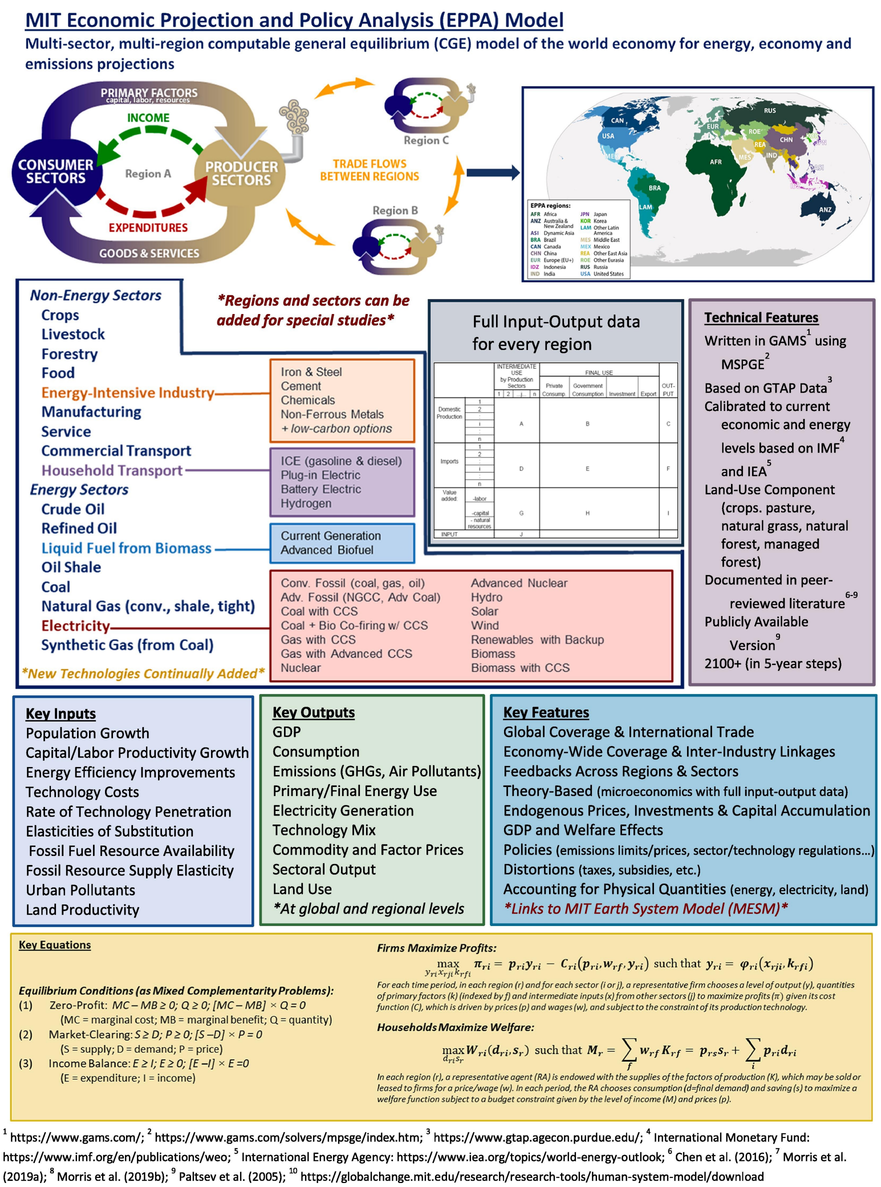
2.1 The EPPA model transition scenarios

The EPPA (Economic Projection and Policy Analysis) model, developed by the MIT Center for Sustainability Science and Strategy (formerly MIT Joint Global Change Program), serves as a tool for understanding the relationships between economic activity and greenhouse gas emissions. This multi-regional, multi-sectoral general equilibrium model enables detailed

[4]Another interesting feature is short-term applicability and regional breakdown in Europe, also available in other models, for instance NiGEM (Allen *et al.*, 2023).

analysis of how various sectors and regions interact, allowing for comprehensive forecasting of emissions in response to economic growth, technological advancements, and policy interventions. By integrating scientific insights on climate change and climate policies, the EPPA model produces future emissions pathways and evaluates the economic impacts of diverse climate policies, such as carbon taxes, technology subsidies, and cap-and-trade systems. Its dynamic framework facilitates long-term projections, making it an attractive resource for policymakers and researchers seeking to navigate the complexities of climate strategy and its implications for global economies. This model can be used for testing several '*what-if*' scenarios and manage strategic allocation accordingly.

Figure 2: Schematic of the EPPA model



Source: Gurgel *et al.* (2023)

As illustrated in Figure 2, EPPA modeling divides the world into 18 different regions (Africa, Australia and New Zealand, Dynamic Asia region (excluding: Japan, India and China that are represented separately), Brazil, Canada, China, Europe, India, Japan, Korea, Indonesia, Latin America (excluding: Brazil that is represented separately), The Middle East, Mexico, Other East Asia, Other Eurasia, Russia and the United States of America). It also accounts for 22 different sectors of activity (Coal, Crop, Ownership of dwellings, Products (metals, pharmaceuticals, chemicals...), Renewables, Food, Forestry, Gas, Live (animals, milk, wool...), Oil, Other (other manufacturing, woods, minerals), Roil (petroleum and coal products), Services and Transportation).

Transition Scenarios We project economic variables in these 18 regions and 22 sectors and scale the projection at the company level according to 5 different NGFS-like scenarios matching different objectives of reduction of emissions.

Current Trends (Baseline) The present study updates the current trends scenario from Le Guenedal et al. (2023) to the corresponding projection from the MIT Global Change Outlook 2023. By 2060, over half of IGSM's [5] Current Trends projections (based on the uncertainty in the climate system) exceed 2°C warming, rising to 75% by 2070 and 95% by 2090. By 2100, 95% indicate at least 2.2°C warming, with a median of 2.8°C. After 2050, all projections surpass 1.5°C, and by mid-22nd century, warming reaches at least 2.9°C, with a median of 3.8°C and a maximum of 4.6°C.

Global primary energy use in the Current Trends scenario grows to about 650 exajoules (EJ) by 2050, up by 15% from about 560 EJ in 2020. The share of fossil fuels drops from the current 80% to 70% in 2050. Variable renewable energy (wind and solar) is the fastest growing energy source with more than an 8.6-fold increase in 30 years. In the Current Trends scenario, global electricity production (and use) grows by 73% from 2020 to 2050. In comparison to primary energy growth of 15% over the same period, electricity consumption grows much faster, resulting in a continuing electrification of the global economy. Generation from variable renewables exhibits the fastest growth (see Global Primary Energy, above). EPPA7 modeling projects a rather stable crude oil price, with a five-year average of around USD 75/barrel. Global oil consumption also remains fairly stable. Global GHG emissions in the Current Trends scenario stay relatively constant, initially increasing from about 47 gigatonnes of CO2equivalent (Gt CO2e) in 2020 to about 48 Gt CO2e in 2030, and then gradually decreasing to about 45 Gt CO2e in 2050 due to policies in countries with more stringent emissions targets.

Accelerated Actions (1.5°C with an overshoot) In the Accelerated Actions scenario of the MIT Outlook 2023, global primary energy consumption declines after 2025 due to price- and policy-driven energy-efficiency measures, and reaches about 430 EJ in 2050. The share of low-carbon energy sources grows from 20% in 2020 to slightly more than 60% in 2050, a much faster growth rate than in the Current Trends scenario. Wind and solar energy in the Accelerated Actions scenario undergo more than a 13.3-fold increase. In the

[5] Integrated Global System Modeling (IGSM) framework consists of the Economic Projection and Policy Analysis (EPPA) model and the MIT Earth System Model (MESM), that is a linked set of computer models to analyze interactions among human and Earth systems.

Accelerated Actions scenario, global electricity production grows even faster, rising by 87% between 2020 and 2050. More ambitious climate policies lead to a larger growth in variable renewables. In the Accelerated Actions scenario, this trend is changed by a decrease in oil demand after 2030. The oil price declines from about USD 75/barrel by 2025 to USD 60/barrel in 2050, a 20% reduction. In this scenario, global oil consumption drops from about 190 EJ in 2025 to about 105 EJ in 2050. In the Accelerated Actions scenario, global GHG emissions follow the same path as in the Current Trends scenario until 2025, and then more aggressive policies reduce them to 18 Gt CO2e by 2050, a 62% decrease relative to 2020.

Net-Zero 2050 (1.5°C) with limited BECCS: An alternative scenario, where deployment of limited access to carbon dioxide removal technologies is limited. Uncertainties in CCS technologies cost and availability and their public acceptance.

Below 2°C immediate (orderly): In this scenario, starting in 2020, collective global action is taken to reduce emissions with the goal of keeping temperatures below 2°C by 2100. Early investments, planning, and management enable forests to become a small net sink by mid-century. The pace of technological change is moderate, and the availability of CDR technologies is limited in line with NGFS reference scenario.

Below 2°C delayed (disorderly): This scenario follows the Current Trends trajectory up to 2030, and then collective global action is imposed to align with a 2°C target by 2100. A steeper transition is needed to compensate for the additional decade of continued emissions growth. Delayed investments, planning, and management prevent forests from becoming a net sink by mid-century. The pace of technological change is moderate, and the availability of CDR technologies is limited.[6]

Carbon price Carbon prices reflect the emission constraints imposed by governments on CO2 equivalent emissions to fight global warming. Carbon pricing affects companies around the world, public institutions and households (either directly or indirectly). Carbon pricing (emission constraints) can be set locally at the country level, or globally. The scenarios compared in Table 1 have all in common that the transition is enabled through direct carbon pricing, i.e. imposing a penalty on fossil fuel intensive sectors (that applies to the amount of CO2 they emit). These penalties affect the behavior of consumers and producers, who adapt their consumption choices, output prices and levels of production.

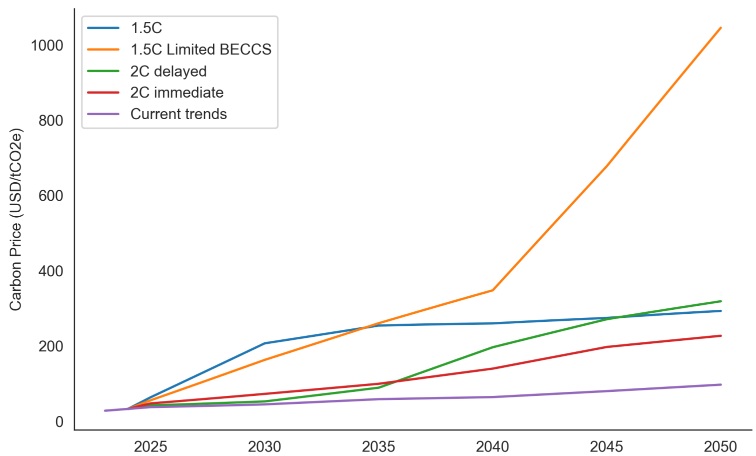
Figure 3 presents the evolution of the carbon price, by year and scenario as calculated by the EPPA model. The chart projects carbon prices (USD per ton of CO2) from 2025 to 2050, highlighting significant differences driven by climate action. The 1.5°C scenario sees prices rise to around USD 300 by 2050, while the 1.5°C Limited BECCS scenario peaks above USD 1000. Nevertheless, in the near term, the two scenarios yield comparable outcomes with regard to the carbon price. In the 2°C Delayed scenario, the carbon price also surpasses

[6]Exceeding this 2°C limit could lead to severe and irreversible damage to natural and human systems, with particular vulnerability for small island nations and low-lying coastal areas. Keeping temperatures within this range would still entail significant environmental changes, but it is considered achievable if there is a rapid transition to renewable energy, sustainable practices, and technological innovations in carbon capture.

Table 1: Comparison of Climate Scenarios

Scenario	**T°C in 2100**	**Key Features**	**Energy Use & Emissions**
Current Trend (Baseline)	~3.2°C	• Follows pre-2019 climate policies • Slow technological change • Limited availability of CDR technologies	• Global primary energy use: 650 EJ by 2050 (up 15% from 560 EJ in 2020) • Fossil fuel share: 80% in 2020 to 70% by 2050 • GHG emissions: 47 Gt CO2e in 2020 to 45 Gt CO2e in 2050
Net-Zero 2050	1.5°C	• Collective global action from 2020 • Strong early actions enable forests to become a net sink by mid-century • Fast technological change and moderate availability of CDR technologies	• GHG emissions reduction to 18 Gt CO2e by 2050 (62% decrease from 2020) • Oil demand decreases after 2030 • Low-carbon energy sources grow significantly
Accelerated Actions	1.5°C	• Global primary energy consumption declines after 2025 • Rapid growth of low-carbon energy sources • Significant increase in wind and solar energy • Decrease in oil demand and price	• Global primary energy: 430 EJ by 2050 • Low-carbon energy share: 20% to 60% by 2050 • GHG emissions follow Current Trends until 2025, then decrease to 18 Gt CO2e by 2050
Net-Zero 2050 with limited BECCS	1.5°C	• Limited access to carbon dioxide removal technologies • High costs and operational challenges • Uncertainties in biomass supply	• Similar to Net-Zero 2050, but with more constraints on CDR technologies
Below 2°C Immediate (Orderly)	<2°C	• Collective global action from 2020 • Early investments enable forests to become a small net sink by mid-century • Moderate technological change and limited availability of CDR technologies	• GHG emissions reduction aligned with orderly transition
Below 2°C Delayed (Disorderly)	<2°C	• Action begins after 5 years of current policies • Steeper transition needed due to delayed action • Moderate technological change • Limited availability of CDR technologies	• GHG emissions initially grow, then require rapid reduction to meet targets

Figure 3: Carbon price trajectories in transition scenario (weighted average)



Source: MIT EPPA Model

USD 300 by 2050, whereas the 2°C Immediate scenario also exhibits a price trajectory that remains approximately USD 200. In contrast, the Current Trends scenario remains mainly flat, starting near USD 50 and only reaching about USD 100 by 2050. These figures underscore the critical importance of timely climate policies, as proactive measures may lead to significantly lower carbon prices compared to delayed actions when both scenarios are set to reach the same ultimate target.

2.2 Modeling the impact on financial statements

Macroeconomic signals from Integrated Assessment Model (IAM) We detail and extend the mechanisms of the method introduced in Le Guenedal *et al.* (2023). For each sector i, region r, scenario φ, and year t, the model provides the results for:

$$\begin{aligned}
\text{Revenues}_{t,i,r,\varphi} &= p_{t,i,r,\varphi} \times x_{t,i,r,\varphi} && (1)\\
\text{Carbon Costs}^{Direct}_{t,i,r,\varphi} &= \text{Emissions}_{t,i,r,\varphi} \times \text{Carbon Price}_{t,i,r,\varphi} && (2)\\
\text{Carbon Costs}^{Indirect}_{t,i,r,\varphi} &= \sum_j \Delta p'_{t,i,r,\varphi} \times Z_{t,i,j,\varphi} && (3)\\
&= \text{Emissions}_{t,i,r,\varphi} \times \text{Carbon Price}_{t,i,r,\varphi} \times Z_{t,i,r,\varphi} &&\\
&\sim \text{Indirect Emissions}_{t,i,r,\varphi} \times \text{Carbon Price}_{t,i,r,\varphi} && (4)
\end{aligned}$$

where $p_{t,i,r,\varphi}$ and $x_{t,i,r,\varphi}$ are respectively the unitary price of output and the production output of sector i obtained from the EPPA model for a particular scenario. The indirect costs reflect all intermediate inputs (i.e., all inputs excluding capital and labor) from supplying sectors j in production of sector i, with $p'_{t,i,r,\varphi}$ denotes the carbon-penalty-inclusive price paid by sector i for goods from sector j at time t in scenario φ and $Z_{i,j,\varphi,t}$ denotes the amount of transactions between sector j and sector i at time t in scenario φ from the Global Trade Analysis Project. These intermediate inputs are calculated by the EPPA model.

Capital expenditures (CapEx) is the amount of money a corporate entity spends to buy, maintain, or improve its fixed assets, such as buildings, vehicles, equipment or land. Within the EPPA model, the dynamics of investment over time are driven by the additional investment required by existing and new technologies. For example, capital may be invested in lower-emitting sources of electricity, or in the removal and decommissioning of fossil fuel plants. CapEx does not appear directly on the balance sheet for the income computation but can be subtracted from future Free Cash Flows. In the EPPA model, the capital expenditures (CAPEX) are computed as follows:

$$\text{Capital expenditure}_{t,i,r,\varphi} = \text{Capital price}_{t,i,r,\varphi} \times \text{New capital added}_{t,i,r,\varphi} \tag{5}$$

The projected amount includes all the new capital added in the sector and in a given region, and not only capital that is used for decarbonization. The difference between the sectoral revenue and a sum of direct and indirect costs equals to the sectoral value-added, $VA^t_{i,\varphi}$:

$$\begin{aligned}\text{Value Added}_{t,i,r,\varphi} &= \text{Revenues}_{t,i,r,\varphi} \\ &\quad - \text{Carbon Costs}^{Direct}_{t,i,r,\varphi} - \text{Carbon Costs}^{Indirect}_{t,i,r,\varphi}\end{aligned} \tag{6}$$

The EPPA model also calculates the changes in consumer price index (CPI) inflation in different scenarios. CPI is calculated in the EPPA model as a price of consumption (final consumption goods), by a representative consumer in each region. Changes in CPI are endogenously calculated by the model based on the economic growth, changes in relative prices, resource depletion, productivity changes and other factors. To simplify the representation in the current paper, we do not introduce CPI projection in the modeling of the different variables.

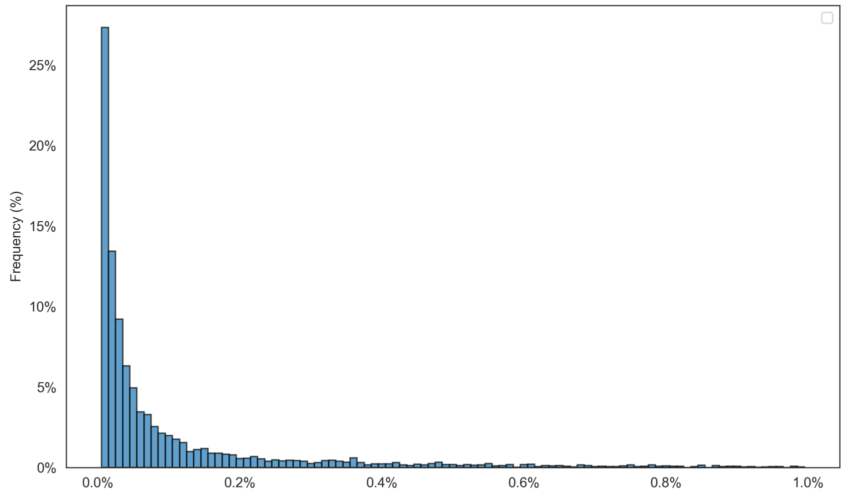
Sector and regional activity allocations To downscale sectoral variables calculated by the EPPA mode to company level, we allocate company-specific emissions in the following way. For an issuer (company) k in sector i in country r, we determine carbon emissions contribution as:

$$\alpha_{k,i,r} = \frac{\text{Issuer Revenues}_{k,i,r}}{\text{Total Revenue}^{EPPA}_{i,r}} \tag{7}$$

$$= \frac{\text{Issuer Carbon Emissions}_{k,i,r}}{\text{Total Carbon Emissions}^{EPPA}_{i,r}} \quad \text{if} \quad CI_{i,r} \text{ is constant} \tag{8}$$

where α represents the contribution of the issuer k to the total carbon emissions in an EPPA sector i and region r. This supposes that all issuers have the same carbon-equivalent intensity $\mathcal{CI}(i,r)$ when operating in a given sector, in a given region. The distribution of this metric is represented in Figure 4. While the majority of companies represents only a negligible proportion of the total activity in one sector and country, a selected few have a ratio approaching 100%.

Figure 4: Illustration of company contributions in sector/region activities $\alpha(k, i, r)$



Note: For visualization purposes, we focus on contributions between 0.01% and 1% on this chart. Most companies inherit less that 0.2% of the total costs in one activity and region. Average contribution over the whole MSCI World is 0.13%.

To construct company-level carbon emissions distributions, we need to map the breakdown of activities of each issuer to different sectors and regions. The process is based on multiple steps, allowing an advanced representation of company activities, with for example details of its revenues repartition by sector and region. First, we retrieve company level information on sectoral revenues using the FactSet Revere Business Industry Classification System (RBICS), which provides a highly granular description of the activity breakdown for investors. This breakdown is also available on companies annual report and / or 10K.

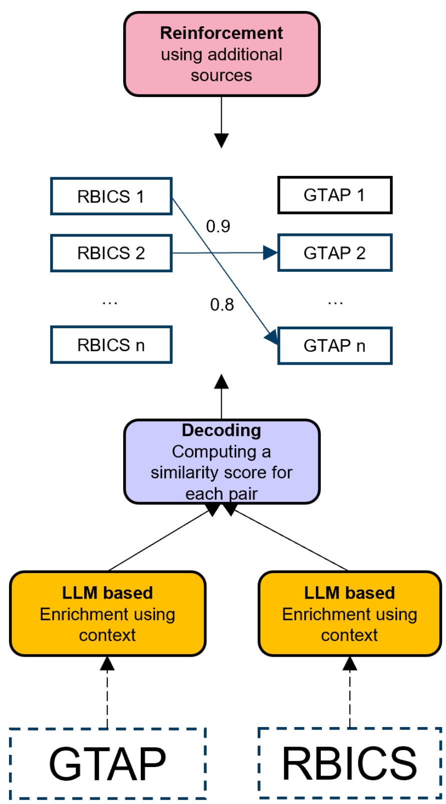
For a subset of 6 000 companies that have been studied specifically for the current paper out of a larger set of almost 200K companies (available in RBICS), the combination of the reported '*business segment*' and RBICS level 6 activity classification and description lead to millions possible different activities for a large universe of companies (c.f. Table 11 in the appendix), since we can have a RBICS level 6 activity for each sector/country/revenue split where the company operates. To map these vast number of instances to the Global Trade Analysis Project (GTAP) sectors (which, in turn, are mapped to EPPA in Chen *et al.*, 2022b), it is necessary to project the embedding of all the descriptions and to identify the optimal matches. We use a cosine similarity measure of the numeric transformation of the descriptions of RBICS on one side and of GTAP on the other side and keep the correspondence where the distance is smallest. This is an initial approach to associating each RBICS description of each company's revenue fraction with the relevant EPPA sector, given that EPPA is based on GTAP. [7]

The results of this first guess step are mostly satisfactory, although some allocations can

[7]We use state of the art open-ai incrustation model illustrated in Figure 5

be somewhat complex. For example, “uranium extraction” RBICS L6 description could be both allocated to “other materials” and “metals extraction”, or to “nuclear energy” GTAP descriptions. Moreover, for some sectors the energy mix is not properly specified (e.g. Europe Mixed Wholesale Power, Global Energy Utilities, etc.). In order to reduce the error due to wrong matching, we add to the matching additional sources of information: European commission taxonomy for eligible revenues share, Trucost breakdown of emissions and company reports accounting. Multiplying the sources of revenue breakdown for companies allows to reduce the uncertainty of matching company metrics by sector and region to the proper EPPA sector/region.[8]

Figure 5: Embeddings based semi-automatic sectoral allocation between RBICS and GTAP



At a second level, geographic information is available in RBICS (c.f. Table 10 in the appendix). Nevertheless, the geographical description of revenues is not aligned with that of EPPA’s region (c.f. Table 12 in the appendix). If the activity is mapped to several regions, not reported or to ‘*international*’ activity (for multinational companies), we introduce a geographic allocation of revenues from Factset GeoRev. Consequently, we distribute the

[8]Figure 21 in the appendix describes the process. We start with an embedding algorithm based on similarity distance between GTAP sectors and RBICS sectors. For low similarities scores and energy or utilities companies, we update the repartition using energy mix information. For companies that present EU Taxonomy metrics, we check using company reports that the new breakdown improves the one coming from the previous steps. The reason not to trust fully each data source comes from the hardness to extrapolate emissions from specific activities, recency of the source, etc.

sub-sectors in different regions where the company operates, in accordance with the global repartition of each sub-sector worldwide. For example, if we only have sectoral repartition of the activities of company A, we break down each activity according to its worldwide repartition.[9] In the absence of information regarding the geographic distribution of the company's activities, we utilise a proxy, namely the geographic breakdown of the companies that are most similar to the one under study. Dividing the revenues share of companies in EPPA sector i and region r allows us to define the carbon emissions contribution (c.f. Eq. (8)).

Direct emission and first-tier indirect correction The direct emissions (Scope 1) and activity in Le Guenedal *et al.* (2023) are defined as:

$$\text{Activity Carbon Emissions}_{k,i,r}^{computed} = \theta_{k,i,r} \times \text{Revenues}_k \times \text{Carbon Intensity}_{i,r}^{EPPA}$$

where $\theta_{k,i,r}$ is the fraction of revenues of company k in EPPA activity i in region r, Revenues_k are the total revenues. Carbon Intensity for each sector x region $\mathcal{CI}(i,r)$ is defined in a top-down fashion as:

$$\text{Carbon Intensity}_{i,r}^{EPPA} = \frac{\text{Carbon Emissions}_{i,r}^{EPPA}}{\text{Revenues}_{i,r}^{EPPA}} \tag{9}$$

Using EPPA implicit carbon intensities of activities (dividing sector emissions by revenues in 2020 in each region), we have an equivalence between emissions and activity. However, this representation does not take into account the difference of carbon emissions intensity among companies.

Thus, we correct direct emission using reported emissions from Trucost to have a more accurate representation of companies intensities (for this we can use direct, indirect or first tier indirect emissions which are all likely to generate costs for companies). The total modeled emissions of the company k follows:

$$\text{Carbon Emission}_k^{computed} = \sum_{i,r} \text{Activity Carbon Emission}_{k,i,r}^{computed} \tag{10}$$

we define the error ratio as:[10]

$$\varepsilon_k = \frac{\text{Carbon Emission}_k^{computed}}{\text{Carbon Emission}_k^{reported}} \tag{11}$$

where $\text{Carbon Emission}_k^{reported}$ are reported scope 1 emissions in Trucost (direct or direct and first tier indirect emissions). The direct and indirect costs associated to each company activity at initial state are scaled with these corrected carbon emissions. To limit the impact

[9] In our graphic representations, to have a country level projection of revenues, we downscale our variables using each country's contribution in terms of GDP in its region. This is particularly evident in Europe, which contributes significantly to market capitalization and revenues. This enables more precise identification of the roles of France, Germany and England.

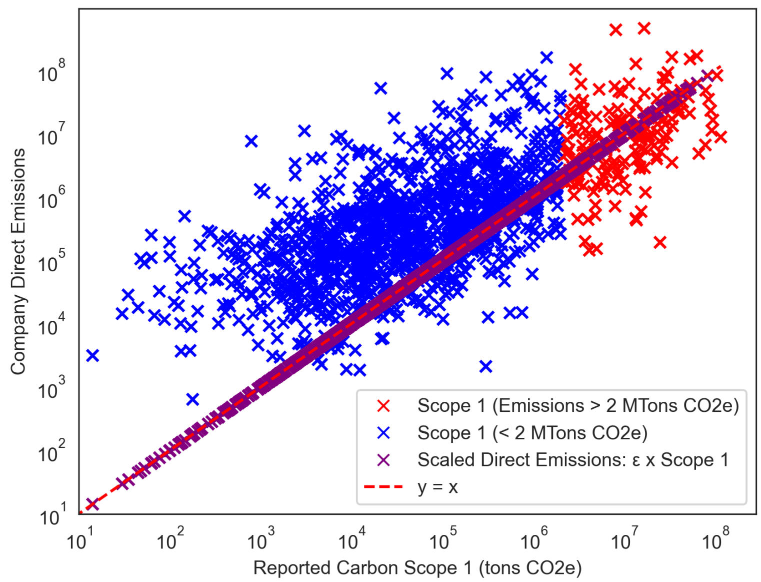
[10] We reiterate Table 5 on page 34 (ssrn version), where this ratio was called specific carbon intensity (Spe. CI).

of reported carbon data on the scaling of the cost per activity, we control sector-specific estimation errors, as illustrated in Figure 6. The proposed correction allows for the scaling of the initialization cost at the level of disclosed scope 1 emissions. We then compute each company's contribution to the evolution of the sector emissions using the updated contribution ratio:

$$\hat{\alpha}(k,i,r) = \underbrace{\frac{\text{Carbon Emission}_k^{computed}}{\text{Carbon Emission}_k^{reported}}}_{\text{Company intensity correction factor}} \times \alpha(k,i,r) = \varepsilon_k \times \alpha(k,i,r)$$

where the total contribution (that will determine the cost burden) of the companies are scaled according to their global intensity.

Figure 6: Direct emissions correction illustration (log scale)



Note: the Scope 1 Estimation on the y axis is based on the carbon intensity assumed by MIT EPPA model per activity, and companies revenues share. Scope 1 on x axis are reported by companies (and potentially corrected by Trucost).

As shown in Figure 6 largest emitters (above 2 million tons of CO2e) are mostly located below the scaled y=x axis, while lower emitters are located mainly above the axis, illustrating that companies have different intensity profiles as compared to the average reference universe.

Projection of financial statements Once a mapping has been established between the breakdown of revenues of each company by sector and country and the corresponding allocation in EPPA7, the financial statements of the companies can be projected over time. This will provide insight into their future behavior in relation to transition scenarios. For $t > t_0$, we use EPPA7 projections such as, for a specific company k:

$$\begin{aligned}\text{Total Assets}_{t,k,\varphi} = \beta_{1a} \cdot \text{Total Assets}_{t-1,k,\varphi} + \beta_{2a} \cdot \log(\text{GDP}_{t,\varphi}) \\ + \beta_{3a} \cdot \text{Inflation}_{t,\varphi}\end{aligned} \tag{12}$$

For revenue projection, we use the following framework:

$$\text{Revenues}_{t,k,\varphi} = \text{Revenues}_{t-1,k,\varphi} \times \sum_{a,r} \theta_{a,k,r} (1 + \delta_t \text{Revenues}_{t,(a,r)\sim(i,r),\varphi}) \tag{13}$$

where revenues and inflation temporal variation are computed with geometric differences (e.g. $\delta_t X = \frac{X_t}{X_{t-1}}$) between time steps deduced from EPPA's trajectories. The subscripts $(a,r) \sim (i,r)$ denotes the activity a of the company mapped to EPPA sector i in region r. θ follows the previous notation to embody the breakdown of revenue of each company by sector.[11]

This projection offers several advantages. Primarily, it allows for the incorporation of inflation and revenue projections within a framework that permits the integration of multiple, non-concurrent anticipations of future sales for each company. Additionally, it enables the anticipation of shifts in the revenue breakdown, reflecting the comparative growth of each sector in any given projection scenario.

Operating expenditure (OPEX) refers to the ongoing costs involved in the day-to-day functioning of a company. These expenses are necessary for maintaining operations and include costs such as salaries, rent, utilities, and maintenance. Unlike capital expenditures, which are long-term assets, operating expenditures are typically fully deductible in the year they occur. Most of these costs are not dependent on transition policies (salaries, rental, equipment, inventory costs, etc.), even though fuel expenses, for example are sensitive to transition. Costs trajectories associated with transition scenarios proposed by the EPPA7 model are also included in the computation of the total operating expenditures:

$$\begin{aligned} \text{Opex}_{t,k,\varphi} &= \text{Other Opex}_{t,k,\varphi} \\ &+ \sum_{a\sim i,r} \left[\text{Carbon Costs}^{Direct}_{t-1,k,\varphi,i,r} + \text{Carbon Costs}^{Indirect}_{t-1,k,\varphi,i,r} \right] \\ &+ \sum_{a\sim i,r} \hat{\alpha}_{k,i,r} \times \left(\Delta_t \text{Carbon Costs}^{Direct}_{t,k,\varphi,i,r} + \Delta_t \text{Carbon Costs}^{Indirect}_{k,t,\varphi,i,r} \right) \\ &= \text{Other Opex}_{t,k,\varphi} + \left[\text{Carbon Costs}^{Direct}_{t,k,\varphi,i,r} + \text{Carbon Costs}^{Indirect}_{t,k,\varphi,i,r} \right] \end{aligned} \tag{14}$$

where:

$$\text{Carbon Costs}^{Direct}_{t,k,\varphi,i,r} = \text{Carbon Costs}^{Direct}_{t-1,k,\varphi,i,r} + \sum_{a\sim i,r} \hat{\alpha}_{k,i,r} \times \left(\Delta_t \text{Carbon Costs}^{Direct}_{t,k,\varphi,i,r} \right)$$

$$\text{Carbon Costs}^{Indirect}_{t,k,\varphi,i,r} = \text{Carbon Costs}^{Indirect}_{t-1,k,\varphi,i,r} + \sum_{a\sim i,r} \hat{\alpha}_{k,i,r} \times \left(\Delta_t \text{Carbon Costs}^{Indirect}_{t,k,\varphi,i,r} \right)$$

The direct and indirect carbon costs variations Δ_t for sector i in region r (in which belong issuer k) are computed with arithmetic variations (e.g. $\Delta_t X = X_t - X_{t-1}$) distributed propor-

[11] Note that additional fundamental variables and revenues lags can be taken into account in projecting company revenues through time. They can be generalized to any information (news, company report, due diligence, background checks, etc.) as well as external factors (inflation, sector dynamics) that can be taken into account to build a more accurate projection of future revenues. Complete modeling goes beyond the objectives of the current paper.

tionally to the share of activity (corrected by the company level intensity factor), $\hat{\alpha}(k,i,r)$.[12] This approach ensures that both direct and indirect costs are allocated to agents operating within sector and region in a proportional fashion, based on their individual contributions. [13]

Indeed, most companies operate in several activities, the computation of the direct and indirect costs are performed for each segment and then aggregated at the company level. The estimation of carbon-related operating expenditures associated to each sub-activities also is determined with their revenues share $\theta_{a,k,r}$. The estimation of remaining other costs are made at the company level subtracting direct and indirect costs implied by the baseline (or any scenarios) in the base year.[14]

The net income[15] (also known as earnings) and profitability follow:

$$\text{Net Income}_{t,k,\varphi} \approx \text{EBITDA}_{t,k,\varphi} = \text{Revenues}_{t,k,\varphi} - \text{Opex}_{t,k,\varphi} \tag{15}$$

$$\text{Profitability}_{t,k,\varphi} = \frac{\text{Net Income}_{t,k,\varphi}}{\text{Total Assets}_{t,k,\varphi}} \tag{16}$$

Free cash flow (FCF) is a financial metric that measures the amount of cash generated by a company after accounting for capital expenditures necessary to maintain or expand its asset base. It represents the cash available for distribution to the company's investors, such as shareholders and debt holders, or for other purposes like paying dividends, reducing debt, or reinvesting in the business.[16] Ultimately, analysts use it to value companies. The modeling of free-cash flows (FCF), is based on the assumption that earnings are good predictors of

[12]Total transition costs are distributed among companies assuming direct costs, associated with direct emissions pricing mechanisms, and indirect costs, passed-on from the supply-chain, are accounted for in the costs of product sold. In practice, carbon taxes are mostly associated with costs of fuels paid at their acquisition. The cost of fuels is a purchase price, including customs duties and other non-recoverable taxes. Indirect costs affect other purchases and are therefore part of the operating expenditures.

[13]We introduce a subsequent correction ratio to increase the cost burden of more intensive companies, and reduce those of companies with lower direct carbon intensity.

[14]We have:

$$\text{Other Opex}(2023) \sim \text{Total Opex}(2023) - [\text{Direct Costs}(2023) + \text{Indirect Costs}(2023)]$$

and other costs are maintained constant in this stress-test. They can be influenced by external parameters such as the size of the companies, its revenues or macroeconomic factors like GDP.

[15]We make the approximation in the current paper that net income is equivalent to EBITDA. In practice, one has to add interest, taxes, depreciation and amortization.

[16]FCF can either refer to FCFF (Free Cash Flow to Firm) or FCFE (Free Cash Flow to Equity). In the current paper we use the FCFF approach which is most natural in long term projection as we want to exclude the impact of interest expense and repayments.

$$\text{FCFF} = \text{FF\_OPER\_CF} - \text{FF\_CAPEX\_FIX} + [\text{Interest Expenses (Net of Interest Capitalized)} \times (1 - \text{Tax Rate})]$$

where FF_OPER_CF is the Net Cash from Operating Activities and FF_CAPEX_FIX are Capital Expenditures Fixed Assets Capex future cash-flows (Nallareddy *et al.*, 2018). It can be written (Francis *et al.*, 2000):

$$FCF_{t,k,\varphi} = (\text{Net Income}_{t,k,\varphi} - \text{Depr}_{t,k,\varphi}) \times (1-\tau) + \text{Depr}_{t,k,\varphi} - \Delta WC_{t,k,\varphi} - \text{CAPEX}_{t,k,\varphi} \quad (17)$$

Simplified as:

$$FCF_{t,k,\varphi} \sim \text{Net Income}_{t,k,\varphi} - \text{CAPEX}_{t,k,\varphi} \quad (18)$$

ΔWC is the variation of working capital is each period's beginning working capital minus ending period working capital, which can be defined as operating current assets minus operating current liabilities. Should a company experience an increase in its Net Working Capital year-on-year, this would indicate that either its operating assets have grown or its operating liabilities have declined in comparison to the previous period. An increase represents and outflow of cash, diminishing the corresponding Free Cash Flow. [17]

The VAT (τ) is introduced as control and will not differ from one scenario to another. Thus it should not impact the level of transition risk between companies.[18] Table 9 reiterate all the financial statements that are modeled for the companies in the transition scenarios following EPPA model sensitivities. [19] The capital expenditure (CAPEX) is also scaled at company level with the same downscaling formulas than the ones created for revenues:

$$\text{CAPEX}_{t,k,\varphi} = \text{CAPEX}_{t-1,k,\varphi} \times \sum_{a,r} \theta_{a,k,r}(1 + \delta_t \text{CAPEX}_{t,(a,r)\sim(i,r),\varphi})$$

2.3 Financial valuation and investment guide modeling

In this section, we present valuation ratios and investment guide modeling. We model variations of discounted cash flows and probability of default in scenarios of interest.

2.3.1 Equity valuation

Discounted cash-flows Equity is particularly sensitive to investors perception of future cash flows, that are discounted using the Weighted Average Cost of Capital (WACC), to build a unique indicator per scenario. WACC is a metric that calculates a company's cost of capital, taking into account the relative weights of each component of the capital structure, which typically includes debt and equity. WACC represents the average rate of return a company is expected to pay its security holders to finance its assets. The rational of introducing asset specific WACC is to account for company specific measure of market riskiness. The WACC is computed as follows:

$$WACC = \frac{E}{E+D} \times R_E + \frac{D}{E+D} \times R_D \times (1-\tau) \quad (19)$$

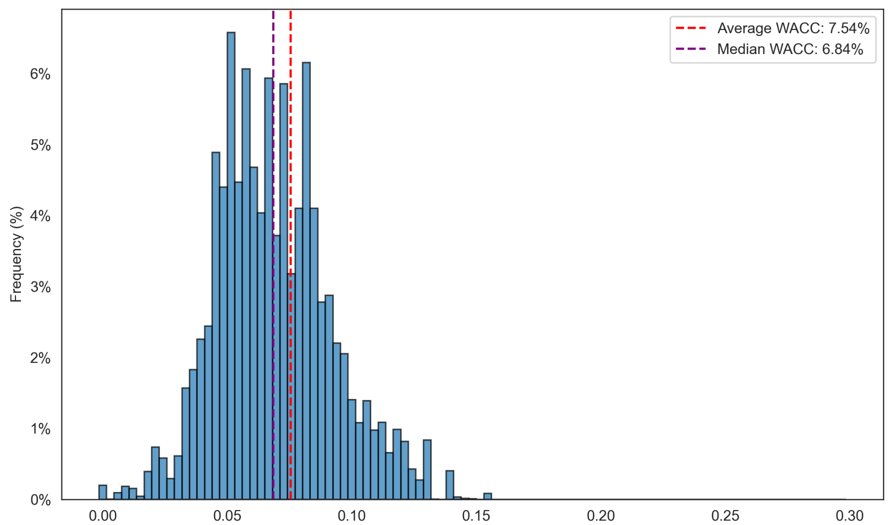
[17] In the current paper, given the time horizon we are working with, delta working capital are neglected.

[18] The Table 13 to 15 in the appendix justifies this simplifying choice, as we can observe high adjusted Rsquare using net income as single predictor ~ 60%.

[19] Table 9 in the appendix summarizes the transmission channel of the macroeconomic modeling from EPPA, to the company financial statement and valuation ratios.

where E is the equity value (last market cap), D is the debt (last total debt) retrieved from the financial statements of the company. [20] It is important to note that the calculation of beta will significantly impact the results when using the CAPM model to compute the Weighted Average Cost of Capital (WACC) for the selected companies. For example, the values of the WACC are provided Figure 7 for companies in the MSCI World Index.

Figure 7: WACC distribution of companies within the MSCI World Index



In general, there are several modeling options for the WACC (e.g. Constant WACC, Leverage adjusted, Sectoral, etc.). Specific calibration is presented in Le Guenedal *et al.* (2023). The application of the leverage-adjusted formula (presented above) with asset-specific betas fixed at 1 in the cost of equity and the same risk-free rate assumption yields substantially different WACC values (though these remain globally concentrated between 3-10%, c.f. Figure 7). Notably, the median value approximates the market-cap-weighted average WACC depicted in the graph. This is due to the fact that some large companies have a small amount of debt, and therefore a much higher WACC than the rest of the universe, due to the financing using the equity part of their capital structure. Although the model of asset level WACC is particularly sensitive to parametric uncertainties, it allows to capture country specific effect or differences in companies leverage.

This method is deemed more consistent as it accounts for the share of debt and other company-specific factors (cost of debt, beta, ERP) in the pricing of companies. Discounted Cash Flow (DCF) is a widely adopted valuation method for estimating an investment's intrinsic worth by projecting its future cash flows and discounting them to their present

[20] $R_E = R_f + \beta \times ERP$ with R_f, the risk free rate (e.g. yield of government bonds with maturity of 10 years issued by the country where the company is based or a broader region), β represents the risk of an investment relative to overall market, ERP is the equity risk premia, we use the value from Damodaran (Damodaran *et al.*, 2013; Damodaran, 2019), and aggregate them at the European level. R_D is the cost of debt obtained from corporate credit rating, τ is a corporate tax rate from Damodaran *et al.* (2013) and Damodaran (2019).

value. The discount rate used in DCF analysis typically reflects the investment's risk profile and incorporates the time value of money, thereby providing a more accurate measure of the investment's real worth over time:

$$DCF(t,k,\varphi) = \sum_{s=2023}^{\infty} \frac{FCF_{s,k,\varphi}}{(1+WACC)^{(s-t)}} \tag{20}$$

Investment guide ratios We compute the equity valuation ratio in scenario φ as:

$$\pi_{t,E,\varphi} = \frac{DCF_{t,k,\varphi}}{DCF_{t,k,\text{baseline}}} \tag{21}$$

That represents the (possibly unpriced) equity return associated to issuers that are better positioned, in terms of revenues share of different activities that comply with, Below 2°C, Delayed 2°C or Net Zero Emission scenarios requirements. We assume that the shocks in the market perception in terms of plausible realization of transition scenarios will translate into shocks to equity value.[21]

Remark 1 *This is a simplification in discrete time of the probability-weighted cash flow setting used, for example, in Le Guenedal and Tankov (2024) in the context of bond pricing. Using continuous time modeling, the value of actualized future cash-flows at time t is given by:*

$$\begin{aligned} DCF_t &= \mathbb{E}\left[\int_t^{\infty} e^{-WACC(s-t)} FCF_s \middle| \mathcal{F}_t \, ds\right] \\ &= \underbrace{\sum_{\varphi=1}^{n} \mathbb{P}[I=\varphi|\mathcal{F}_t]\, \mathbb{E}\left[\int_t^{\infty} e^{-WACC(s-t)} FCF_s \middle| \mathcal{F}_t, I=\varphi \, ds\right]}_{\textit{probability weighted future discounted cash-flows}} \end{aligned} \tag{22}$$

where $P[I=\varphi|\mathcal{F}_t]$ denotes the probability of each scenario $\varphi = 1,..,n$ materializing, under filtration $\mathcal{F}_t$. In the present discrete case, we assume that the market currently prices the baseline only, i.e. $P[I = Baseline] = 100\%$. Therefore, we assume that the equity value E_t is proportional to the discounted cash flow in the baseline at time t:

$$E_t \sim A \times DCF_{t,Baseline} = \sum_{s=t}^{\infty} \frac{FCF_{s,Baseline}}{(1+WACC)^{(s-t)}} \quad \textit{and}$$
$$\forall\varphi \quad DCF_{t,\varphi} = \sum_{s=t}^{\infty} \frac{FCF_{s,k,\varphi}}{(1+WACC)^{(s-t)}}$$

where A is a scaling coefficient, which could be for example a price to future cash-flow (forward price earning ratio (PER)). This matches illustratively a situation where the market does not price any transition risk and suddenly realizes that the energy transition φ is a

[21] Note that in most academic or practitioners stress-tests, the assumption are quite similar. For example, introducing the EV/revenues and Equity/revenue ratio (Bouchet & Le Guenedal, 2020), one can easily channel the carbon price driven shocks transmitted to the Equity portfolio.

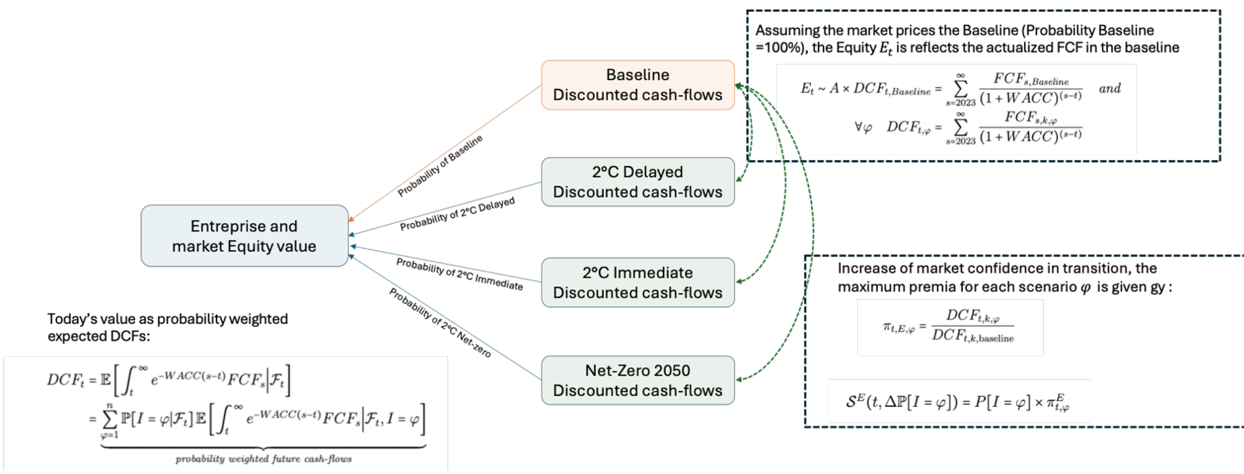
necessity. In reality, this is not realistic, as the current market price is a probability weighted combination of different scenarios, following more strictly:

$$DCF_t = \sum_{\varphi=1}^{n} \mathbb{P}[I = \varphi] \times \mathbb{E}\left[\sum_{s=t}^{T} \frac{FCF_s}{(1+WACC)^{(s-t)}} \Big| I = \varphi\right] \tag{23}$$

$$= \sum_{\varphi=1}^{n} \mathbb{P}[I = \varphi] \sum_{s=t}^{T} \frac{FCF_s}{(1+WACC)^{(s-t)}} = \sum_{\varphi=1}^{n} \mathbb{P}[I = \varphi] \times DCF_{t,\varphi} \tag{24}$$

where $\mathbb{P}[I = NZE]$, $\mathbb{P}[I = Current\ trend]$, $\mathbb{P}[I = Delayed]$, etc., are the probability of each scenario to materialize, and T the time horizon considered by the market (it is common practice to consider a 5-years forward period). In this setting, a more realistic measure would be a shift in market perception in the materialization of the transition. We may thus introduce a more realistic stress-test measure on the basis of deterministic scenarios posed by the Network for Greening the Financial System (or other) using this change in perception.

Figure 8: Illustration of pricing under scenario uncertainty



Market perception based stress-test measure for Equity As Equity prices are sensitive to market sentiment, in line with Remark 1 illustrated in Figure 8, we introduce a shift measure to quantify the impact on a portfolio of varying market's pricing of a mixture of scenarios. For each time step, this measure reflects the proportion of a future scenario that is implemented, thereby progressively transitioning from the baseline to the target scenario. In effect, it represents the fraction of the investment gains or losses that result from the partial implementation of each scenario in comparison to retaining the baseline. In this section, we simplify the scenario-weighted discounted cash-flows expression for corporate value:

$$DCF_t = \sum_{\varphi=1}^{n} \mathbb{P}[I = \varphi] \times DFC_{t,\varphi} \tag{25}$$

Let $\Delta\mathbb{P}[I = \varphi]$, ranging in $[0, 1]$ for example $5, 10, ..50\%$, be our stress-test input, applying a shift in market perception of 5% to 50%, in the market belief in the scenario φ. We simply define the spot shift metric for the portfolio of N assets as the probability weighted return of DCF mixture:

$$\mathcal{S}^E(t, \Delta\mathbb{P}[I = \varphi]) = P[I = \varphi] \times \pi^E_{t,\varphi} \tag{26}$$

Remark 2 *To capture the scenario implied Equity prices, we can also use the earning projections and PER ratio (which is the price of a company divided by its earnings):*

$$E_{t,k,\varphi} = Earnings_{t,k,\varphi} \times PER_{t,k,\varphi} \tag{27}$$

The probability of scenario φ is given by the sum of sequential changes in market perception that occur through time steps s:

$$\mathbb{P}[I = \varphi]_t = \sum_{s<T} \Delta\mathbb{P}[I = \varphi]_s \in [0, 1]$$

The shock implied by a shift in probabilities $\Delta\mathbb{P}[I = \varphi]_s$ for each future steps s perceived at time t on the portfolio becomes:

$$\mathcal{S}'_{t,\Delta\mathbb{P}[I=\varphi]_t} = \sum_{k=1}^{N} w_k \times \left(\frac{\Delta\mathbb{P}[I = \varphi]_t \times E_{t,k,\varphi} + (\Delta\mathbb{P}[I = b]_{t-1} - \Delta\mathbb{P}[I = \varphi]_t) \times E_{t,k,b}}{E_{t,k,b}} - 1 \right) \tag{28}$$

where $\Delta\mathbb{P}[I = \varphi]_t$ is the shift proportion related to the market's confidence across each scenario occurring each year, w_k the weight of each issuer in the portfolio, N the total number of issuers and the suffix $_b$ to indicate that the variable is related to the baseline scenario. Assuming the forward PER remains identical between scenarios,[22] *the Equation (28) simplifies to:*

$$\mathcal{S}'^E_{t,\Delta\mathbb{P}[I=\varphi]_t} = \sum_{k=1}^{n} w_k \times \left(\frac{\Delta\mathbb{P}[I = \varphi]_t \times Earnings_{t,k,\varphi} + (\Delta\mathbb{P}[I = b]_{t-1} - \Delta\mathbb{P}[I = \varphi]_t) \times Earnings_{t,k,b}}{Earnings_{t,k,b}} - 1 \right)$$

In order to account for capital expenditures and corporate tax rates, we employ free cash flow (FCF) instead of earnings:

$$\mathcal{S}'^F_{t,\Delta\mathbb{P}[I=\varphi]_t} = \sum_{k=1}^{n} w_k \times \left(\frac{\Delta\mathbb{P}[I = \varphi]_t \times FCF_{t,k,\varphi} + (\Delta\mathbb{P}[I = b]_{t-1} - \Delta\mathbb{P}[I = \varphi]_t) \times FCF_{t,k,b}}{FCF_{t,k,b}} - 1 \right) \tag{29}$$

For each forward time step s, we want to actualize the cash flows. The discounted FCF (DFCF) is:

$$DFCF_{t,k,\varphi,s} = \frac{FCF_{s,k,\varphi}}{(1 + WACC)^{(s-t)}} \tag{30}$$

and Equation (29) becomes:

$$\mathcal{S}''^F_{t,\Delta\mathbb{P}[I=\varphi]_t} = \sum_{k=1}^{n} w_k \times \left(\frac{\Delta\mathbb{P}[I = \varphi]_s \times DFCF_{s,k,\varphi} + (\Delta\mathbb{P}[I = b]_{s-1} - \Delta\mathbb{P}[I = \varphi]_s) \times DFCF_{s,k,b}}{DFCF_{s,k,b}} - 1 \right) \tag{31}$$

[22] This is a strong assumption, we keep the conditional modeling of PER ratio in transtion scenario for further research.

The portfolio weighted discounted shock for a given value of the probability parameter variation follows:

$$\mathcal{ES}_{t,P[I=\varphi]} = \sum_{s=t}^{T} \mathcal{S}''^{F}_{s,\Delta\mathbb{P}[I=\varphi]_s} \tag{32}$$

As introduced, at each time step s, there is a shift of $\Delta\mathbb{P}[I = \varphi]_s$ *to the scenario* φ*. We have at the end of the period a shift of* $\sum_{s=t}^{T} \Delta\mathbb{P}[I = \varphi]_s = P[I = \varphi] \in [0,1]$*, assuming initial probability is null. For example, if there is each year a 25% shifted from the baseline to the 2°C immediate scenario each year and n = 4, the cumulative effect by the end of the period is a complete (100%) transition to the 2°C immediate scenario. This approach allows to integrate progressive discovery of market confidence in scenarios realization. The shift in probability can be calibrated on observed change in prices, and alternative signals (such as news, policy implementation, change in effective carbon price e.g. Le Guenedal and Tankov, 2024, etc.). We leave this calibration for further research.*

2.3.2 Fixed-income

Probability of Default Probability of Default (PD) refers to the likelihood that a borrower will be unable to service its debt obligations in a timely manner. PD is a key component in credit risk assessment and is used by lenders, investors, and financial institutions to evaluate the creditworthiness of borrowers and to determine the appropriate interest rates, loan terms, and capital reserves.[23]

In practice, PD is used in various financial models and regulatory frameworks, such as the Basel Accords, to calculate expected credit losses, determine capital requirements, and manage credit risk. It is also a critical input in the calculation of other credit risk metrics, such as Loss Given Default (LGD) and Exposure at Default (EAD). We model the increases in the cost of debt separately using sensitivities first introduced in (Alogoskoufis *et al.*, 2021), simplified in Emambakhsh *et al.* (2023) as:

$$PD_{t,k,\varphi} \sim \alpha_{PD} + \beta_{1,PD} \cdot \text{Leverage}_{t,k,\varphi} + \beta_{2,PD} \cdot \text{Profitability}_{t,k,\varphi} \tag{33}$$

with parameters provided in Table 2.

Implicit credit spread The spread refers to the difference in yield between a corporate bond and a comparable maturity government bond. It represents the additional yield that investors demand for taking on the additional credit risk associated with a corporate bond compared to a risk-free government bond. The credit spread compensates investors for the risk of default and other credit-related risks. It can also be written as follows:

$$\text{Spread}(t,k,\varphi) = PD(t,k,\varphi) \times (1 - \mathcal{R}) \tag{34}$$

[23] PD is influenced by various factors, including: (*i*) Borrower's Credit History: (*ii*) Current financial health condition, including income, assets, and liabilities; (*iii*) Overall economic environment and industry-specific factors and (*iv*) specific characteristics: Terms of the loan, such as interest rate, maturity, and collateral. PD is often expressed as a percentage. For example, a PD of 5% corresponds to a 5% chance that the borrower will default within the specified time period.

Table 2: Regression results for probabilities of default

	Fossil Fuels	**Energy Utilities**	**Energy-Intensive**	**Buildings**
Constant	-7.6***	-7.16***	-7.09***	-6.63***
Profitability	-14.06***	-10.99***	-9.71***	-7.8***
Leverage	3.28***	3.96***	4.11***	3.13***
Observations	1,622	20,037	229,642	261,560
	Transportation	**Agriculture**	**Scientific R&D**	**Other**
Constant	-6.27***	-7.08***	-6.2***	-6.44***
Profitability	-9.47***	-12.26***	-10.58***	-7.51***
Leverage	3.004***	3.17***	2.1***	2.98***
Observations	81,223	27,218	3,014	1,159,501

Source: reproduced from Emambakhsh *et al.* (2023, p. 83): ECB calculations based on Orbis data. Sectors refer to Climate Policy Relevant Sectors (CPRS) defined in Battiston et al. (2017). Notes: Standard errors in parentheses. $*p < 0.1$, $**p < 0.05$, $***\ p < 0.01$.

Where $\mathcal{R}$ is the recovery rate (percentage of the bond's face value that is expected to be recovered in the event of default). Similarly we measure in basis point the transition scenario credit spread as:

$$\pi_{B,\varphi,t} = \text{Spread}(k, \varphi, t) - \text{Spread}(k, \text{Baseline}, t) \tag{35}$$

3 Financial impact

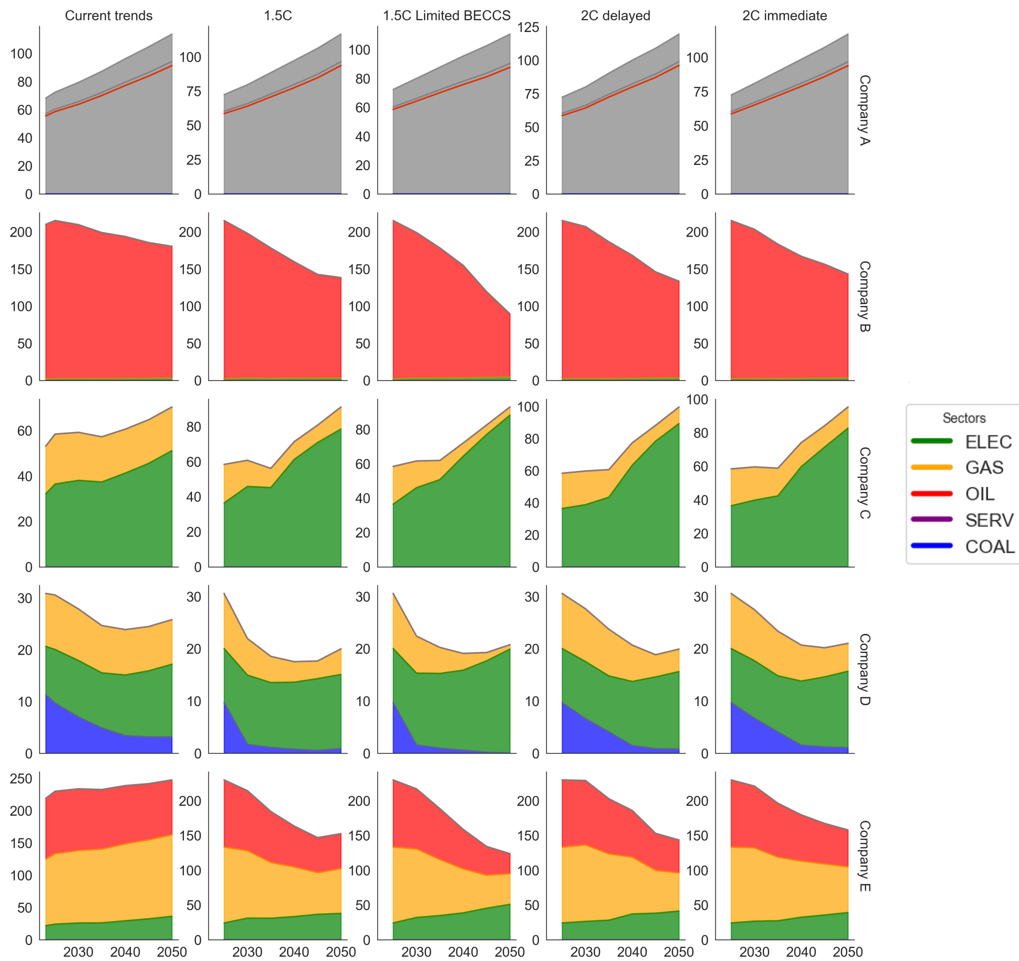
3.1 Case studies: impact on specific issuers

Revenues In this study, we assess the impact of several climate transition scenarios on a diverse set of companies, each exhibiting different sectoral profiles. To illustrate the varying revenues and cost drift in transition scenarios, we focus on 5 companies with different activity mixes.[24]

Figure 16 presents the impact of EPPA revenues variations on modeled activities in the transition scenario of interest scaled at the company level. Company A, with minimal involvement in both fossil fuels and renewables, globally benefits from the implementation of the scenarios, and is not very sensitive to scenario specifics (the behavior of its revenues remains the same whether the transition is achieved immediately or delayed). On the other hand, Company B, heavily weighted in oil, experiences a substantial impact under these transition scenarios. The more aggressive the scenario is with regard to transition and carbon dioxide removal technologies, the more revenues are penalized over time. As oil sees a marked reduction in demand under stricter climate policies, Company B faces considerable transition risks on the demand side, particularly in scenarios with a rapid decline in oil activity, such as

[24] In this section, we smooth the projected revenues by employing a piecewise approach with a third-order polynomial—while preserving the initial and terminal values—to account for forward modeling uncertainties, ensuring that abrupt fluctuations do not overshadow the fundamental revenue trends. We verify that the resulting smoothed values sufficiently retain the core characteristics of the original projection while mitigating abrupt spikes linked to changes in carbon pricing policies, thereby enhancing the realism of converting 5-year interval representation in EPPA to annual intervals for financial applications.

Figure 9: Projection of the revenues per EPPA activities on 5 illustrative companies

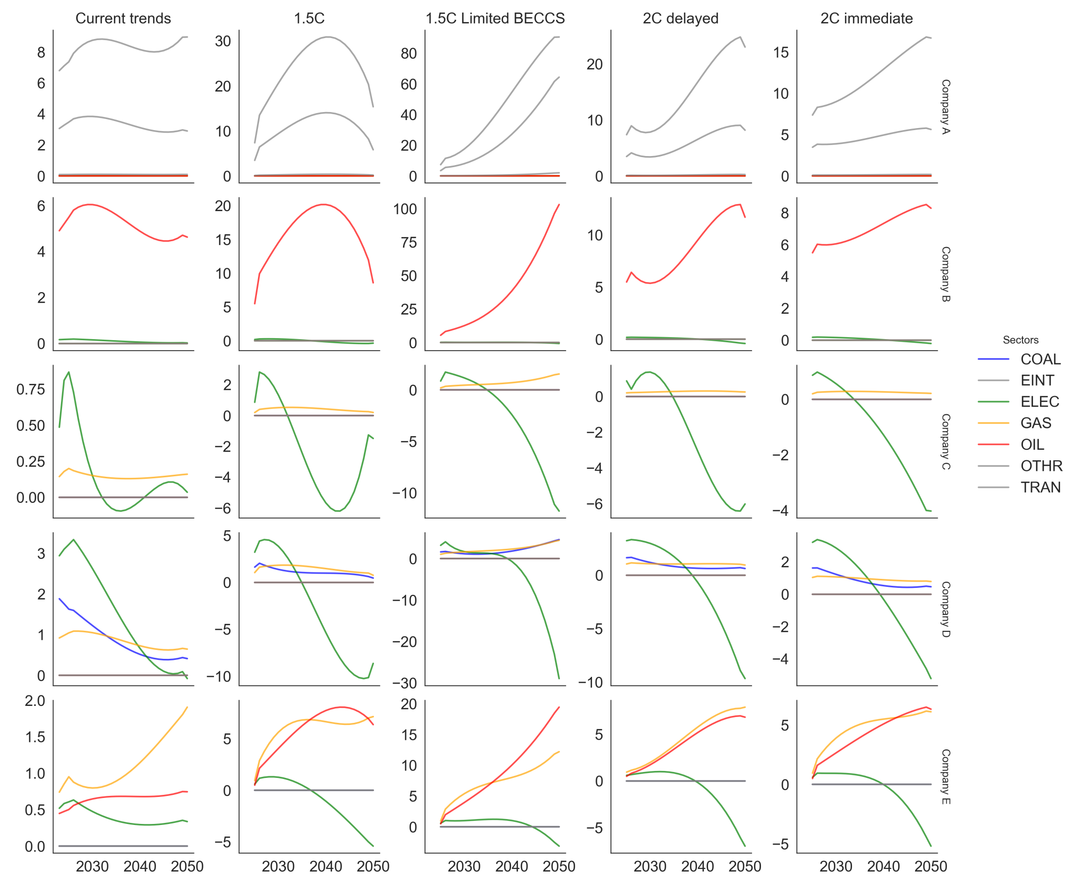


1.5°C or 2°C immediate. The decrease in oil-related revenues is a key factor in the company's vulnerability to policy shifts aimed at meeting climate targets.

Conversely, Company C, which presents a high proportion of renewables in its business mix, stands to benefit from the transition to lower-carbon energy systems. The increasing demand for renewables in all scenarios allows this company to capitalize on the growing market, especially in the scenarios targeting a 1.5°C or 2°C limit on global warming. Also, transition scenarios see the renewable share of revenues take over the gaz share contrarily to current trends where the proportion stays well balanced. Company D, despite having some renewable energy involvement, struggles to maintain its revenues due to significant exposure to coal and gas, sectors that face sharp declines in demand in transition scenarios. This demonstrates the complexity of business models where a partial transition towards renewables does not necessarily shield companies from the broader systemic risks posed by fossil fuel activities. Finally, Company E, with only a marginal proportion of renewables in its portfolio (about 10%), suffers considerably across all scenarios. Its dependency on oil and gas makes it particularly vulnerable to transition-related revenue losses, highlighting the importance of rapidly shifting business strategies towards more sustainable sectors to mitigate climate-related financial risks.

Carbon-related costs In Figure 10, we analyze the total scenario costs, including both direct and indirect costs, for the same set of companies. Interestingly, the cost burden does not exhibit a straightforward relationship with the energy mix of each company. It is also not monotonic through time, also because indirect costs are proportional to the activity of the company, which may decrease in time. [25]

Figure 10: Projection of the costs on a set of companies



Company A sees its costs increasing gradually through time in every scenarios with different scales, reflecting the high emissions specific to, in this example, steel manufacturing. It is logically most penalized in the 1.5°C with limited access to carbon dioxide removal technologies. Interestingly, 1.5°C scenario sees the company costs increasing until 2040 before

[25] The smoothing procedure detailed in the Appendix effectively mitigates abrupt fluctuations arising from changes in carbon pricing policies. More importantly, it enhances the realism of converting the EPPA model's five-year steps interval into annual intervals, thereby making the outputs more suitable for financial applications. Although this approach could be refined further to accommodate higher temporal resolutions (e.g., quarterly intervals), we leave such explorations to future research.

decreasing slightly (although remaining significantly positive). This can be seen both as a reward of implementing early action and having access to extended access to carbon dioxide removal technologies. For Company B, the costs associated with its oil-heavy portfolio are significantly higher in scenarios with more stringent climate action, such as 1.5°C Limited BECCS and 2°C delayed. Under these scenarios, oil-related costs rise dramatically, particularly between 2030 and 2040, before normalizing slightly after 2045. This pattern reflects the immediate financial burden of decarbonizing oil activities, which aligns with the projected decrease in oil demand under these climate goals.

Conversely, Company C, which is largely involved in renewables, experiences a notable decrease in costs related to its renewable portfolio across all scenarios. This cost reduction is particularly pronounced under scenarios with accelerated climate action, such as 1.5°C Limited BECCS. [26] For Company E, the cost burden remains high throughout the scenarios due to its significant exposure to oil and gas sectors, especially under the 2°C delayed and immediate scenarios. Interestingly, while Company E sees a slight reduction in costs from its minimal renewable involvement, it is outweighed by the persistent high costs from its oil and gas activities, confirming the unsustainable nature of its current business mix in the context of climate transition.

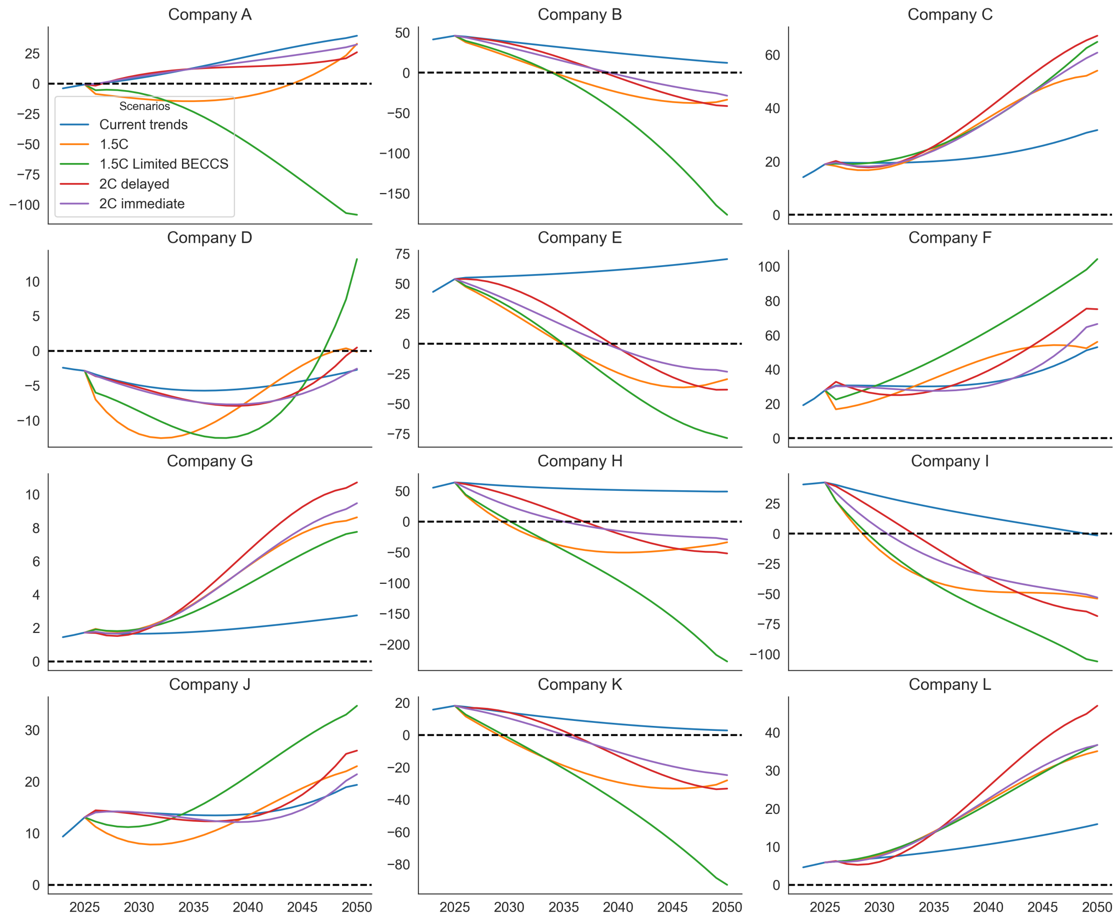
In summary, the cost curves reveal that companies with a higher proportion of renewables in their portfolios, like Company D, benefit significantly from transitioning to a low-carbon economy. Meanwhile, companies such as Company B and Company E, which remain heavily dependent on fossil fuels, particularly oil and gas, face substantial financial risks, especially in scenarios that aim for rapid decarbonization. This highlights the urgent need for these companies to realign their business strategies towards more sustainable energy sources to mitigate the increasing costs and risks associated with climate policy transitions.

Earnings We compute earnings based on the latest financial statements of the companies, including revenues growth projection, direct and indirect carbon-related costs, as well as operating expenditures that are not carbon-related. In this section, we expand our analysis from the first five companies presented earlier in the paper to a broader set of 12 companies.

The results illustrated in Figure 15 reveal significant variations in the financial trajectories of the companies analyzed, particularly in relation to their revenue composition and carbon management strategies. Companies C, G and J, which demonstrate a high share of renewable energy in the revenue mix, indicate a proactive approach to sustainability. This is particularly noteworthy for Companies G an J, pure players focusing on green energy production. Company A is a steel manufacturer, as the steel industry is traditionally associated with high carbon emissions, one could expect a strong negative impact on the earnings, however, materials sectors benefits from high demand and revenue growth in the transition

[26] The reason the sum of direct + indirect costs has sometimes a smaller negative cost (higher in absolute value) is that with limited BECCS, the carbon price is much higher (about 9 times for that in 1.5C case in 2050: 1260 USD/mt-CO2e vs. 140 USD/mt-CO2e). At the same time, the power sector negative emissions under 1.5C (-1600 mt-CO2e) in 2050 is just slightly over 2.5 times more than the limited BECCS case (-620 mt-CO2e). That is why in 2050, the negative cost under limited BECCS (-770 billion USD) is more than three times as much as the 1.5C case (-220 billion USD).

Figure 11: Projection of the earnings on a set of companies

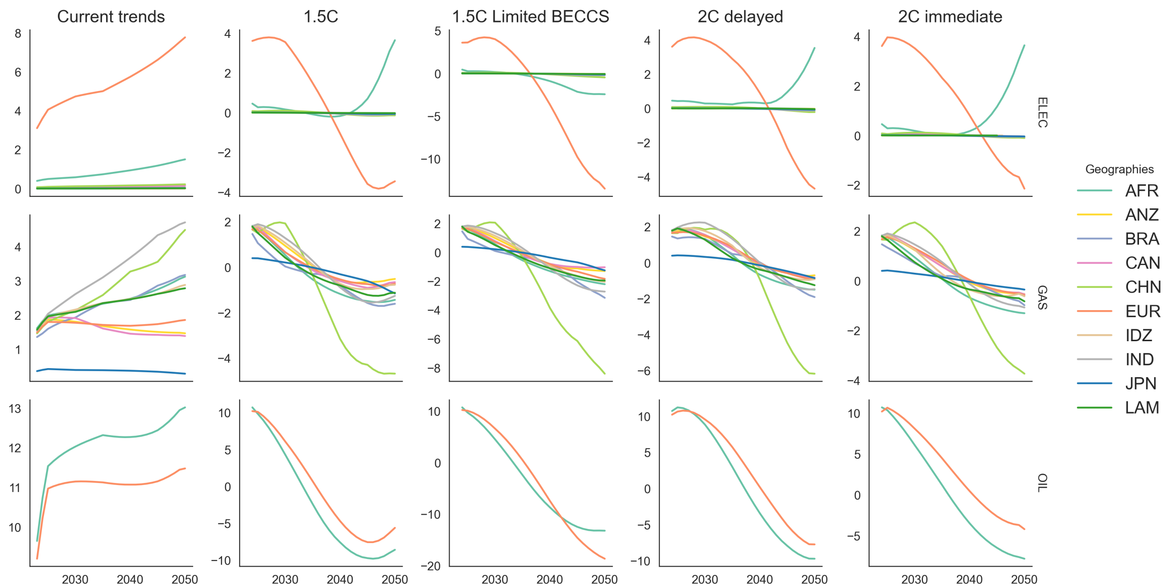


scenarios as well, which balance the negative increase in costs and results in a relatively neutral impact of transition policies (as suggested by the scenario investigated with EPPA). This is however strongly conditioned by extended access to carbon dioxide removal technologies. For energy and utilities companies, the adoption of renewable energy sources not only mitigates carbon footprints but may also enhance long-term financial resilience by aligning with global sustainability trends and regulatory frameworks.

Furthermore, the role of carbon dioxide removal technologies is highlighted as a critical factor influencing future financial performance. The hypothesis that BECCS technology can effectively reduce net carbon emissions while providing a viable energy source suggests that companies investing in such technologies may gain a competitive edge. The financial projections indicate that increasing the cost of BECCS deployment (in the scenario 'limited BECCS'), strongly improve the earnings projections after 2030 of companies currently invested in the renewables.

In contrast, companies with lower renewable energy shares may face increasing financial pressures as carbon regulations tighten and consumer preferences shift towards more sustainable practices. The divergence in earnings trajectories underscores the importance of strategic investments in renewable technologies and carbon management solutions. As the market evolves, companies that fail to adapt may find themselves at a disadvantage, both financially and reputationally.

Figure 12: Earnings by region for company E



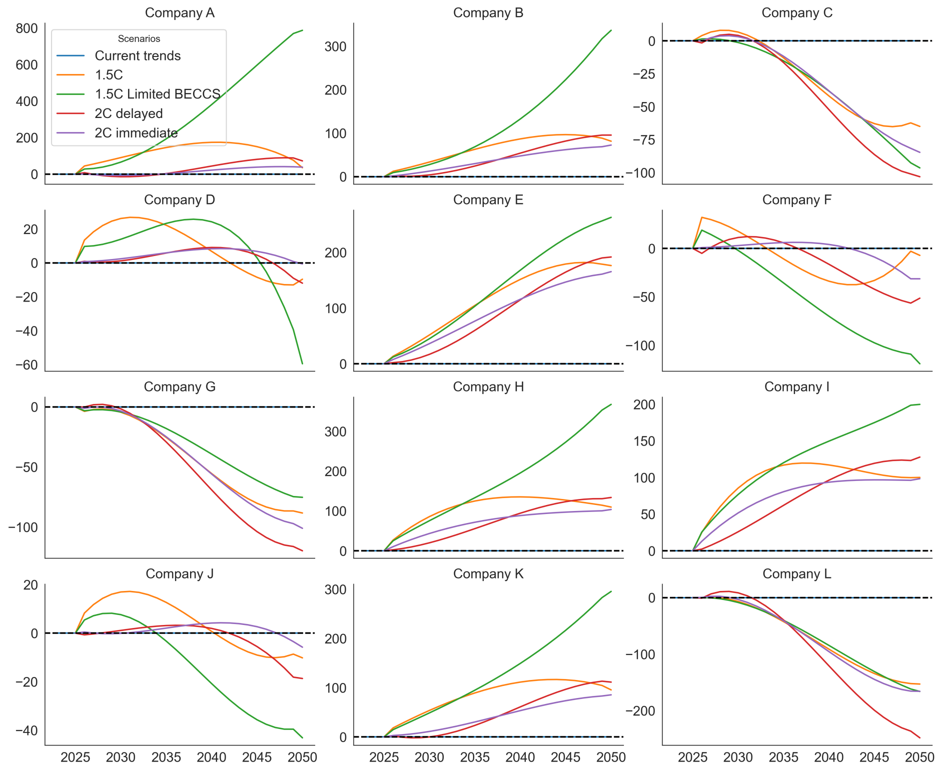
On Figure 12, we highlight the regional disparities of company E, present in various regions of the world. Aside the obvious differences between the tactical allocations the company has made strategically as regards its implementation, that the geographic dynamics of its earnings are very different. Especially, the Chinese branch of the gas activity of the company is more severely impacted than the other activities due to global need to more severely legislate in the region in the transition scenarios. As regards renewables, we can see that the dynamics of the sector is also very different between Africa and Europe. For this specific examples, operating expanses tend to increase as the company invests more on the activity, and the additional revenues generated are not sufficient to cover the rise in costs.

Excess Spread Using a conservative global sensitivity of -10% of probabilities of default to profitability variations,[27] we can project implicit PD growth (or reduction), and deduce a top-down variation of spread following the Equations (33) to (35). Similarly as in Le Guenedal *et al.* (2023), results suggest that change in profitability of companies operating in fossil-fuel activities are likely to increase their cost of debt (up to 200 pbs and more) by 2030.

Figure 13 also shows that companies engaged in renewable may benefit from lower cost of capital. More importantly, the perception of high cost associated with BECCS increases

[27] Figure 13 with -10% probability of default is above the previously used -5.3% sensitivity factor in Alogoskoufis *et al.* (2021), but aligns the factors of Emambakhsh *et al.* (2023) for fossil fuel (-14.06) and engery utilities (-10.99) in terms of magnitude (c.f. Table 2).

Figure 13: Excess-spread in transition scenarios (in basis points)

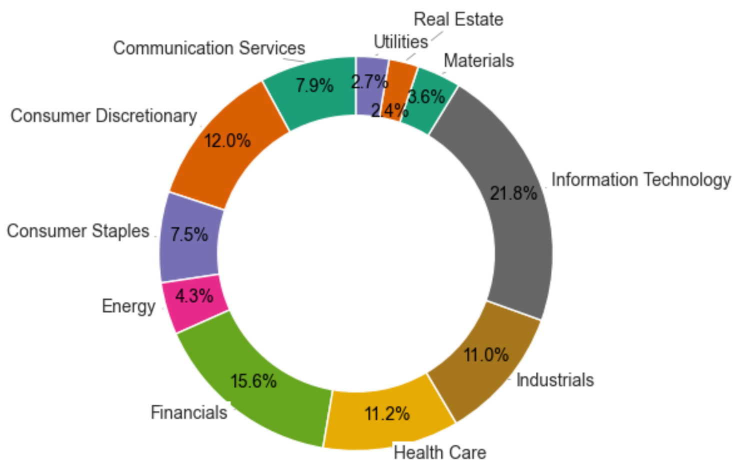


further the attractiveness of debt issued in the renewable sector, as climate policy becomes more likely and carbon dioxide removal less realistic. For example, under the assumption of this exercise, we show maximum decrease of cost of debt of -20 pbs by 2030 over this illustrative sample. The delayed scenario appears less costly in the short term because impact are delayed after 2035/40. We can also notice that the steel manufacturer (company A) is projected to experience an excess-spread of 800 basis points by 2050 under the 1.5°C with limited BECCS scenario. This indicates that the company is subjected to substantial penalties due to its very high scope 1 emissions and the increasing demand for steel to support the transition, compounded by the limited availability of advanced carbon dioxide removal technologies.

3.2 Impact on the MSCI World Index

MSCI World Index The illustrative index used in this study is a benchmark that tracks the performance of large and mid-cap companies across 23 developed countries, accounting for 85% of the global market capitalization. Maintained by MSCI Inc., formerly known as Morgan Stanley Capital International, the index serves as a comprehensive indicator of the performance of developed market equities. It includes approximately 1,500 stocks from developed markets around the globe, making it a broad representation of these economies. However, it does not include stocks from emerging or frontier markets; MSCI offers the MSCI All Country World Index (ACWI), which encompasses both developed and emerging markets.

Figure 14: MSCI World Index - Sector composition - sept. 2024



The sectoral classification traditionally used, especially by equity portfolio managers, is the Global Industry Classification Standard (GICS), developed by MSCI and Standard & Poor's (S&P) in 1999, categorizes companies into 11 sectors, 25 industry groups, 74 industries, and 163 sub-industries based on their principal business activities. GICS serves as the basis for many MSCI and S&P indices, including the MSCI World Index. Thus, we provide the composition of this index using this classification focusing on the 11 main sectors. [28]

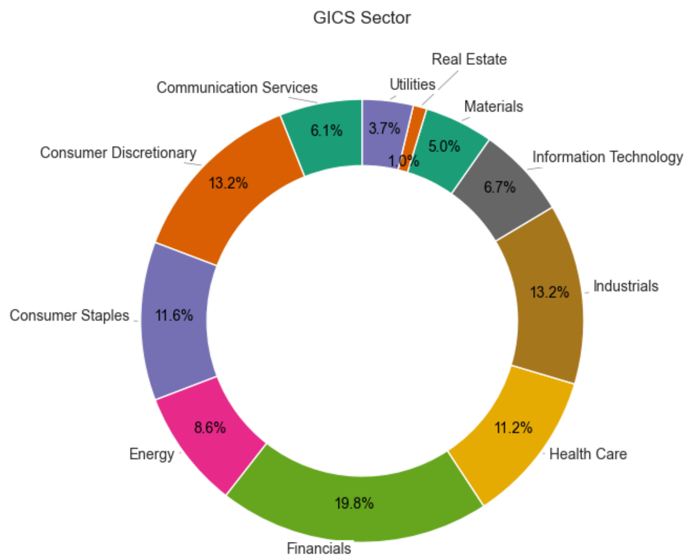
Figure 14 presents the breakdown by sector of the MSCI World Index globally using Market Capitalization. Information Technology dominates the index with more than $1/5^{th}$ of the total Market Capitalization (77 trillion USD as of sept 2024). Consumer Discretionary (non-essential products), Health Care, Communication Services and Financials follow with more than or about 10% of index share. While the relative proportion of each sector has been fairly stable for the last few years, Information Technology has gained 7% since 2020 and the Financials lossed 5%, a tendency started in 2002 and the dot-com bubble burst.

On the left side of the Figure 15, we plot the repartition of companies earnings by GICS Sector. On the right side, the repartition by EPPA sector (MIT's definition of sectors for the EPPA model based on GTAP). The proportion of earnings by GICS sector in the Index tells a slightly different story, with Information Technology accounting for 6.7% of the earnings and Financials 19.8%. Consumer Staples (often referred to as non-cyclical) present also a far higher share of earnings than market capitalization. Communication Services, with connections to Information Technology, are also underweighted in earnings repartition.

In addition, the graph on the right side of the Figure 15 shows the repartition of the earnings from a climate point of view using EPPA sectors. It can be observed the proportion of direct earnings coming from COAL (1%), OIL (7%), GAS (3.6%) and ELEC (3.5% which

[28] Note that the NACE '*statistical classification of economic activities in the European Community*' is also broadly used in Europe.

Figure 15: MSCI World Index - revenues by sector - 2023



is the share for renewable energy). The MSCI World earnings, dominated by services, has a lesser concentration in Fossil fuel activities than what could be found in emerging countries, for example. [29]

Figure 16: MSCI World Index revenues by EPPA regions - 2023

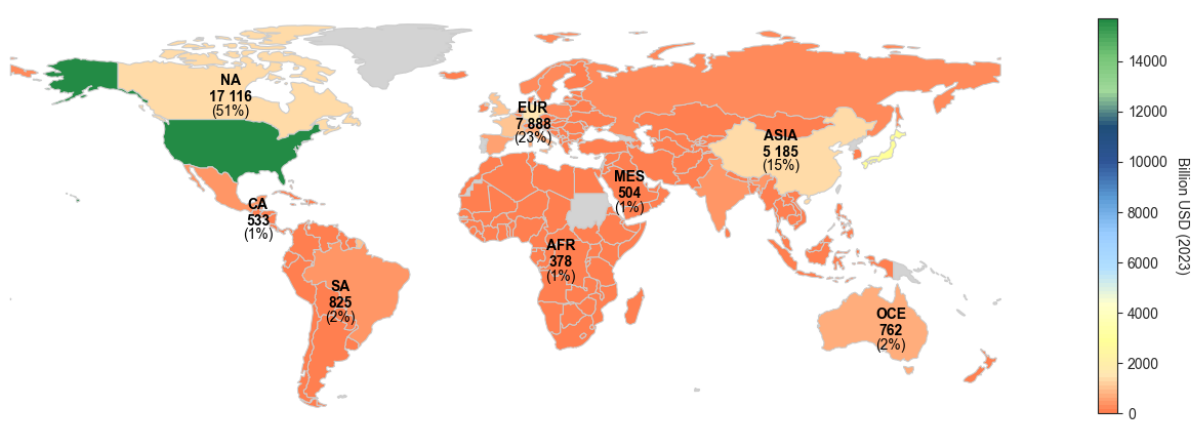


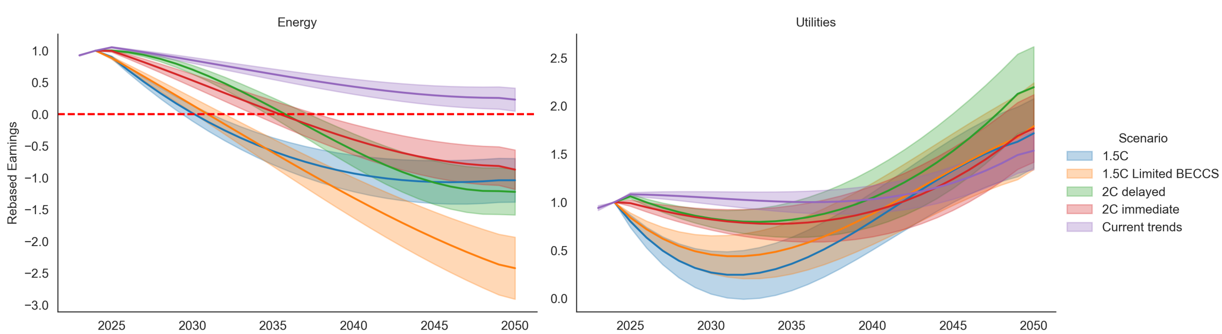
Figure 16 presents the total revenues of about 1 500 companies of the MSCI World broken down by country as of 2023. The MSCI World accounts for 85% of the market capitalization

[29]Following sectors in EPPA stand for: EINT: Energy intensive Nec, CROP: rice, wheat, cereals, vegetables, oil seeds, sugar cane, plant-based fibers, WATER: water supply, waste management, MAN: Manufacture of products, TRAN: transport, SERV: services, communication, financial, real estate, public administration and defense, LIVE: horses, animal products, raw milk, wool

of the developed markets (about 33 300 billion USD of revenue) and $1/3^{rd}$ of the world global GDP (101 000 billion USD). The portion of the GDP not accounted for by listed companies is comprised of private companies, households, and public non-listed entities. North America and Europe account for about 74% of the total revenues and Asia 15%. Part of the revenue of the companies of the MSCI World locate in regions that are absent from it.[30]

Earnings projections As illustrated in Figure 17, there will be significant variations in projected earnings for companies in the two most impacted GICS sectors (Energy and Utilities) under different climate transition scenarios. The analysis benchmarks earnings to 2025 levels and extends through to 2050. It reveals a pronounced divergence between sectors, with the Energy sector experiencing a significant and persistent downward trend in earnings under more ambitious climate scenarios, such as 1.5°C and 1.5°C Limited BECCS, compared to the more moderate pathways like Current trends. Earnings in the Energy sector generally decline across all scenarios, with a steep drop observed around 2030-2035 as stringent policies and reduced fossil fuel demand take effect. Under the 2°C immediate and 1.5°C Limited BECCS scenarios, mean earnings are projected to fall below zero. This indicates that companies with a significant reliance on fossil fuels may face unprofitable operations if these transition pathways are implemented. The variance within each scenario band suggests that companies with different levels of renewable integration may experience varying degrees of impact, though the sector as a whole remains vulnerable.

Figure 17: Climate-relevant sectors earning variation (rebased 2024)



In contrast, the Utilities sector shows a more resilient earnings trajectory, with most scenarios projecting a recovery post-2040, especially under Current trends and 2°C delayed. This resilience is likely due to the sector's capability to adapt to a low-carbon economy by integrating renewable energy sources and transitioning away from high-carbon assets, even though it will be costly before that date. The mean earnings in the Utilities sector remain relatively stable, with minor fluctuations, and display an upward trend from 2035 onward,

[30] Figure 22a and 22b in the Appendix shows current direct and indirect costs by region: North America, particularly the United States, and Western Europe show high direct carbon costs, as indicated by the green and yellow colors.

particularly in scenarios with delayed or moderate climate actions. Notably, the 1.5°C scenario, which envisions rapid decarbonization, presents the greatest volatility in earnings, underscoring the sector's sensitivity to abrupt shifts in policy and market demand. This comparative analysis between Energy and Utilities underscores the differential impact of transition policies on sectors with varying energy mixes, signaling that companies in the Utilities sector may be better positioned to mitigate climate-related financial risks through adaptation and diversification strategies, whereas those in the Energy sector face more profound structural challenges under aggressive decarbonization scenarios.

Financials, Information Technology, Real Estate, Communication Services, Consumer Discretionary and Health Care are the less impacted, but could still suffer hundreds to thousand of billion of dollars of revenues loss in 2050 for each scenario as compared to current trends. Economies are highly interconnected, and a significant shock to one company is likely to propagate to other firms with which it maintains relationships. Consumer behavior and chain effects are also not to be neglected. We also have to remind that the current modeling takes into account Scope 1 to project direct costs impact, and Carbon direct and First tier indirect emissions to assess indirect costs impacts. Airlines scope 1, for example, does not take into account the amount of pollution they generate by emitting high in the sky, and are not shielded against more specific regulation in the future, even though they currently are heavily penalized by the different transition scenarios. Durable negative earnings for energy companies that would refuse to implement proper climate actions could also mean severe impacts for Financials that would have lent money to them.

The impact for the Materials sector is more significant, both in US and in Europe with a total above 300 billion USD difference in total earnings in 2050 between current trends and 1.5C with limited BECCS scenarios. This difference is driven by the metals, mining and steel industries that are in most scenarios unable to find back their 2023 earnings level while chemicals shows more resiliency, everything else being equal.

FCF, DCF and shift ratios In this section, we discuss the impact of a shift on the MSCI World Index from the baseline to each scenario. It represents an intermediate step, where equities suffer a shock due to a partial transition from the baseline to a composite scenario. For example, a 25% shift means that markets price 75% current trends and 25% 2°C immediate as an intermediate step to a transition to the 2°C immediate scenario.

Table 3: Equity shocks of alternative scenario realization assuming Current Trends is priced - MSCI World Index

Scenario	$\pi_{E,\varphi}$ (in %)	$\Delta\mathbb{P}[I]$ = 25%
1.5C	-14.23%	-6.02%
1.5C limited BECCS	-15.43%	-6.67%
2C delayed	-8.72%	-3.31%
2C immediate	-8.33%	-3.14%

Table 3 summarizes the results at the index level, displaying changes in equity valuation under varying climate scenarios, highlighting the implications of changes of market perceptions about the future of the index value. The results indicate that, if the consensus stops pricing the baseline (current trends), and starts pricing a scenario with more ambitious GHG limitation policies, there is a notable shift in the $\pi_{E,\varphi}$ ratio. For instance, the 1.5°C scenario shows significant negative losses of -14.2% over the whole MSCI World Index value. The 1.5°C with limited access to carbon dioxide removal technologies further exacerbates the negative losses to -15.4%.[31] Under the current EPPA modeling assumptions, equity shocks in the 2°C delayed scenario are not substantially greater than those in the 2°C immediate scenario, with losses ranging from -8.72% to -8.33%.[32] This is largely because, although delayed action entails higher costs, those costs are subject to greater discounting, thereby diminishing their impact on discounted free cash flows.

In this stress-testing approach, rather than defining an absolute earnings floor below which a company is deemed bankrupt (for example, when its enterprise and equity values drop to zero), we floor the losses of the implementation of a specific scenario, as compared to the baseline, at -100%. It means that a company cannot loss more than 100% of its earnings if a scenario materializes, which allows not to take assumptions as regards how long a company can sustain negative earnings. [33]. In the 2°C delayed scenario, some firms benefit more from the later, more pronounced shift towards greener electricity production, while the number of bankruptcies remains relatively stable.

Globally, such findings underscore the equity market's sensitivity to climate-related risks and the potential for increased volatility as investors adjust their expectations based on evolving climate policies and scientific insights.

Although the results are globally negative, some actors in the investment universe may experiment positive shocks. Figure 18 compares the distribution of changes in equity values under different climate scenarios: 1.5°C with and without limited access to carbon dioxide removal technologies, 2°C with delayed action, and 2°C with immediate action. In each scenario, the majority of equity changes are negative (red), with limited positive shifts (green). The 1.5°C scenarios (both with and without limited access to carbon dioxide removal technologies) show a similar, concentrated negative impact, indicating significant financial strain under aggressive decarbonization, particularly when carbon dioxide removal technologies options are constrained. The 2°C delayed scenario shows a slightly broader distribution, suggesting a marginally less immediate impact. In contrast, the 2°C immediate scenario reflects the broadest distribution of negative impacts, highlighting substantial but more varied losses, likely due to the accelerated need for rapid adjustments.

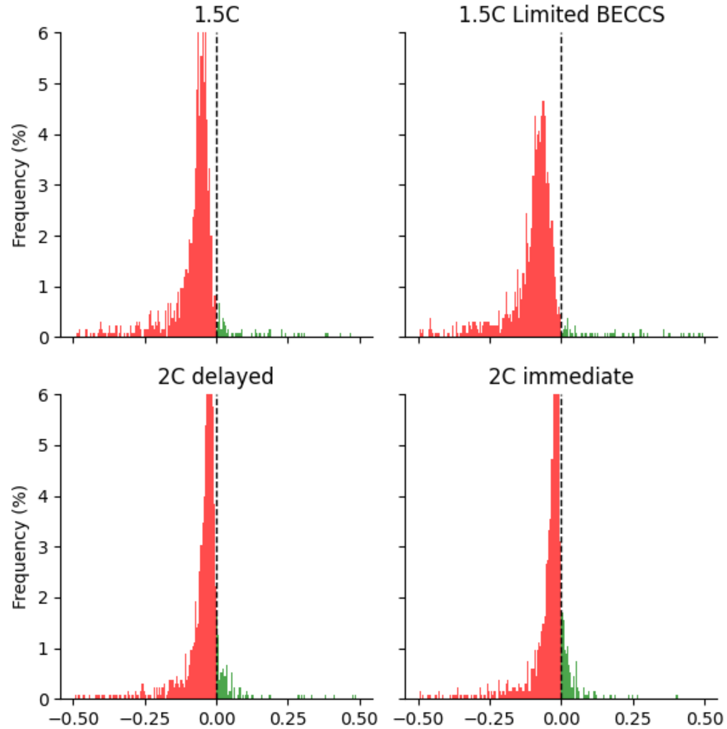
Figure 19 illustrates the varying impacts on equity values across sectors under a stringent 1.5°C transition scenario without extensive use of BECCS. Sectors with heavy reliance on fossil fuels, such as Energy and Industrials, face severe declines, with distributions heavily

[31] These figures are actualized shifts in valorization computed with the FCF approach. They characterize the spot change in valuation expected if transition scenarios trajectories are formally applied to each individual company in the portfolio. They can not be compounded and are not explicitly risk premias formally speaking.

[32] Globally, across the MSCI World Index, 1041 companies discount equally or better in the 2°C immediate scenario compared to the 2°C delayed scenario, which accounts for more than 75% of the companies in the universe.

[33] Negative earnings projection is admittedly open to debate, as firms with consecutive negative earnings do not invariably file for bankruptcy if investors or governments continue to provide financing. (see for example Almeida *et al.* (2003))

Figure 18: FCF scenario vs. baseline ratio distribution in transition scenarios



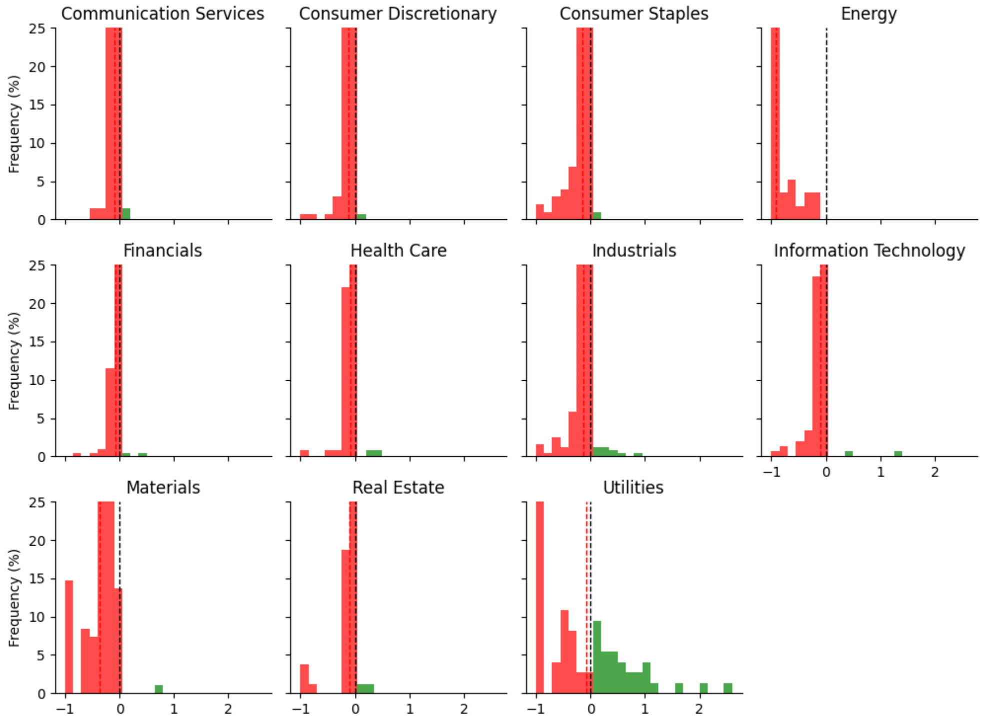
Note: we focus on shocks between -40% and 50% for visualization purpose.

skewed towards negative equity changes. Utilities show a mix of positive and negative shifts, reflecting both risks and potential opportunities as some companies transition towards renewable energy. [34]

Apart from limiting BECCS which further emphasize the positive effect of transition policies on actors engaged in electricity generation, the distribution of the ratio appears to be relatively similar in each scenario. Indeed, the scenarios are more differentiated by the level of ambitions (1.5 vs. 2°C) than by GHG reduction mechanisms (targeting one sector, are specific imports or not etc.). Therefore, we observe similar distributions in this exercise (Figure 18). However, the average exposure is different across sectors. Table 4 summarizes the impact on expected returns across various GICS sectors under different climate policy scenarios, including a stringent 1.5°C target with and without limited access to carbon dioxide removal technologies, and 2°C scenarios with immediate and delayed action. Even if impacts between transition scenario are relatively homogeneous in each GICS sector we observe heterogeneous impacts mainly in HICS (High Impact Climate Sectors), with more important losses generated by carbon pricing to reach 1.5°C objectives.

[34] We reiterate that companies cannot incur losses exceeding 100% of their earnings as a result of global climate policies. In practice, large corporations can report negative earnings—even significant ones—over multiple years without having their market capitalization reduced to zero. However, incorporating such dynamics would require more company-specific modeling and lies beyond the scope of this paper.

Figure 19: $\pi_{E,\varphi}$ distribution in 1.5°C with limited BECCS per GICS sector



Note: we focus on shocks between -100% and 300% for visualization purpose.

The results indicate that the Energy GICS sector experiences the most pronounced negative impacts under all climate scenarios, with mean returns ranging from -90 % under the 1.5°C Limited BECCS scenario to -70% under the 2°C immediate scenario.[35] These reductions suggest a significant revaluation risk as the sector faces stringent climate policy pressures, especially under ambitious 1.5°C scenarios with higher challenges in BECCS implementation. This is natural because Energy GICS classification is mostly attributed to companies operating in fossil-fuel related sectors, and in the conditions posed to each 1.5°C scenario, these operations should have started to decrease and nearly stopped already - which raises questions about the feasibility of this scenario. Moreover, companies operating in fossil-fuel have started diversifying their revenues and some of them can easily buy smaller greener ones to increase the speed of their transition.

On the other hand, the Utilities sector shows much more resilience, highlighting the potential for a relatively stable performance. The range is wide, evidenced by a 95th percentile reaching up to 180% (e.g. x1.8 in equity share value) in the 1.5°C with limited BECCS scenario, suggesting potential gains depending on specific utility positioning, in particular for pure players. 75th percentile is also about positive with gains above 40% in the same

[35] Figures below 100% would show that the present value of operators in fossil fuel company market value would be zero, if the market believed in the 1.5°C scenario. It also does not account for the plan of these companies to reduce their emission faster than suggested by EPPA, or to shift their revenues towards greener sources, acquiring clean technology companies for example (as discussed in Le Guenedal *et al.*, 2023).

Table 4: Summary statistics of actualized FCF ratios

GICS Sector	Scenario	Mean	25 pct	Median	75 pct	95 pct
Energy	1.5C	-89%	-100%	-100%	-97%	-34%
	1.5C Limited BECCS	-91%	-100%	-100%	-100%	-36%
	2C delayed	-76%	-100%	-93%	-52%	-14%
	2C immediate	-72%	-100%	-81%	-50%	-17%
Utilities	1.5C	-30%	-100%	-43%	7%	110%
	1.5C Limited BECCS	-7%	-100%	-28%	41%	177%
	2C delayed	-6%	-51%	-14%	4%	133%
	2C immediate	-19%	-59%	-19%	-7%	82%
Com. Services	1.5C	-6%	-7%	-5%	-4%	-1%
	1.5C Limited BECCS	-9%	-11%	-8%	-6%	-1%
	2C delayed	-3%	-5%	-3%	-2%	1%
	2C immediate	-3%	-4%	-2%	-1%	1%
Cons. Discretionary	1.5C	-9%	-10%	-7%	-5%	-3%
	1.5C Limited BECCS	-12%	-13%	-9%	-7%	-4%
	2C delayed	-5%	-6%	-4%	-2%	-1%
	2C immediate	-4%	-5%	-3%	-1%	-1%
Consumer Staples	1.5C	-11%	-10%	-6%	-3%	2%
	1.5C Limited BECCS	-15%	-16%	-9%	-6%	-1%
	2C delayed	-5%	-5%	-3%	0%	5%
	2C immediate	-4%	-4%	-2%	1%	5%
Financials	1.5C	-5%	-6%	-4%	-3%	-1%
	1.5C Limited BECCS	-7%	-9%	-7%	-5%	-2%
	2C delayed	-3%	-4%	-3%	-2%	0%
	2C immediate	-3%	-3%	-2%	-1%	0%
Health Care	1.5C	-7%	-7%	-6%	-4%	0%
	1.5C Limited BECCS	-8%	-10%	-8%	-6%	0%
	2C delayed	-4%	-4%	-3%	-2%	2%
	2C immediate	-3%	-3%	-2%	-1%	2%
Industrials	1.5C	-10%	-11%	-7%	-4%	3%
	1.5C Limited BECCS	-13%	-15%	-9%	-6%	2%
	2C delayed	-5%	-5%	-3%	-1%	4%
	2C immediate	-4%	-5%	-2%	-1%	4%
Inf. Technology	1.5C	-9%	-9%	-6%	-4%	-2%
	1.5C Limited BECCS	-10%	-11%	-7%	-5%	-3%
	2C delayed	-5%	-5%	-3%	-2%	-1%
	2C immediate	-4%	-5%	-2%	-1%	0%
Materials	1.5C	-31%	-39%	-21%	-9%	-2%
	1.5C Limited BECCS	-36%	-53%	-30%	-14%	-4%
	2C delayed	-19%	-18%	-8%	-3%	3%
	2C immediate	-18%	-19%	-7%	-3%	4%

scenario. Indeed, in a context where climate policies enforce the 1.5°C, in addition with limited access to BECCS, the operators that have the means to deploy sufficient green energy will highly gain in value. Again, this is highly conditioned by the market belief in the rationality of this scenario, but these positive forward discounted cash flows are more realistic than negative ones for fossil-fuel companies. Indeed, clean tech and green energy producing companies are likely to either be both by larger fossil-fuel companies looking for diversification, either increase in share value because of more stringent carbon policies.

The impacts across sectors exhibit similar patterns: Consumer Staples and Consumer Discretionary face modest negative returns due to moderate climate risk exposure, with Consumer Staples showing slightly higher average sensitivity but also some positive neutral impacts. Information Technology is notably vulnerable to transition costs, especially with rising electricity demands from AI (not accounted for in the present simulation), which will elevates emissions and indirectly affects other sectors indirect costs. Financials and Health Care sectors experience very little negative impacts, with Financials which would present sharper declines under stringent climate scenarios due to its exposure to other activities. Meanwhile, Industrials and Materials sectors demonstrate moderate sensitivity, with Materials consistently declining, reflecting ongoing transition challenges.

Table 5: Market cap weighted actualized 25% shift in percent (%)

Sector	**1.5°C**	**1.5°C Ltd BECCS**	**2°C Delayed**	**2°C Immediate**
Communication Services	-1.53%	-2.24%	-0.80%	-0.64%
Consumer Discretionary	-2.52%	-3.22%	-1.25%	-1.00%
Consumer Staples	-4.17%	-5.36%	-2.30%	-1.51%
Energy	-51.10%	-56.62%	-32.60%	-31.39%
Financials	-1.29%	-1.84%	-0.78%	-0.63%
Health Care	-2.22%	-2.71%	-1.51%	-1.38%
Industrials	-2.93%	-3.69%	-1.50%	-1.29%
Information Technology	-2.26%	-2.50%	-1.25%	-1.08%
Materials	-12.91%	-15.39%	-6.65%	-6.54%
Utilities	-18.49%	-12.57%	-5.04%	-7.83%

Note: these are the market cap weighted actualized shocks of a 25% gain in confidence in the scenarios with respected to the current trends in percentage variation per sector GICS.

Analysis of actualized shift DCFs weighted by market cap in Table 5 in various GICS sectors under different climate scenarios reveals critical insights into the potential impacts of climate change policies on an investment portfolio. For example, the Communication Services and Consumer Discretionary sectors exhibit slight losses if market perception of the transition scenario increases, with expected losses of -1.5% and -2.5% under the 1.5°C scenario, primarily driven by adverse impacts on consumer spending implied by transition scenarios. In contrast, the Consumer Staples sector is less impacted, with shifts close to zero, suggesting that demand for essential goods may remain more resilient to transition policies. The Energy GICS sector faces the most substantial negative impacts, particularly in the 1.5°C Limited BECCS scenario, with a shift of -51%. The non High Impact Climate Sectors (HICS), such as Financials, Consumer Staples and Discretionary or Health Care sectors show negative shocks around -2%.

Short term impacts In Table 6, we compute a DCF according to equation (20), meaning that we actualize every anticipated FCF over the next 5 years related to a 25% shift towards every scenario starting from initial probability of the baseline of 100%. This assumes that the companies of the MSCI World will not be able to change their business mix on the very short term above the shift percentage, which seems reasonable given their size. This also represents a soft transition with the remaining 75% to be realized between 2030 and 2050. We can notice that, even in the most aggressive scenarios, the impact until 2030 remains relatively limited.

Table 6: 5-Year Discounted Cash Flows (until 2030) with a 25% shift from baseline to each scenario

Sector	1.5°C	1.5°C Ltd BECCS	2°C Delayed	2°C Immediate
Communication Services	-1.46%	-1.04%	-0.36%	-0.47%
Consumer Discretionary	-1.87%	-1.42%	-0.30%	-0.63%
Consumer Staples	-3.73%	-2.71%	-0.74%	-1.28%
Energy	-21.20%	-17.34%	-4.72%	-8.44%
Financials	-1.00%	-0.74%	-0.13%	-0.30%
Health Care	-1.60%	-1.16%	-0.28%	-0.42%
Industrials	-3.65%	-3.01%	-0.86%	-1.23%
Information Technology	-2.26%	-1.76%	-0.65%	-0.81%
Materials	-10.93%	-9.22%	-1.78%	-4.76%
Real Estate	-1.60%	-1.15%	-0.40%	-0.56%
Utilities	-26.14%	-19.77%	-8.16%	-9.93%

Utilities are more impacted by the transition than energy companies in average in the most aggressive 1.5°C scenarios, with figures such as -26% under the 1.5°C scenario and -20% under the 1.5°C Limited BECCS scenario, while their risk exposure is more limited in the 2 degrees immediate scenario. This is however misleading, as the utilities put to contribution are the ones directly related to the energy sector: Electric, Gas, Independent Power Producers and Energy Traders. This result can be inferred from the earnings projection shown in Figure 17, which indicates a rapid decline in net incomes for utility companies due to higher short-term transition costs. However, this trend quickly stabilizes and reverse after 2035, an outcome not fully captured by the truncated-horizon DCF approach commonly employed in operational applications.

Bouchet and Le Guenedal (2022) conducted a comprehensive literature review on the exposure of financial assets to transition risk. Their findings indicate that the level of exposure varies significantly, ranging from 2% to 20% depending on the sector and geographic region. Similarly, the TCFD estimates that companies could incur carbon pricing costs of up to USD 283 billion, potentially placing 13% of earnings at risk by 2025. These figures align closely with the estimates presented in this paper.

Credit risk measure We apply the Emambakhsh *et al.* (2023) sensitivity to measures the impact on the probability of default and spread and generalize the impact on the companies within the above mentioned Equity index in the context of this illustrative exercise. Figure 20a illustrates the results. We note that shocks percentiles are relatively homogeneous in transition scenarios. The only very different scenario is the case with limited BECCS and the other differ mostly by level of ambition. There are winner in Utilities, Materials and Consumer Staples sectors.

Table 7 gives the figures associated with percentiles illustrated on Figure 20a, focusing on the short term horizon (2030). It shows that climate policies differently impacts credit spreads across sectors, with higher excess-spreads indicating increased risk and cost of debt compared to the baseline level.[36] Sectors like Energy, Materials, Consumer Staples and Utilities face the highest costs under aggressive climate scenarios (1.5°C), reflecting their vulnerability to transition risks, such as regulatory changes and increased production costs. Indeed, the 1.5°C scenario, Energy faces a high mean spread of 64 bps, signaling significant perceived risk in this sector. It even reaches 103 in 2040 while Materials reaches 45 (see Table 8). Meanwhile, Health Care, Financials, and Real Estate[37] maintain low spreads, indicating resilience and less exposure to climate-related financial risks. More interestingly, the percentiles give more robust information as the means are strongly distorted by extreme values.

In less stringent 2°C scenarios, most sectors experience reduced credit spreads, suggesting that delayed climate action eases short-term financial pressure. This is especially true for the Energy (64 bps to 10 bps between 1.5°C and 2°C delayed) and materials (24 to 3 bps respectively). Consumer Stapes sees even its spread becoming negative in the 2C delayed scenario. However, this could lead to greater long-term risks as delayed adjustments may become more abrupt and costly. Overall, stringent climate policies drive higher debt costs for sectors closely tied to fossil fuels or resource dependency, while more resilient sectors, such as Health Care and Financials, appear relatively stable across scenarios.

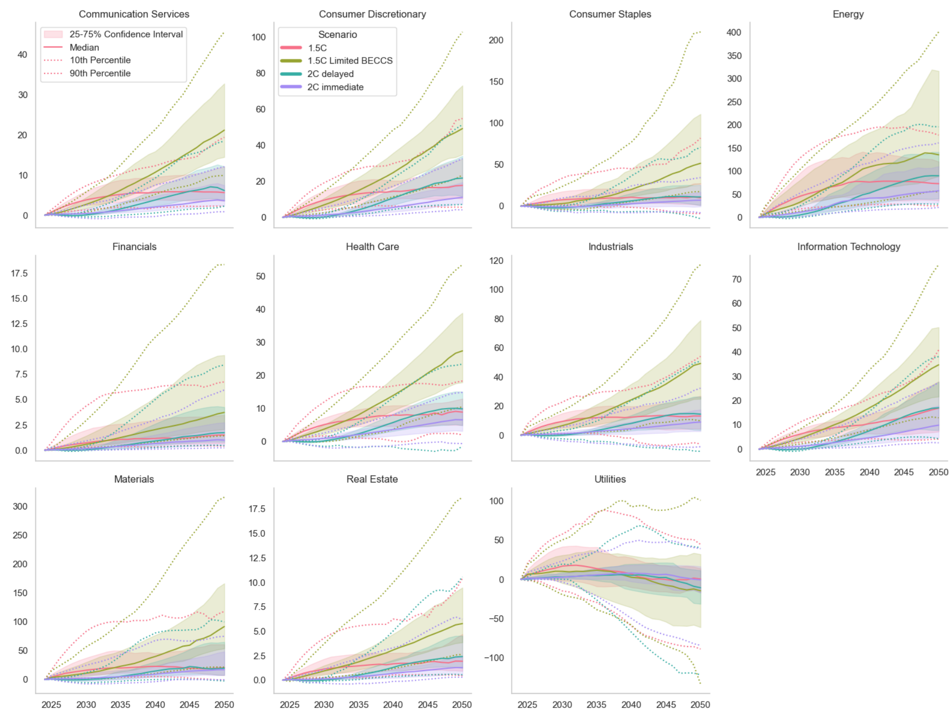
In fact, we can also consider several scenarios superposed and play on several assumptions (mechanism, pass-through, delays, etc.) and define the VaR (Desnos *et al.*, 2023) of each actor and of the portfolio for both equity and bonds portfolio. For example, Figure 20b, presents a version of Figure 20a without the specification of scenarios.

[36]Note that the baseline assumes the current trends continuation, which includes a decrease of GHG during recent years.

[37]By contrast, Health Care indeed maintains a relatively low mean excess-spread of 6.2 bps, and Financials sits at just 1.5 bps under the same 1.5°C scenario, reflecting their resilience to climate-related financial risks. In the 2°C delayed scenario, Utilities has a mean spread of 7.4 bps compared to its 1.5°C spread of 24.5 bps, illustrating equivalent immediate financial pressure and potential long-term risk.

Figure 20: Excess spread (in bps)

(a) Statistics grouped by transition scenarios



(b) Overall statistics

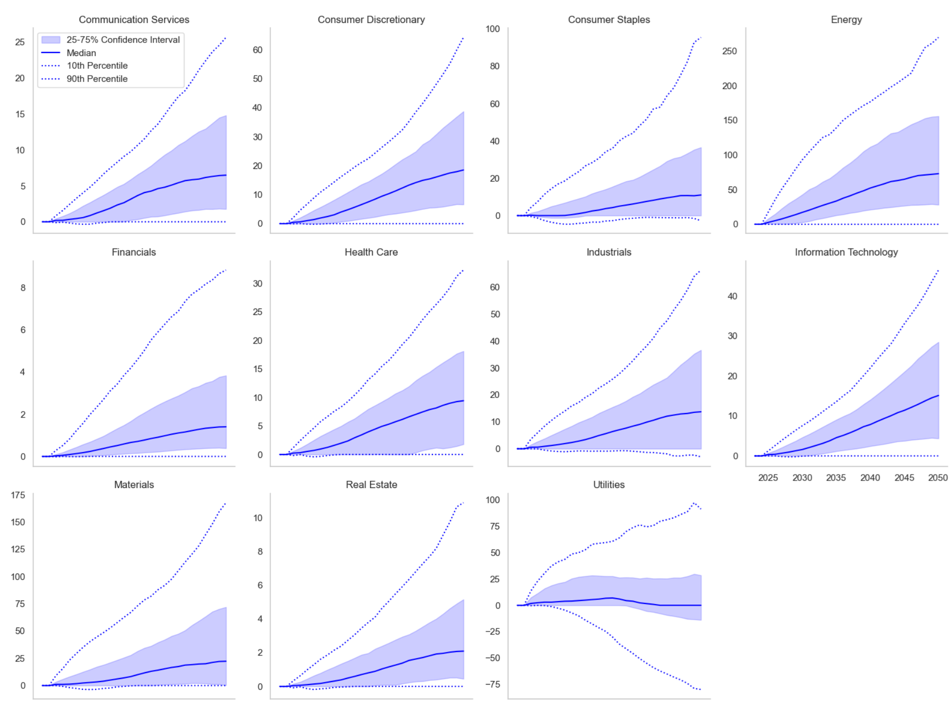


Table 7: Credit Spread impact across investment sectors (in bps) by 2030

Sectors	scenario	mean	10th	25th	median	75th	90th
Energy	1.5C	64.00	18.53	30.77	46.14	96.82	127.45
	1.5C Ltd BECCS	53.32	13.68	23.75	33.45	81.27	103.30
	2C delayed	10.47	-0.44	2.02	5.65	13.38	25.65
	2C immediate	22.54	2.17	5.92	11.56	26.49	53.03
Utilities	1.5C	24.51	-14.82	-1.80	16.96	41.66	60.00
	1.5C Ltd BECCS	17.38	-19.53	-4.89	10.27	30.06	50.49
	2C delayed	7.37	-0.06	1.66	2.95	9.06	19.70
	2C immediate	7.24	-3.56	0.29	2.70	6.95	23.40
Com. Services	1.5C	4.18	1.29	2.53	3.82	5.97	7.33
	1.5C Ltd BECCS	2.92	0.80	1.71	2.70	4.42	5.77
	2C delayed	0.04	-0.40	-0.06	0.09	0.26	0.99
	2C immediate	0.66	-0.76	0.20	0.45	1.62	2.53
Cons. Discretionary	1.5C	11.06	4.13	5.65	9.56	14.70	19.17
	1.5C Ltd BECCS	8.02	2.62	4.24	6.93	10.64	14.42
	2C delayed	0.56	-0.52	-0.06	0.21	0.70	1.71
	2C immediate	2.29	0.27	0.65	1.27	3.10	5.33
Consumer Staples	1.5C	16.98	1.98	4.26	7.65	17.60	33.70
	1.5C Ltd BECCS	9.09	-4.04	0.39	3.18	8.86	23.74
	2C delayed	-2.07	-6.27	-3.73	-1.89	-0.77	0.62
	2C immediate	0.08	-5.62	-2.85	-0.84	1.84	9.83
Financials	1.5C	1.54	0.29	0.46	0.72	1.98	4.37
	1.5C Ltd BECCS	1.11	0.20	0.33	0.58	1.42	2.93
	2C delayed	0.09	-0.03	0.01	0.05	0.14	0.38
	2C immediate	0.34	0.01	0.06	0.18	0.42	0.92
Health Care	1.5C	6.21	1.73	3.53	5.19	7.12	11.99
	1.5C Ltd BECCS	4.06	-0.03	2.20	3.91	5.18	8.59
	2C delayed	0.23	-1.45	0.01	0.19	0.48	1.05
	2C immediate	0.92	-1.78	0.35	0.97	1.67	2.64
Industrials	1.5C	11.85	1.25	5.17	9.60	14.99	22.71
	1.5C Ltd BECCS	8.02	0.73	3.50	6.64	9.83	16.82
	2C delayed	0.53	-2.46	-0.52	0.09	0.74	3.39
	2C immediate	1.69	-3.82	0.03	1.05	2.43	5.60
Inf. Technology	1.5C	6.35	2.80	4.12	6.24	8.30	11.20
	1.5C Ltd BECCS	4.47	2.12	3.02	4.51	6.17	8.32
	2C delayed	0.15	-0.72	-0.21	0.02	0.29	0.64
	2C immediate	1.70	0.12	0.37	1.17	2.27	4.27
Materials	1.5C	28.83	2.54	7.96	16.17	37.03	83.42
	1.5C Ltd BECCS	22.44	0.55	5.64	11.00	29.86	56.62
	2C delayed	2.94	-5.20	-2.32	-0.09	2.49	11.89
	2C immediate	8.46	-7.72	-1.58	2.39	10.25	24.61
Real Estate	1.5C	1.59	0.28	0.62	1.14	2.32	4.31
	1.5C Ltd BECCS	1.11	0.25	0.53	0.95	1.51	3.72
	2C delayed	0.00	-0.14	0.00	0.01	0.04	0.25
	2C immediate	0.06	-0.32	0.05	0.13	0.32	1.12

Table 8: Credit Spread impact across investment sectors (in bps) by 2040

Sectors	scenario	mean	10th	25th	median	75th	90th
Energy	1.5C	103.29	27.83	41.97	76.47	137.77	189.15
	1.5C Ltd BECCS	133.22	31.87	56.23	109.29	183.51	226.03
	2C delayed	75.27	20.63	27.35	52.73	95.59	140.64
	2C immediate	61.47	15.36	22.95	41.75	76.65	117.63
Utilities	1.5C	7.30	-59.67	-10.20	6.83	27.64	81.11
	1.5C Ltd BECCS	4.53	-58.53	-36.06	2.57	30.17	98.56
	2C delayed	-1.72	-67.59	-13.64	5.13	19.61	63.85
	2C immediate	3.02	-49.92	-2.72	8.10	18.36	47.78
Com. Services	1.5C	6.48	1.94	3.84	5.73	9.52	12.31
	1.5C Ltd BECCS	12.06	5.21	7.56	10.69	15.90	21.34
	2C delayed	4.56	0.57	2.36	3.80	6.56	9.25
	2C immediate	3.08	-0.32	1.18	2.06	4.72	7.51
Cons. Discretionary	1.5C	16.46	6.29	9.99	14.33	20.27	29.90
	1.5C Ltd BECCS	27.80	11.42	17.21	24.83	36.10	48.60
	2C delayed	12.22	4.38	6.86	10.73	15.56	21.87
	2C immediate	8.09	1.53	3.09	5.51	10.69	17.32
Consumer Staples	1.5C	16.63	-1.46	3.75	10.77	19.52	46.52
	1.5C Ltd BECCS	37.01	5.69	11.24	20.12	43.18	76.99
	2C delayed	12.52	-6.47	2.68	6.34	15.44	36.78
	2C immediate	5.66	-7.68	-0.74	2.88	7.46	24.35
Financials	1.5C	2.39	0.33	0.64	1.15	2.95	6.21
	1.5C Ltd BECCS	4.18	0.82	1.19	2.04	5.23	11.17
	2C delayed	1.86	0.27	0.49	0.92	2.62	5.01
	2C immediate	1.25	0.11	0.27	0.66	1.52	3.01
Health Care	1.5C	8.78	0.10	4.70	8.02	10.98	16.77
	1.5C Ltd BECCS	14.80	3.74	9.32	13.99	19.41	28.67
	2C delayed	6.21	-1.53	3.19	5.80	8.41	13.33
	2C immediate	4.06	-1.19	1.74	3.66	5.98	8.10
Industrials	1.5C	14.11	-1.86	4.64	12.27	19.78	31.81
	1.5C Ltd BECCS	24.74	4.17	12.18	24.33	35.58	54.07
	2C delayed	8.35	-7.19	3.11	8.08	13.98	24.00
	2C immediate	5.99	-6.19	0.67	4.48	9.19	17.96
Inf. Technology	1.5C	10.90	4.25	6.44	10.54	14.39	20.82
	1.5C Ltd BECCS	16.52	7.97	11.20	17.06	23.17	32.67
	2C delayed	8.33	3.14	4.92	7.59	11.11	15.54
	2C immediate	6.33	0.93	2.13	4.71	8.54	14.07
Materials	1.5C	44.58	5.51	13.38	22.81	46.44	102.08
	1.5C Ltd BECCS	68.42	10.51	22.67	39.96	76.69	159.12
	2C delayed	30.58	0.08	5.48	14.77	32.47	73.89
	2C immediate	24.74	-3.59	3.95	9.36	23.54	64.76
Real Estate	1.5C	2.02	0.54	0.99	1.67	2.84	5.88
	1.5C Ltd BECCS	3.67	1.18	1.93	3.09	4.85	9.96
	2C delayed	1.67	0.36	0.80	1.31	2.25	4.90
	2C immediate	0.79	-0.12	0.23	0.70	1.21	3.30

4 Conclusion

This working paper provides a comprehensive examination of the implications of climate change policies on various sectors, revealing critical insights that underscore the need for strategic adaptation and planning. Our approach reconciles top-down modeling based on scenario narratives with highly granular information on company activities.[38]

The analysis highlights the pronounced vulnerabilities faced by the Energy sector as well as sectors directly related to it. They are projected to experience significant and persistent declines in earnings under ambitious climate scenarios, particularly the 1.5°C and 1.5°C Limited BECCS pathways. The data indicates that companies heavily reliant on fossil fuels may encounter unprofitable operations as stringent policies and reduced demand for fossil fuels take effect, particularly around 2030-2035, unless these companies behave strategically to avoid these losses. This trend underscores the necessity for these companies to transition towards more sustainable practices to remain viable in a rapidly changing regulatory environment.

In contrast, the Utilities sector exhibits a more resilient earnings trajectory, with projections indicating a recovery post-2035, especially under moderate climate scenarios. This resilience can be attributed to the sector's capacity ability to shift to renewable energy sources and transition away from high-carbon assets. The analysis reveals that while the Utilities sector may face volatility, particularly under aggressive decarbonization scenarios, it is better positioned to mitigate climate-related financial risks through diversification and strategic investments in sustainable technologies.

Furthermore, the findings regarding sectors such as Financials, Information Technology, Consumer Discretionary, and Health Care indicate that while these sectors may be less impacted overall, they are still susceptible to substantial revenue losses, potentially amounting to hundreds of billions of dollars by 2050 under various scenarios. This highlights the interconnectedness of sectors in global economies, where a major shock to one sector can reverberate through supply chains and impact related industries. The analysis also emphasizes the importance of considering both direct and indirect costs associated with climate change, as companies may face significant financial repercussions from regulatory changes and shifts in consumer behavior.

The weighted actualized shift DCF ratios further illustrate the broader market's vulnerability to climate change, with significant negative ratios across all scenarios. This reinforces the need for companies to adopt proactive measures in response to evolving climate policies. As the landscape of climate finance continues to shift, firms that embrace sustainability and invest in innovative solutions will likely be better positioned to navigate the challenges ahead. The analysis provides figures for every sector of the economy (for example, the industrials sector of the MSCI World has a -2.36% lower 2030 discounted cash flow in the 1.5C scenario as compared to the baseline). By 2040, the credit spread impact will be 25 bps higher in average if the 1.5C scenario with limited BECCS materializes as compared to current trends. A radical shift from the baseline to the 2°C and 1.5°C scenarios would imply losses of up

[38] In line with standard methodological components of most stress-testing exercise, e.g. EIOPA (2022, p. 14).

to 7% and 12%, respectively, using our discounted cash flow approach, keeping the current importance of each company in the index.

Ultimately, this working paper serves as a call to action for investors, policymakers, and corporate leaders to recognize the profound implications of climate change on financial performance and to prioritize strategic planning and adaptation. By fostering a deeper understanding of the sector-specific impacts of climate policies, stakeholders can make informed decisions that not only mitigate risks but also capitalize on emerging opportunities in a transitioning economy. The findings presented herein emphasize the critical importance of integrating climate considerations into financial and operational strategies, as the path towards a sustainable future will require collective efforts across all sectors of the economy.

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A Complementary materials

Smoothing process for temporal downscaling The MIT EPPA model forecasts economic variables over time, incorporating periodic revisions. These changes can be viewed as shocks, where values shift abruptly from one level to another, representing a plausible scenario. As climate risks become increasingly evident, governments worldwide are likely to be motivated to take more immediate action. However, it is also anticipated that they will allow some time for businesses to adapt, ensuring that the transition is not overly abrupt. On the other hand, big players often have massive challenges to shift their activities from fossil fuel-emitting businesses to ones that are more virtuous. Overall, due to uncertainty going forward as regards the exact timing of economic variable revisions, we have implemented a polynomial smoothing on projections using a third-order polynomial.

Given a dataset represented as a set of points (t_i, χ_i) where t denotes time and χ denotes the variable values, the polynomial smoothing process can be described mathematically as follows:

Define a set of invariant points based on specified intervals:

$$\text{Invariant Points} = \{\chi \mid \chi = \text{start\_year} + k \cdot \text{interval},\, k \in \mathbb{Z},\, \chi \leq \text{end\_year}\}$$

Let C be the set of indices corresponding to the invariant points:

$$C = \{i \mid t_i \in \text{Invariant Points}\}$$

For each segment defined by consecutive conserved points (t_{C_j}, χ_{C_j}) and $(t_{C_{j+1}}, \chi_{C_{j+1}})$, fit a polynomial of degree d:

$$p(t) = a_d t^d + a_{d-1} t^{d-1} + \ldots + a_1 t + a_0$$

where the coefficients a_k are determined by minimizing the least squares error:

$$\text{minimize} \sum_{i \in [C_j, C_{j+1}]} (\chi_i - p(t_i))^2$$

Apply the polynomial function to the segment:

$$\chi_{\text{smooth}}(t) = p(t) \quad \text{for } t \in [t_{C_j}, t_{C_{j+1}}]$$

Ensure that the values at the invariant points are preserved:

$$\chi_{\text{smooth}}(t_{C_j}) = \chi_{C_j}$$

$$\chi_{\text{smooth}}(t_{C_{j+1}}) = \chi_{C_{j+1}}$$

The final smoothed values are represented as:

$$\chi_{\text{final}} = \{\chi_{\text{smooth}}(t_i) \mid t_i \text{ in the original dataset}\}$$

By conserving the start and end points at the beginning and end of each interval, we make sure that the projection stays true to the initial model.

Statistical Testing to Compare 2°C Immediate and 2°C Delayed Scenarios To determine if the 2°C immediate scenario is significantly different from the 2°C delayed scenario, we perform the Mann-Whitney U Test under the standard hypothesis of the delta of DCF ratios are floored to -100%. Since 75% of the companies have equal or worse DCF ratios under the 2°C delayed scenario and the average DCF ratio is slightly below the 2°C immediate scenario, this test would validate the "statistically worse" scenario assumption. This non-parametric test does not assume a normal distribution of the data and is used to compare the distributions of two independent samples. We can see in Table **??** that the 2°C delayed presents an average lower value than the 2°C immediate scenario in every assumption. The hypotheses are:

- Null Hypothesis (H_0): The distributions of actualized discounted cash flows under the 2°C immediate and 2°C delayed scenarios are the same.
- Alternative Hypothesis (H_1): The distributions of actualized discounted cash flows under the 2°C immediate and 2°C delayed scenarios are different.

The Mann-Whitney U statistic is calculated as follows:

$$U_1 = R_1 - \frac{n_1(n_1+1)}{2} \quad \text{and} \quad U_2 = R_2 - \frac{n_2(n_2+1)}{2}$$

where R_1 and R_2 are the sums of the ranks for the two samples, and n_1 and n_2 are the sample sizes (here the sample sizes are identical so that $n_1 = n_2 = n$). The U statistic is:

$$U = \min(U_1, U_2)$$

The mean μ_U and standard deviation σ_U of the U statistic are given by:

$$\mu_U = \frac{n^2}{2} \quad \text{and} \quad \sigma_U = \sqrt{\frac{n^2(2n+1)}{12}}$$

If there are ties in the data, the standard deviation σ_U is adjusted as follows:

$$\sigma_{U,ties} = \sqrt{\frac{n^2}{12}\left(2n+1-\frac{\sum_i(t_i^3-t_i)}{2n(2n-1)}\right)}$$

where T_i is the number of tied ranks. The z-score is calculated as:

$$z = \frac{U-\mu_U}{\sigma_U}$$

he p-value is calculated based on the z-score and is used to determine the significance of the result:

- U-statistic: $U \approx 10^6$
- P-value: $p \approx 4 \times 10^{-5} < 0.05$, therefore we reject the null hypothesis and conclude that the 2 scenarios are significantly different.

Table 9: Financial statements modeling based on EPPA variables

Variable	Step	Calculus
Sector Value-added	(*)	Extrapolated with EPPA (Eq. (6))
GDP	(*)	Sum of value-added country wise
Revenues	(a)	EPPA (equilibrium solution, Eq. (1))
Direct Cost / indirect cost	(b)	Extrapolated in EPPA (Eq. (2) and (4))
Gross Profits	(c)	(a) – (b)
Operating expenses	(d)	
EBITDA	(e)	(c) – (d)
Depreciation and amortization	(f)	
EBIT	(g)	(e) – (f)
Interest expense	(h)	
Tax expense	(i)	
Net Income	(j)	(g) – (h) – (i)
Total Debt	(k)	Fixed
Total assets	(l)	Equation (5) - Alogoskoufis *et al.* (2021)
CAPEX	(m)	Equation (5)
Free Cash Flows	(n)	Equation (8)
Discounted cash-flow/Equity value	(o)	Equation (16)
Leverage	(p)	(k) / (l)
Profitability	(q)	(j) / (l)
Probability of Default	(r)	Equation (18) - Alogoskoufis *et al.* (2021)
Bond Spread	(s)	Equation (19)

Table 10: Sector with geographic allocation in RBICS

l1 Name	**Geographical indication**
Business Services	FALSE
Consumer Services	TRUE
Consumer Cyclicals	FALSE
Energy	TRUE
Finance	TRUE
Health Care	FALSE
Industrials	TRUE
Non-Energy Materials	TRUE
Consumer Non-Cyclicals	TRUE
Technology	FALSE
Telecommunications	TRUE
Utilities	TRUE
Other	FALSE
Non-Corporate	FALSE

Table 11: Example of the RBICS allocation to EPPA

Business segment	L6 Name	L6 Description	GTAP Description	EPPA7
Contract Drilling - Floaters	*Offshore Oil and Gas Well Drilling*	*Drilling of offshore oil/gas wells.*	Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction excluding surveying (part)	oil
Contract Drilling - Jack-Ups	*Offshore Oil and Gas Well Drilling*	*Drilling of offshore oil/gas wells.*	Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction excluding surveying (part)	oil
Oil & Gas	*Oil and Gas Engineering and Construction*	*Includes platform construction and engineering (reservoir management, supply chain management, pipe laying, general plant maintenance) services.*	Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction excluding surveying (part)	oil
...	...	...	...	...
...	...	...	...	...

Table 12: Example of geographic information of RBICS converted in EPPA region(s)

l6 Geography	Description	EPPA
Africa	Africa	AFR
Asia except Australia, China and Southeast Asia.	Rest of Asia	RUS+ROE+MES+REA+IND+JPN+KOR
Asia/Pacific	Pan-Asia	RUS+REA+IND+ASI+KOR+JPN+IDZ+ANZ+CHN
Asia/Pacific region (excluding Australia and New Zealand).	Other Asia/Pacific	RUS+KOR+JPN+CHN+ASI+IDZ+ANZ
Asia/Pacific region, excluding China.	Other Asia, Asia/Pacific region outside of China.	RUS+REA+IND+ASI+KOR+JPN+IDZ+ANZ
Asia/Pacific region, excluding China and Australia/New Zealand.	Other Asia, Asia/Pacific region outside of China.	RUS+REA+IND+ASI+KOR+JPN+IDZ
Australia	Asia	ANZ
Australia New Zealand & Oceania	Asia	ANZ
Australia/New Zealand	Australia/NZ	ANZ
Canada	Western Canada, located in Alberta and Saskatchewan, British Columbia	CAN
Central & South America and Mexico	Latin America	MEX+LAM+BRA
China	Asia/Pacific	CHN
Eastern Europe	Europe	EUR
Europe	Europe	EUR
International	Multinational	GLB
Latin America	Latin America	LAM+BRA
MENA	Middle East and North Africa region (MENA).	MES+AFR
Middle East	Middle East	MES
Middle East and Africa	Middle East/Africa	MES+AFR
North Sea	United Kingdom. Germany, Denmark and the Netherlands, Other Europe	EUR
Northern Europe	Europe	EUR
Pan-Americas	Americas	CAN+USA+MEX+BRA+LAM
Pan-Europe	Europe	EUR
Russia/CIS/FSU	Russia and the CIS (Commonwealth of Independent States) or the Former Soviet Union (FSU). Includes Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.	RUS+ROE
Southern Europe	Europe	EUR
Sub-Saharan	Sub-Saharan African region. Major countries include Nigeria, Angola, Ghana, Gabon, Guinea and Congo.	AFR
United States	Pan-US, US, Appalachian and Michigan Basins, Alaska, California and the Rocky Mountain States, Other US, New Mexico, Texas, Louisiana and Mississippi, Gulf of Mexico.	USA
US and Canada	United States and Canada	USA+CAN
Western Europe	Europe	EUR
Other Americas (excluding US)	Americas	CAN+MEX+BRA+LAM
Europe	Europe	EUR
Southeast Asia	Southeast Asia	ANZ+ASI+IDZ
Americas (Excluding US)	Americas (Excluding US)	CAN+MEX+BRA+LAM
Mexico	Mexico	MEX
Europe, Middle East and Africa	Europe, Middle East and Africa	EUR+AFR+MES

Table 13: Calibration FCF- AR models

Variable	Role	r.squared	adj.r.squared	sigma	df	nobs
FCF (3V)	Explicit	71%	71%	568757	3	119350
FCF (without depr with Lag)	VAR	64%	64%	606196	3	102961
FCF (Net Income Only)	VAR	63%	63%	633966	1	120129

Figure 21: Activity allocation flow chart

(a) Sector

(b) Geographies

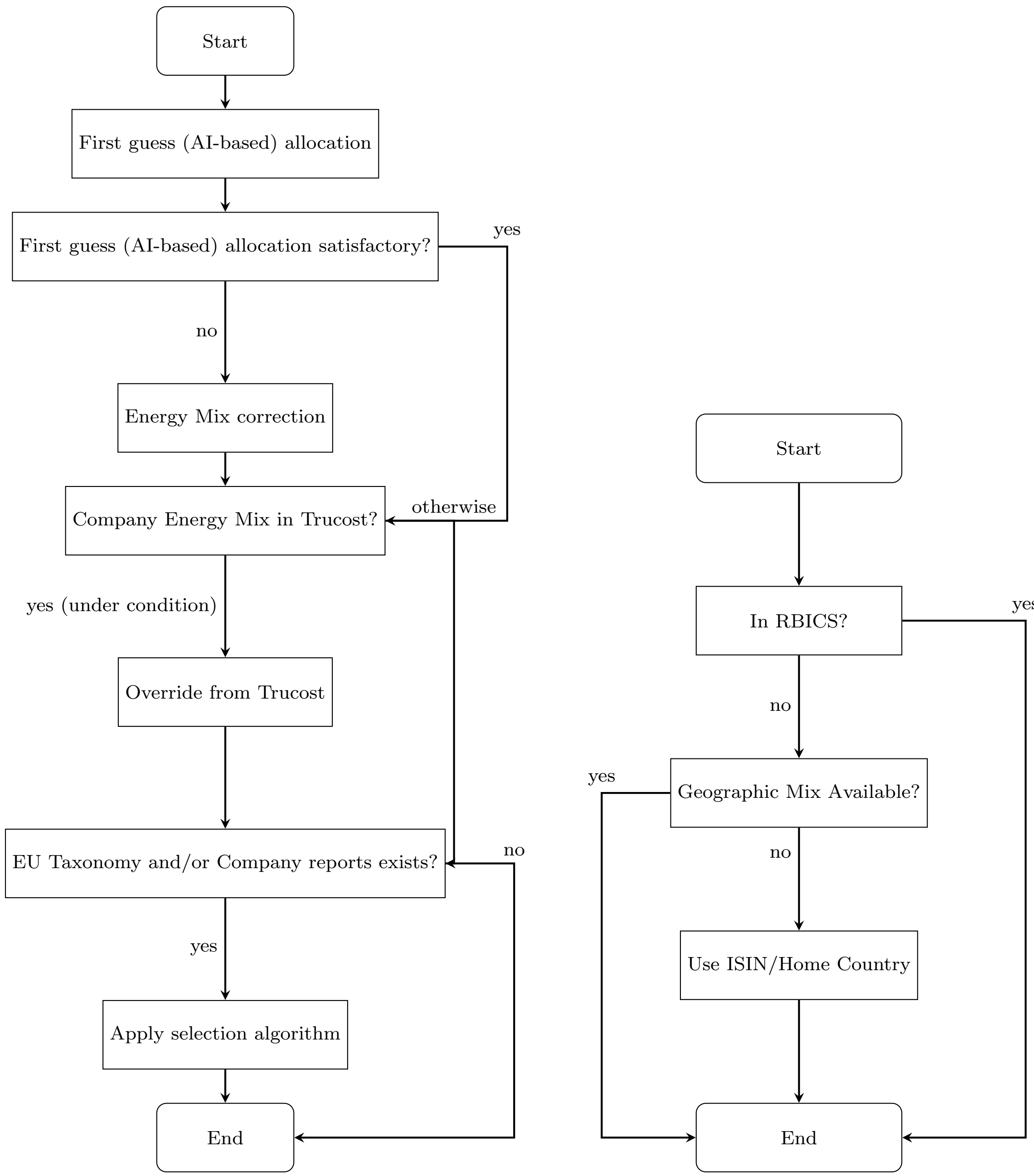


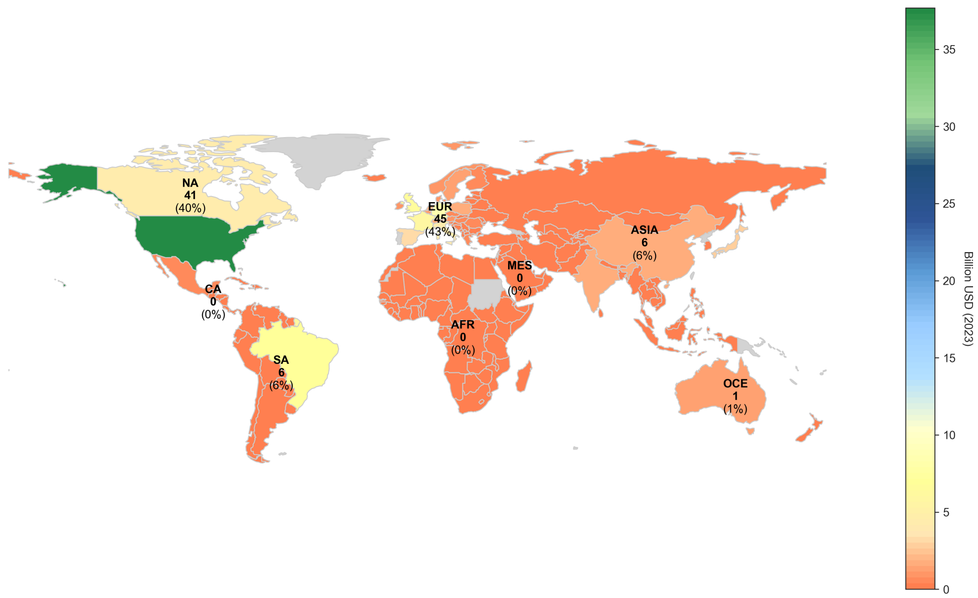
Table 14: Explicit modeling of FCFF including capex and depreciation - Robustness check

GICS1 Name	term	estimate	std.error	statistic	p.value	Model
Communication Services	FCF lag	0.00	0.005	-0.75	0.45439191	FCF
	Net Income	1.15	0.019	59.44	0	FCF
	Capex	0.06	0.011	5.68	1.4627E-08	FCF
Consumer Discretionary	FCF lag	0.05	0.003	18.62	2.4222E-76	FCF
	Net Income	0.54	0.005	106.23	0	FCF
	Capex	-0.48	0.008	-63.16	0	FCF
Health Care	FCF lag	0.00	0.002	0.19	0.85004257	FCF
	Net Income	0.64	0.010	66.44	0	FCF
	Capex	-0.15	0.020	-7.52	5.8951E-14	FCF
Consumer Staples	FCF lag	0.01	0.004	2.36	0.01823205	FCF
	Net Income	1.07	0.008	127.50	0	FCF
	Capex	-0.36	0.012	-30.55	1.248E-192	FCF
Financials	FCF lag	0.02	0.006	3.42	0.00062921	FCF
	Net Income	1.05	0.013	79.13	0	FCF
	Capex	2.79	0.080	34.99	6.968E-258	FCF
Information Technology	FCF lag	0.15	0.005	29.28	1.782E-181	FCF
	Net Income	0.88	0.007	125.71	0	FCF
	Capex	-0.34	0.005	-61.32	0	FCF
Industrials	FCF lag	0.02	0.004	4.90	9.6062E-07	FCF
	Net Income	0.83	0.006	131.41	0	FCF
	Capex	-0.13	0.008	-16.02	2.0772E-57	FCF
Real Estate	FCF lag	0.06	0.002	30.54	1.697E-192	FCF
	Net Income	0.40	0.010	39.77	0	FCF
	Capex	-1.03	0.024	-42.74	0	FCF
Utilities	FCF lag	0.03	0.003	8.54	1.8451E-17	FCF
	Net Income	1.09	0.013	81.10	0	FCF
	Capex	-0.37	0.009	-39.56	4.451E-287	FCF
Materials	FCF lag	0.10	0.008	12.55	7.3128E-36	FCF
	Net Income	0.67	0.009	75.26	0	FCF
	Capex	-0.36	0.008	-43.02	0	FCF
Energy	FCF lag	0.12	0.028	4.53	5.939E-06	FCF
	Net Income	0.89	0.013	68.10	0	FCF
	Capex	-0.15	0.025	-6.03	1.7777E-09	FCF
Communication Services	FCF lag	0.00	0.00	-0.72	0.47290949	FCF (without Capex)
	Net Income	1.25	0.01	151.27	0	FCF (without Capex)
Consumer Discretionary	FCF lag	0.06	0.00	17.44	2.5587E-67	FCF (without Capex)
	Net Income	0.40	0.01	75.77	0	FCF (without Capex)
Health Care	FCF lag	0.00	0.00	0.18	0.85376337	FCF (without Capex)
	Net Income	0.57	0.00	137.01	0	FCF (without Capex)
Consumer Staples	FCF lag	0.01	0.00	1.14	0.25490597	FCF (without Capex)
	Net Income	0.89	0.01	141.83	0	FCF (without Capex)
Financials	FCF lag	0.03	0.01	4.88	1.0753E-06	FCF (without Capex)
	Net Income	1.45	0.01	210.27	0	FCF (without Capex)
Information Technology	FCF lag	0.20	0.01	32.96	4.527E-227	FCF (without Capex)
	Net Income	0.50	0.00	138.73	0	FCF (without Capex)
Industrials	FCF lag	0.02	0.00	4.70	2.5901E-06	FCF (without Capex)
	Net Income	0.76	0.00	171.69	0	FCF (without Capex)
Real Estate	FCF lag	0.04	0.00	19.63	1.3186E-83	FCF (without Capex)
	Net Income	0.32	0.01	28.31	4.546E-167	FCF (without Capex)
Utilities	FCF lag	0.03	0.00	7.61	3.459E-14	FCF (without Capex)
	Net Income	1.04	0.02	65.68	0	FCF (without Capex)
Materials	FCF lag	0.15	0.01	16.55	1.0407E-60	FCF (without Capex)
	Net Income	0.42	0.01	57.08	0	FCF (without Capex)
Energy	FCF lag	0.14	0.03	5.13	2.9509E-07	FCF (without Capex)
	Net Income	0.84	0.01	83.20	0	FCF (without Capex)

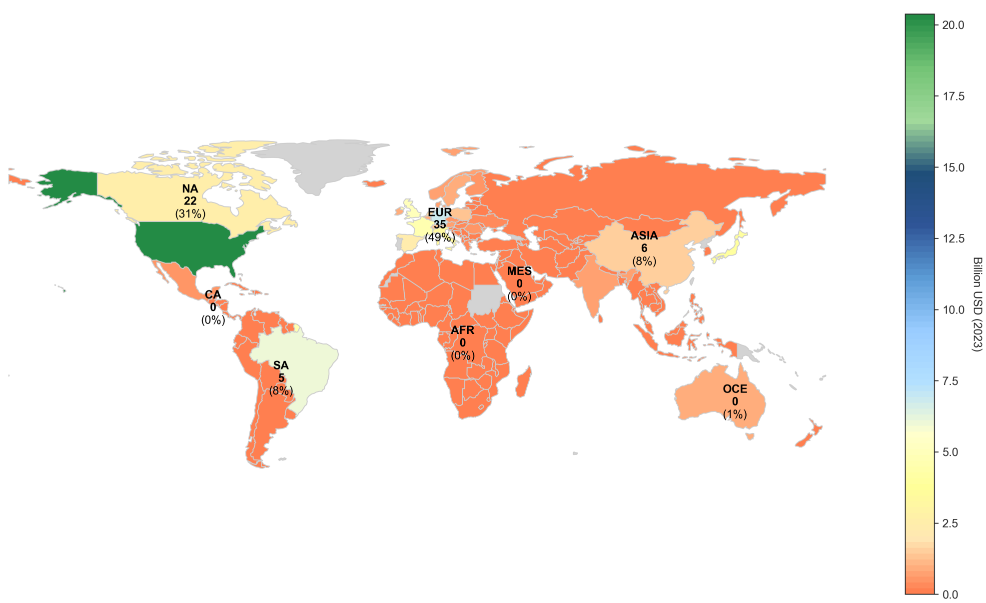
Table 15: Inclusion vs. Exclusion of Capex AR process describing FCF - Robustness check

GICS1 Name	term	estimate	std.error	statistic	p.value
Communication Services	Net Income	1.17	0.01	109.72	0
	Depr	1.02	0.01	91.51	0
	Capex	-0.76	0.01	-70.80	0
Consumer Discretionary	Net Income	0.59	0.00	130.79	0
	Depr	1.34	0.03	50.73	0
	Capex	-1.33	0.02	-73.97	0
Health Care	Net Income	0.49	0.01	63.84	0
	Depr	1.41	0.03	53.66	0
	Capex	-0.53	0.02	-30.80	3.275E-199
Consumer Staples	Net Income	0.96	0.01	156.74	0
	Depr	1.74	0.02	77.18	0
	Capex	-1.15	0.01	-89.27	0
Financials	Net Income	0.87	0.01	69.93	0
	Depr	6.38	0.15	42.73	0
	Capex	0.26	0.09	2.90	0.00376317
Information Technology	Net Income	0.86	0.01	151.75	0
	Depr	1.00	0.01	67.13	0
	Capex	-0.99	0.01	-95.17	0
Industrials	Net Income	0.58	0.01	92.73	0
	Depr	0.98	0.01	71.55	0
	Capex	-0.49	0.01	-58.32	0
Real Estate	Net Income	0.56	0.01	57.69	0
	Depr	0.71	0.04	18.21	1.1648E-72
	Capex	-1.17	0.03	-41.47	0
Utilities	Net Income	1.17	0.01	107.29	0
	Depr	1.05	0.03	41.24	0
	Capex	-1.09	0.02	-57.58	0
Materials	Net Income	0.53	0.01	68.71	0
	Depr	0.91	0.02	57.88	0
	Capex	-0.71	0.01	-80.11	0
Energy	Net Income	0.76	0.01	76.54	0
	Depr	1.51	0.03	56.18	0
	Capex	-1.02	0.02	-44.76	0

Figure 22: MSCI World Index: Costs by Geography



(a) Direct Costs by Geography



(b) Indirect Costs by Geography

Figure 23: Evolution of the earnings by sector in Europe

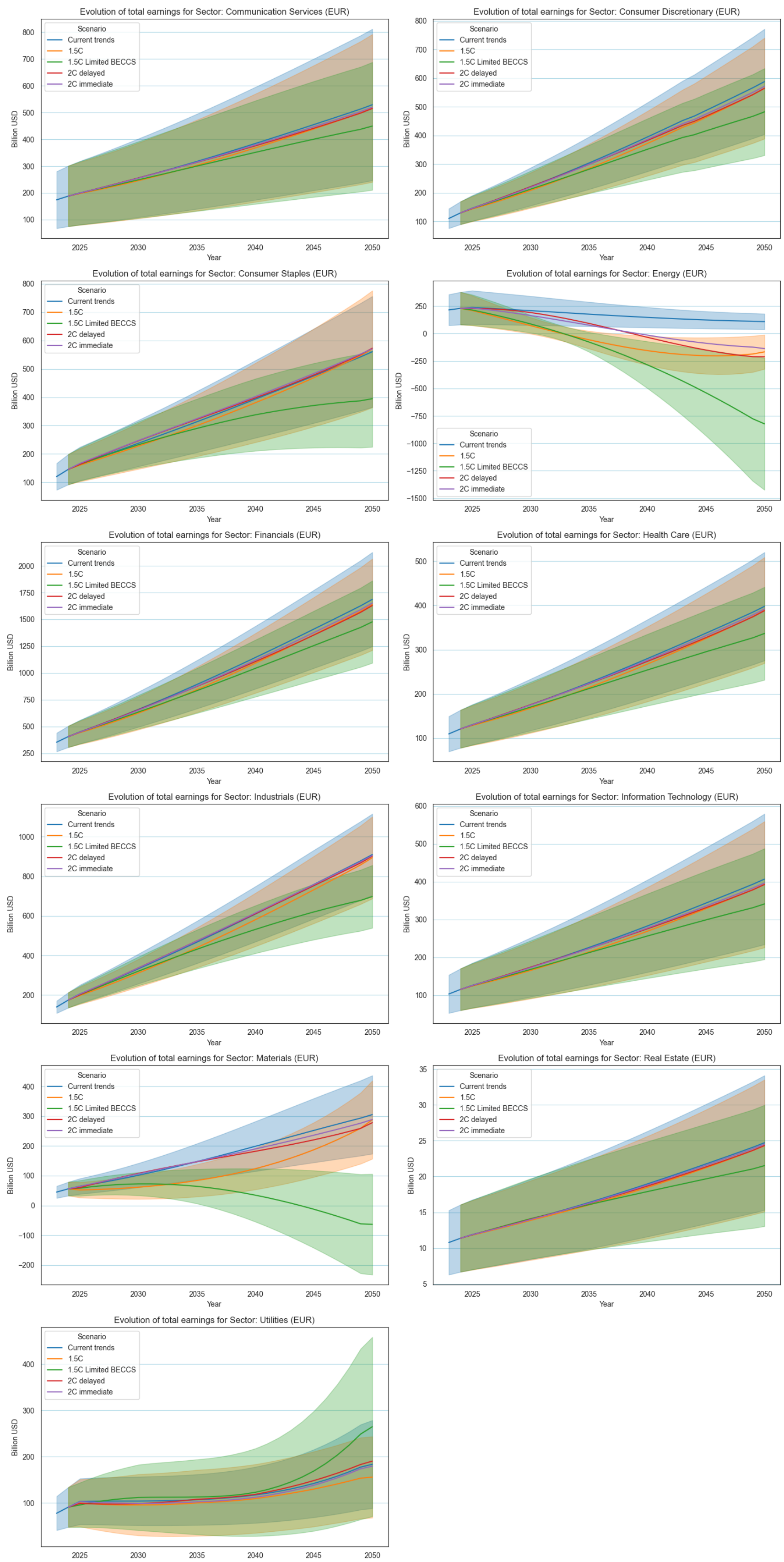
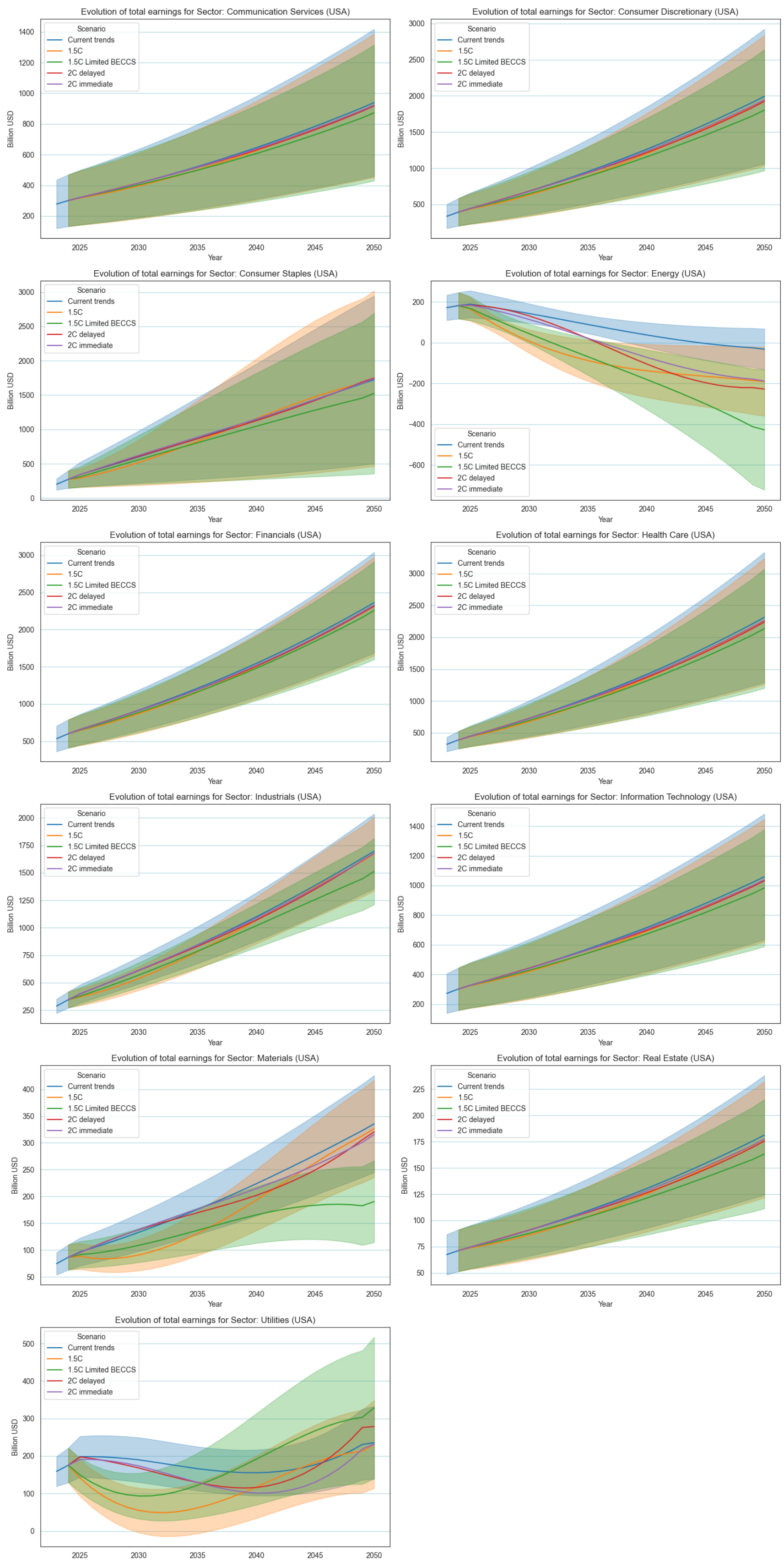


Figure 24: Evolution of the earnings by sector in the USA



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