The Cost for the Financial Sector if Firms Delay Climate Action

Moritz Baer, Jacob Kastl, Alissa Kleinnijenhuis, Jakob Thomae and Ben Caldecott

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Climate Stress Testing and Scenarios Project (CSTS), Oxford Sustainable Finance Group, University of Oxford & 2° Investing Initiative

The new Climate Stress Testing and Scenarios Project (CSTS) sits within the Oxford Sustainable Finance Group at the University of Oxford and is a joint project with the 2°Investing Initiative. CSTS is developing state-of-the-art analytical approaches around climate scenarios and stress testing to allow for a transparent, asset-level based assessment of the impact of climate and other long-term environmental risks on the soundness and stability of the financial system.

To find out more about the work of CSTS, contact moritz.baer@smithschool.ox.ac.uk.

About the Oxford Sustainable Finance Group

Aligning finance with sustainability is a necessary condition for tackling the environmental and social challenges facing humanity. It is also necessary for financial institutions and the broader financial system to manage the risks and capture the opportunities associated with the transition to global environmental sustainability.

The University of Oxford has world-leading researchers and research capabilities relevant to understanding these challenges and opportunities. The Oxford Sustainable Finance Group is the focal point for these activities and is situated in the University's Smith School of Enterprise and the Environment. The Oxford Sustainable Finance Group is a multidisciplinary research centre working to be the world's best place for research and teaching on sustainable finance and investment.

The Oxford Sustainable Finance Group is based in one of the world's great universities and the oldest university in the English-speaking world. We work with leading practitioners from across the investment chain (including actuaries, asset owners, asset managers, accountants, banks, data providers, investment consultants, lawyers, ratings agencies, stock exchanges), with firms and their management, and with experts from a wide range of related subject areas (including finance, economics, management, geography, data science, anthropology, climate science, law, area studies, psychology) within the University of Oxford and beyond. Since our foundation we have made significant and sustained contributions to the field, including in some of the following areas:

- Developing the concept of "stranded assets", now a core element of the theory and practice of sustainable finance.
- Contributions to the theory and practice of measuring environmental risks and impacts via new forms of geospatial data and analysis, including introducing the idea and importance of "spatial finance" and "asset-level data".
- Shaping the theory and practice of supervision as it relates to sustainability by working with the Bank of England, the central banks' and supervisors' Network for Greening the Financial System (NGFS), and the US Commodity Futures Trading Commission (CFTC), among others.
- Working with policymakers to design and implement policies to support sustainable finance, including through the UK Green Finance Taskforce, UK Green Finance Strategy, and the forthcoming UK Presidency of COP26.
- Nurturing the expansion of a rigorous academic community internationally by conceiving, founding, and co-chairing the Global Research Alliance for Sustainable Finance and Investment (GRASFI), an alliance of 30 global research universities promoting rigorous and impactful academic research on sustainable finance.

The Oxford Sustainable Finance Group's founding Director is Dr Ben Caldecott. For more information please visit: https://www.smithschool.ox.ac.uk/research/sustainable-finance

About 2° Investing Initiative and 1in1000

The 2° Investing Initiative (2DII) is an independent, non-profit think tank working to align financial markets and regulations with the Paris Agreement goals. Globally focused, with offices in Paris, New York, Berlin, London and Brussels, 2DII coordinates some of the world's largest research projects on sustainable finance. Its team of finance, climate, and risk experts develop research, tools and policy insights to help financial institutions and regulators hasten and adapt to the energy transition.

In order to ensure its independence and the intellectual integrity of its work, 2DII has a multi-stakeholder governance and funding structure, with representatives from a diverse array of financial institutions, governments and NGOs.

1in1000 is a new research program by 2°Investing Initiative that brings together new and existing research projects on long-termism, climate change and (inter-)connected future risks for financial markets, the economy and society. Its objective is to develop evidence and design tools, and build capacity to help financial institutions and supervisors mitigate and adapt to future risks and challenges. The programme focuses on climate change (inter-) connected risks and challenges, notably risks stemming from ecosystem services and biodiversity loss, as well as risks from social cohesion and resilience. To achieve this objective, 1in1000 operates in three main areas: i) Long-term metrics; (ii) Risk (management) tools and frameworks; and (iii) Policies and incentives.

About our funders

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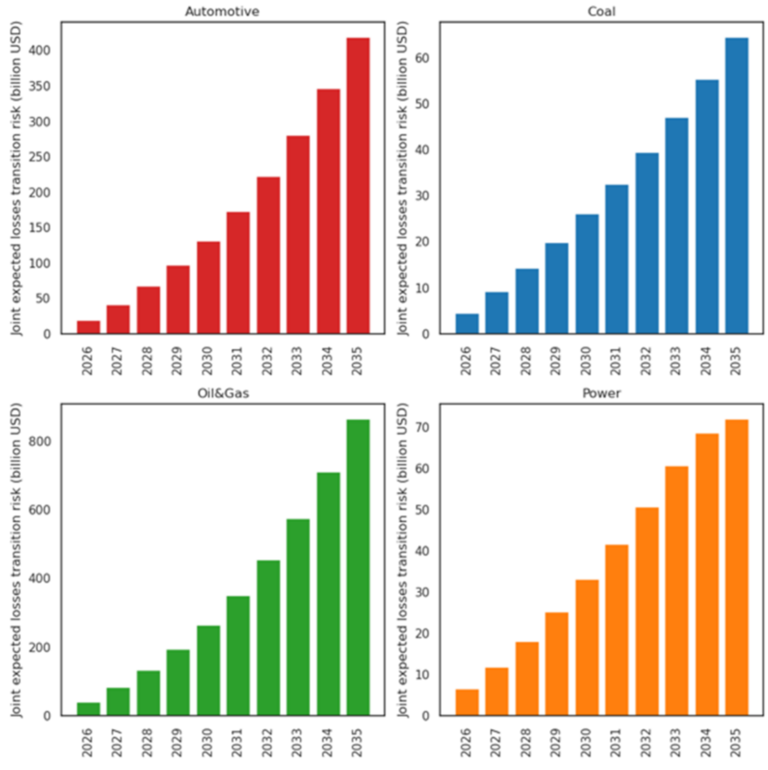
Executive Summary

In this report we estimate the additional costs for the financial sector when climate action by companies is delayed. To do this we model the impact on the equity value and the probability of default for publicly listed companies in polluting sectors resulting from climate-related transition risks that create financial losses.

To undertake this analysis, we have developed an exploratory bottom-up asset-level climate stress testing framework that translates climate-related transition shocks affecting individual firms to the shocks affecting the value of financial assets.[1] Using asset-level data we capture the transition impact on the profitability of publicly listed companies in four of the most climate-critical sectors globally: power generation, oil & gas, coal production and the automotive industry.

Additional yearly joint expected loss from changes in climate-related market and credit risk if transition is delayed beyond 2026



We find that analysed firms are insufficiently aligned with the net-zero transition, highlighting that even in a scenario where climate action is taken by these companies as early as 2026, the cost to the financial sector is estimated to be US$ 2.2 trillion in total.

We find that this financial cost increases by an additional US$ 150 billion for each year climate action by these companies is further delayed.

In our analysis we capture 598 ultimate parent companies that are responsible for between 29% and 84% of estimated global production in their respective sectors[2]. These companies represent

[1] Note that this is an exploratory model that we aim to continously improve through CSTS.

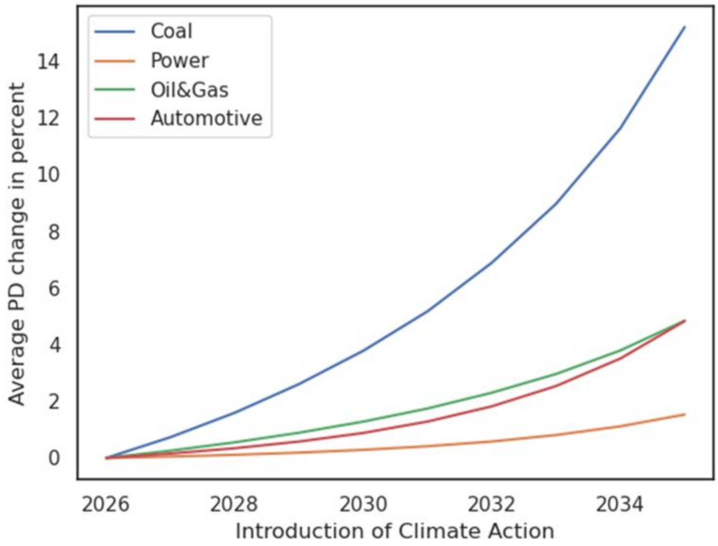
[2] We capture 39 ultimate public parent firms in the automotive sector, accounting for 84% of the estimated global production, 238 firms in the oil and gas sector accounting for 52%, 57 firms in the coal sector accounting for 29% and 264 firms in the power sector accounting for 38% of global production.

US$ 8.7 trillion in market capitalisation and have US$ 5 trillion in outstanding debt. We assume that the total equity and outstanding debt of these companies are held directly or indirectly by financial institutions.

Extrapolating our results by assuming firms not included in our analysis face the same climate-related transition risks, the yearly additional cost of delaying the transition beyond 2026 could then rise to US$ 272 billion every year sufficient climate action is not taken. Yet, this may still significantly underrepresent potential losses when considering a broader universe of sectors and potential risks of a delay to other actors, including governments and households, as well as network effects that may arise as a result.

Delaying the transition increases the probability of defaults (PDs) and impacts on equity valuations non-linearly. Assuming firms align their production with climate targets in 2030 rather than in 2026, we see coal firms' PDs increasing by around four percentage points and for oil & gas firms by around 1.5. Delaying the transition for climate-critical sectors until 2035 results in PDs increasing by 16 percentage points for coal production and four percentage points for oil & gas. Additional yearly expected losses from equity valuation changes nearly double when climate action is significantly delayed. This suggests clear benefits from early climate action to minimize the build-up of climate-related transition risks.

Additional mean change in PDs by sectors per year that the transition is delayed



There is significant heterogeneity in our results across firms. While climate-laggards that are misaligned with the transition face equity value changes of up to 84%, some firms that have been leading the transition to net zero see net benefits to their profitability and creditworthiness. These positive effects are most prominent in the power sector, where individual firms see their equity values increase by up to 44% and reductions in their PDs of six percentage points. Capturing such differences in risk analysis is crucial to inform efficient capital allocation decisions by financial markets, as well as financial policy design by financial regulators.

The costs fall unevenly across the financial sector. Depending on portfolio or loanbook composition the financial cost from climate-related transition risks and delayed climate action vary significantly.

It is important to flag several limitations to the analysis, including but not limited to: 1) the model not capturing all sectors and asset classes, thus significantly underrepresenting potential losses, 2) the model is limited in terms of its inputs, notably in terms of unit costs and the nuance of capturing long-term adaptive capacity (e.g., through R&D), and 3) the model using global scenarios and not fully capturing regional decarbonization pathways.

The new Climate Stress Testing and Scenarios Project (CSTS) will, among other things, seek to improve the modelling approach described here. Advances include an integration of various climate-related physical risk and compounding risk scenarios, expanding sectoral coverage, improving the representation of technological change and other model complexities, as well as accounting for systemic risk more effectively through the representation of amplification mechanisms within the financial sector.

1. Introduction

The potential impact on the financial sector of the transition to a low-carbon economy is now widely recognised by central banks and financial supervisors. This is highlighted by international platforms such as the Central Banks' and Supervisors' Network for Greening the Financial System (NGFS), that aim to support best practices and contribute to building a climate-resilient financial system.

Climate stress-test and scenario exercises developed by these institutions have highlighted the extent to which a disorderly and delayed transition has higher costs than an early and smooth transition. This finding is a core conclusion of the NGFS Progress Report (NGFS, 2018) and work by individual financial supervisors like the European Insurance and Occupational Pensions Authority (EIOPA, 2020) or the European Central Bank (ECB, 2021). The exact relationship and sensitivity of the results to a delayed transition has to date not been analysed in detail. While we know that such a delay comes with higher costs, and scenarios from the OECD and the NGFS highlight the potential additional economic costs of such a delay, there are no studies that map the specific annual estimated additional cost to the financial sector of delaying the climate transition.

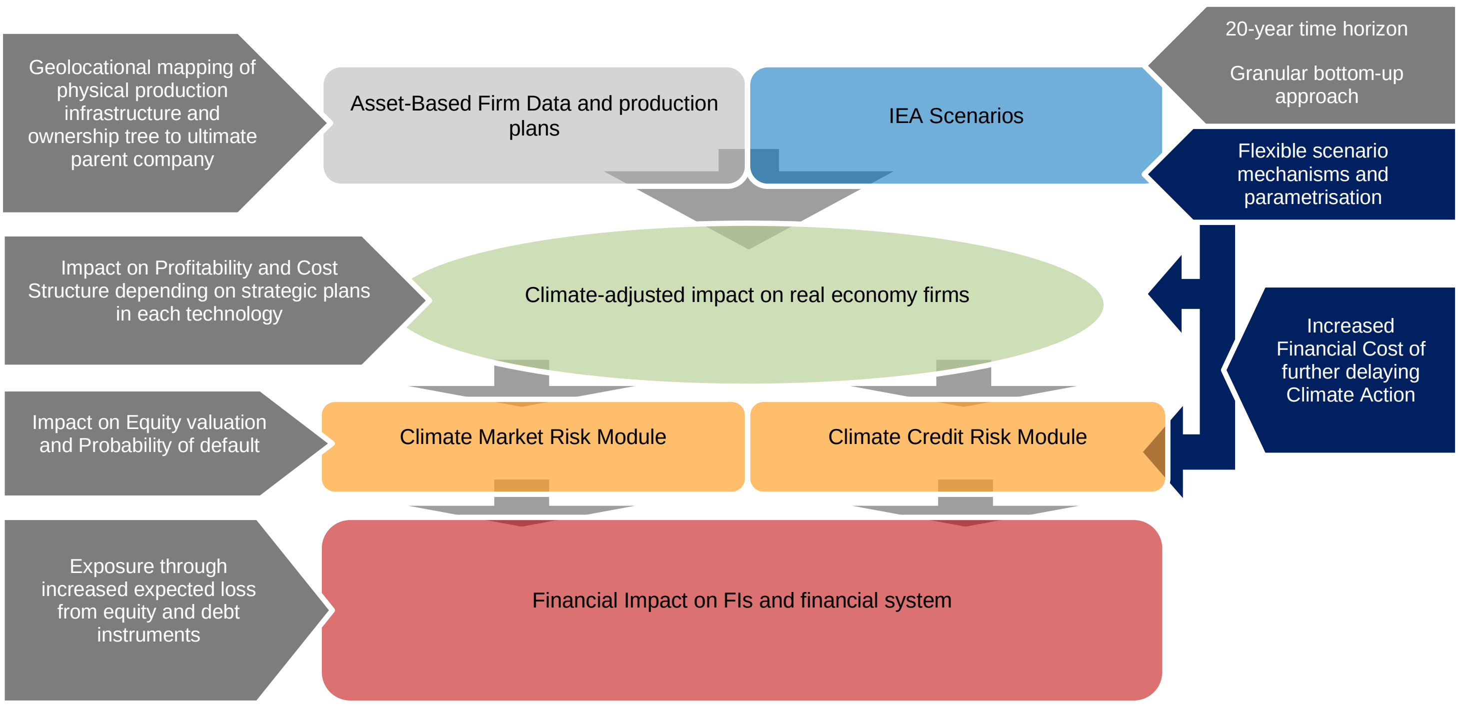
This report for the first time estimates the potential loss to the financial sector for each year the climate transition is delayed, measured in expected loss from changes in the equity value and the probability of default of analysed firms. We apply a novel bottom-up climate stress testing model that translates climate transition shocks affecting individual firms to the shocks affecting the value of financial assets, focused on the power generation, oil & gas, coal production and automotive industry, and building on asset-level data.

This report is structured as follows. In section 2, we outline the analytical climate-financial transition risk model. In section 3, we present in more detail the findings of the potential financial losses that result from further delaying the transition. In section 4 we discuss the limitations and avenues for further research by CSTS. Section 5 concludes.

2. Climate-Financial Transition Risk Model

In this analysis, we apply a granular asset-level climate stress testing framework that translates climate transition shocks affecting individual firms to the shocks affecting the value of financial assets in order to estimate the financial cost of delayed climate action. The model framework integrates scenario analysis into climate-adjusted economic approaches to derive the impact of a set of transition scenarios on the profitability of public companies in the global power, oil & gas, coal production and automotive sectors. We rely on asset-based data from Asset Resolution that allows us to map the physical production infrastructure for each technology in most climate-critical sectors and the associated ownership structure to companies, based on the share of the physical production asset each company owns. *Graph 1* visualises in more detail the components of the model.

Graph 1: Visualisation of Climate-Financial Transition Risk Model and its components



In our framework, we derive the transition-related financial impact from forward-looking production plans of the firms' physical asset-level infrastructure to capture firm-specific alignment and strategic directions. This approach is different to current climate stress-testing practices by central banks and supervisors (APCR, 2020; Battiston et al., 2017; ECB, 2021; Vermeulen et al., 2019), which often use historical and projected carbon emissions as a proxy for transition risk. We argue that our approach better captures the heterogeneity involved in transition risks, as two firms with the same current emissions today could face widely disparate transition risk based on their forward-looking production plans and adaptive capacity. Firms that are planning on transitioning their production into sustainable technologies will be less vulnerable to a forced phase-out or other climate policies that could harm their profits, regardless of their current or historical carbon emissions.

In our analysis we focus on the public firms within the Asset Resolution dataset, for which we can obtain extensive company financial data to perform a robust firm-level analysis. Our sample comprises 598 unique public companies with a total market capitalisation of US$ 8.7 trillion and outstanding debt of US$ 5 trillion.

A detailed representation of the model, the construction of the scenarios and the data used is provided in the ANNEX.

3. Results: The Financial Cost of a Delayed Transition

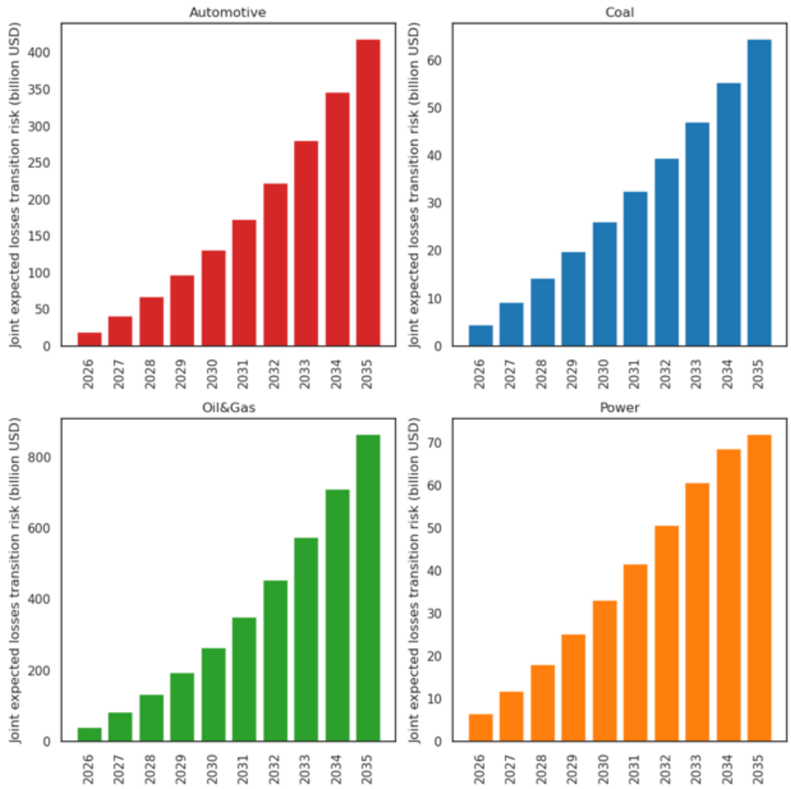
In this section, we present and discuss the results of our analysis. On a high level, our results stress the need for climate action to avoid substantial financial losses and a continued build-up of climate-related transition risks.

3.1 Aggregated Financial Losses of Delayed Action

Our results suggest that even our early transition scenario represents a disorderly transition, given that analysed firms in climate-critical sectors are insufficiently aligned with it. A substantial share of large coal production, power, automotive and oil and gas firms in our sample are planning to continue building out carbon-intensive production over the next years. These firms also build out renewables and more sustainable technologies, but at a slower rate than necessary to comply with the carbon budget of the IEA sustainable development scenario. Based on the current misalignment of these plans, a transition that is in line with the Paris Agreement will be feasible only after 2026, if firms remain true to their production plans (*see Graph 2 in the ANNEX for mis-alignment technology-specific production trajectories)*.

Such a transition will already have severe consequences for the financial sector, with expected losses from transition-related market and credit risk estimated to be US$ 2.2 trillion in total. Overall, this is driven by a 23% change in the equity valuation of climate-critical sectors and transition-related mean changes in the firms' PDs of around 4 percentage points. The oil & gas sector is highly affected, which could see its valuation decline by around US$ 1.7 trillion, although with relatively mild effects on the increased expected loss from credit risk. Given its heterogeneous production across various less carbon-intensive technologies, the impact on the power sector is largely mitigated with an overall expected financial loss of about US$ 55 billion. Some firms in the power sector can even record an average increase in their creditworthiness, resulting in a slight decrease of credit-risk related expected losses. Financial institutions exposed to the coal and automotive sector could be faced with a transition-related increase in expected losses of around US$ 109 billion and US$ 256 billion respectively (*see Graph 2)*. Overall, such risks and the resulting transition-related changes in expected losses may not be adequately reflected in the provisioning of banks or priced in by investors.

Graph 2: Additional yearly joint expected loss from changes in climate-related market and credit risk



We find that, for every year the transition is delayed, the financial cost for financial institutions due to transition-related market and credit risk could increase by US$ 150 billion. This represents a mean increase of financial cost per year of delayed climate action of nearly 7% relative to the baseline cost of US$ 2.2 trillion. The highest yearly cost increase of delaying the transition can be found in the automotive and power sector. Here, early climate action would be especially warranted and effective.

In the automotive sector, the mean increase of the cost to the financial sector per year of delayed action is estimated to be more than 17%. This represents a cost of US$ 44 billion per year additional to the US$ 256 billion market and credit loss that FIs are confronted with even in an early transition in 2026. Delaying sufficient climate action by another nine years, the cost will have almost tripled to US$ 656 billion (*see summary results in Table 1*).

In the power sector, the mean increase of the cost to the financial sector per year of delayed action is around 13%. This represents a relatively moderate cost of US$ 7 billion per year additional to the US$ 56 billion market and credit loss that FIs are confronted with even in an early transition in 2026. Delaying sufficient climate action by another nine years, the cost will have more than doubled to US$ 121 billion.

Financial institutions exposed to the oil & gas sector are faced with the highest expected financial losses of around US$ 1.7 trillion from transition-related market and credit risk even in an early transition in 2026. Based on our model results, every year the transition is further delayed could cost the financial sector an additional US$ 92 billion. This represents a mean increase of financial cost per year of delayed action of around 5%. Expected losses from credit risk are moderate, given the relatively low average leverage of 0.28 for our oil & gas sector sample. However, based on the high market capitalisation of public firms in the oil & gas sector, as well as their misaligned extraction production, these firms are at most risk in the transition.

Table 1: Summary Results of transition-related expected market and credit risk losses. Results on yearly financial cost of delayed climate action

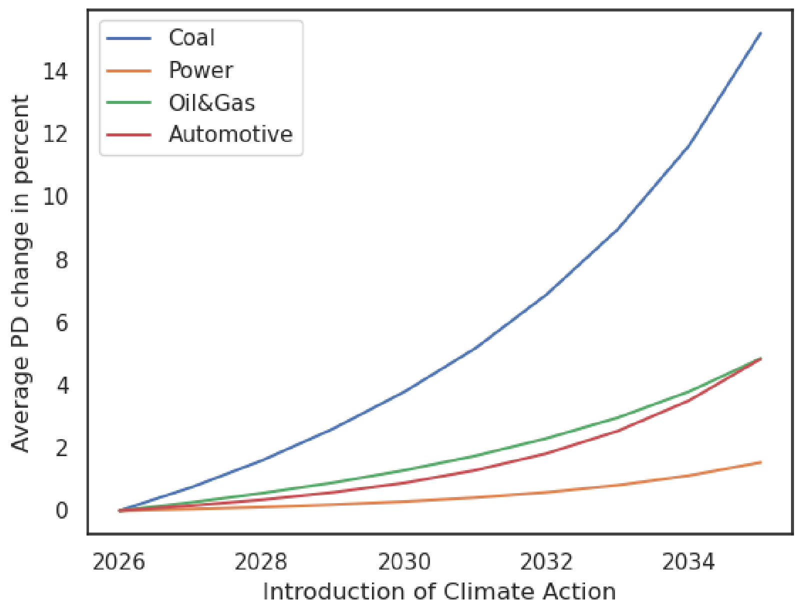
	Expected loss from climate transition-related market risk (in billion US$)			Expected loss from climate transition-related credit risk (in billion US$)			Joint expected loss (in billion US$)			Mean absolute financial cost per year of delayed action (in billion US$)	Mean increase of financial cost per year of delayed action (in %)
	CB2026	CB2030	CB2035	CB2026	CB2030	CB2035	CB2026	CB2030	CB2035		
Automotive	239	341	583	17	27	73	256	363	655	**44**	**17**
Oil&Gas	1,707	1,925	2,505	23	28	48	1,729	1,953	2,553	**92**	**5**
Coal	105	124	157	4	6	12	109	130	169	**7**	**6**
Power	56	81	113	-1	1	8	56	82	121	**7**	**13**
Sample of Climate-Critical Sectors	**2,105**	**2,471**	**3,358**	**44**	**63**	**140**	**2,149**	**2,529**	**3,499**	**150**	**7**
Extrapolated to Global Sector Coverage	4,086	4,764	6,370	79	112	240	4,164	4,870	6,610	**272**	**7**

For coal production firms, the mean increase of the cost to the financial sector per year of delayed action is estimated to be around 6%. This represents a relatively moderate cost of US$ 7 billion per year additional to the US$ 105 billion market and credit loss that FIs are confronted with even in an early transition in 2026. Delaying sufficient climate action by another nine years, the cost will have increased to a total of US$ 157 billion. Note that in our sample we cover only firms that represent around 29% of global coal extraction production.

Extrapolating our findings to all climate-critical sectors and assuming the firms that we cannot capture in our analysis are affected similarly, each year of delaying the transition would then confront the financial sector with an additional cost of more than US$ 270 billion. In a scenario where climate action does not commence until 2026, the total expected losses from transition-related market and credit risk would then amount to US$ 4.16 trillion for the exposure to the automotive, power, coal, oil & gas sectors alone. This extrapolation is, however, not without limitations. A large share of global non-public firms may reflect systematically different profit and cost structures or may be state-owned enterprises that transfer the risk to sovereigns and only indirectly to financial markets. Further, note that this can still be considered a lower bound estimate, as for now we cannot capture other climate-critical sectors such as shipping, steel, cement, aviation, agriculture and real estate. These sectors can be highly vulnerable to transition risks.

We find that delaying the transition non-linearly increases the expected loss from transition-related market and credit risks. While for simplicity we presented above the average yearly increases in the additional cost of delayed action, we highlight that the additional expected losses from market and credit risk exhibit non-linear dynamics. For instance, additional yearly expected losses from equity valuation changes for FIs nearly double when climate action is delayed from 2034 to 2035 as opposed to delaying the transition from 2025 to 2026 (*see for more details subsection 3.2*). This is even more prominent for the expected losses from transition-related credit risk that is driven by non-linearities in the PDs.

Graph 3: Additional mean change in PDs by sectors per year that the transition is delayed

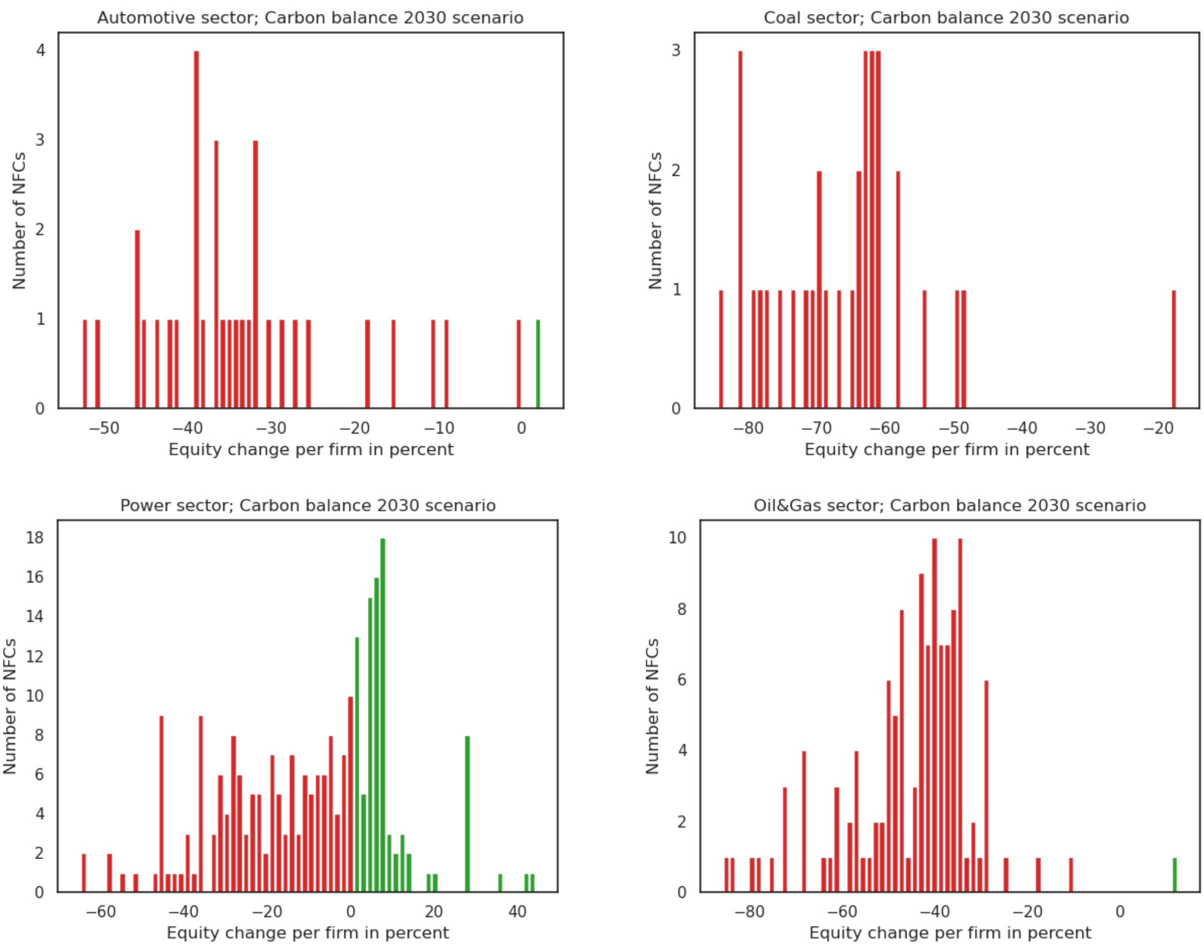


Delaying the introduction of climate action that transitions firms' production onto a Paris-aligned pathway, non-linearly increases the additional PD change. *Graph 3* above shows the yearly additional PD changes for each shock year between 2026 and 2035. Assuming decisive action and firms aligning their production in 2030 rather than in 2026, we see coal firms' PD additionally increasing by around 4% and oil & gas firms' around 1.5%. Delaying the transition for climate-critical firms until 2035 results in additional increased probabilities of default by 16% and 4.5% for coal and oil & gas respectively. This results in a total transition-related mean PD change of 24 percentage points in the coal sector (*for absolute PD changes and within sector-variation see subsection on heterogeneity 3.2*). We identify the strongest non-linearity in the PD change due to delayed action in the coal, oil & gas and automotive sector. Early climate action in these respective sectors could minimise significant increases in the expected loss for exposed financial institutions.

3.2 Heterogenous Transition Impact within Sectors

Transition impacts entail significant heterogeneity in our results across individual firms. We observe a significant standard deviation of transition-related equity changes and probability of defaults changes within the analysed climate-critical sectors. In a transition starting in 2026, we observe that highly misaligned coal firms face negative equity valuation changes of almost 73% while individual power firms see their equity valuation increase by 14%. Interestingly, we find that these within-sector variations are increasing when the transition and climate action is further delayed. This heterogeneity is increasing non-linearly across all sectors, stressing the need for early climate action to minimise financial losses.

Graph 4: Within-sector variation of equity changes of firms for a delayed transition in 2030 by sector[3]



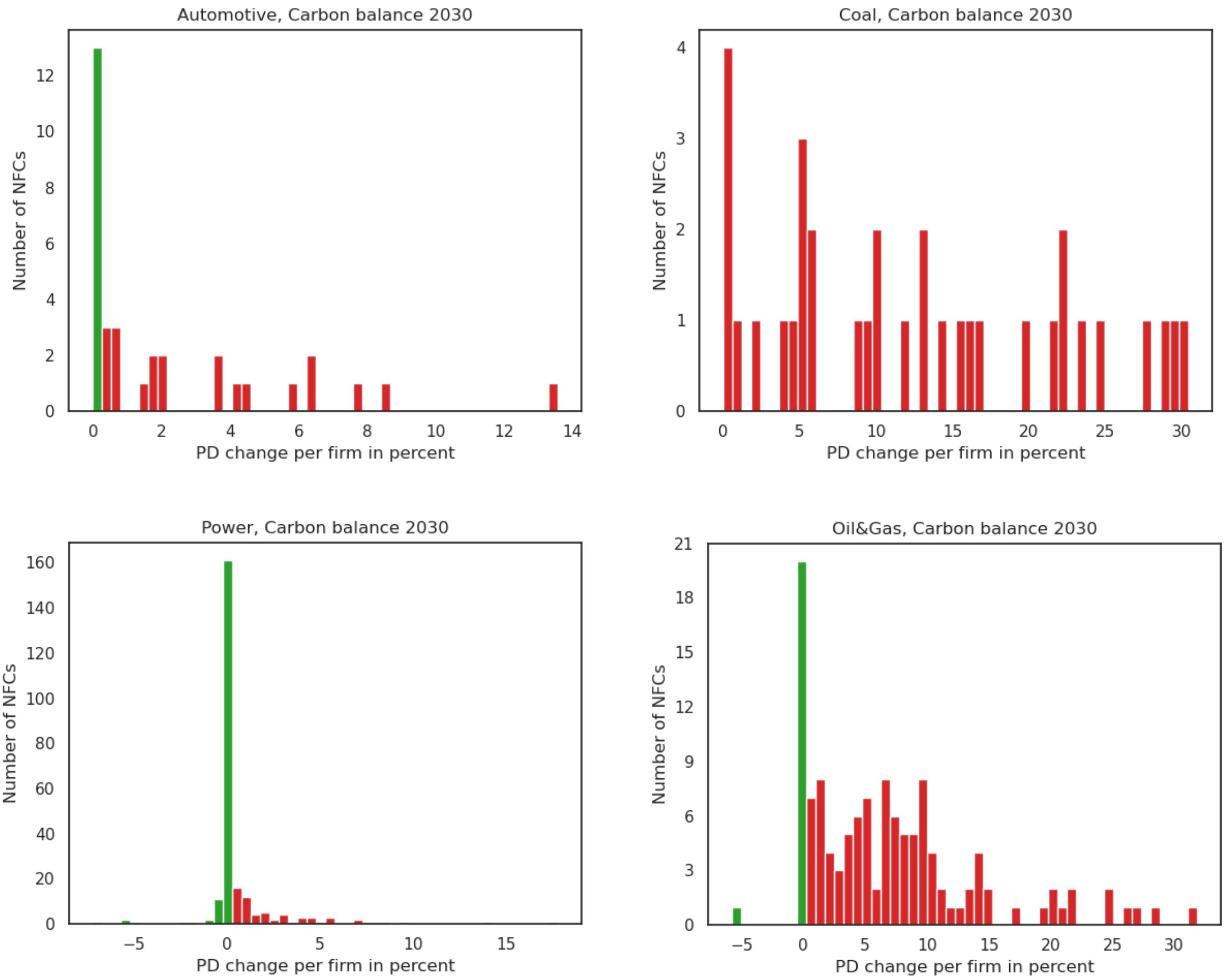
[3] The number of NFCs on the y-achses refers to the number of companies

We identify the strongest heterogeneity in the transition-related impact on firms' equity valuation in the power sector. Firms that have more aligned production in sustainable technologies, such as power generation from renewables, record positive equity changes of up to 44% (*see Graph 4*). We identify a spike for a large share of power firms that see their discounted cash flows increase slightly and hence their equity values increase by around 5-10%. That this is mainly driven by European power firms that have already diverted a significant share of their production to less-carbon intensive technologies. In contrast, individual companies with high-carbon intensive production such as electricity generated from coal and gas, see their equity values drop significantly by more than 60%, assuming a delayed transition starting in 2030.

The coal, oil and gas sectors are most affected by the transition due to the necessary phase-out assumptions of the IEA scenarios to meet the goals of the Paris Agreement. While these overall sectors face sharp equity declines, individual firms are heterogeneously affected, depending on their profit margins and their individual production split between, e.g., oil or gas. Where firms' profitability is highly reliant on oil extraction, a more disruptive pathway is prescribed in our scenarios, while firms more reliant on gas extraction see their production increase in the medium term to meet global energy demands (*see Graph 1 in the ANNEX for technology-specific scenario pathways*).

The transition-related impact on firms in the automotive sector is severe. This is driven by a significant demand reduction for ICE (internal-combustion-engine) cars that sharply reduces the revenue of misaligned firms. The magnitude of this impact is dampened for automotive firms that are planning to shift their production to alternative technologies, such as hybrid and electric cars. For most firms, however, building out these new technologies is not happening at the rate necessary to comply with the scenario trajectories, and hence this positive impact on their firm's revenue cannot compensate for the decrease in ICE car sales.

Graph 5: Within-sector variation of PD changes of firms for a delayed transition in 2030 by sector



We observe a similar heterogeneity in the within sector variation of transition-related PD changes. As shown in *Graph 5*, we observe the highest negative impact on firms in the coal, oil & gas industry, reaching increases of over 30 percentage points for highly impacted firms. This is consistent with their sharp decline in equity values in a delayed transition scenario starting 2030. While for these firms we observe a significant standard deviation, the impact on firms in the automotive and power sectors is relatively mild, with most of the firms seeing their PD changes significantly lower than seven percentage points. Nevertheless, the expected loss is relatively high, given the on average high levels of debt and leverages ratios of around 0.7 for the automotive, and 0.94 for the power sector, in our sample (*See Table 2*).

<u>*Table 2: Summary Results of within sector variation of transition-related discounted cash flow and PD changes by set of transitions*</u>

	Climate Transition-Related equity valuation change in %									Climate Transition-related PD change in %								
	CB2026			CB2030			CB2035			CB2026			CB2030			CB2035		
	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile
Automotive Firms	-34	-23	-4	-48	-32	-6	-72	-54	-6	0	1	5,0	0,0	2	8	0	6	20
Oil&Gas Firms	-64	-41	-27	-73	-45	-29	-87	-53	-33	0	6	17,7	0,0	7	22	0	11	36
Coal Firms	-73	-56	-43	-81	-66	-49	-93	-82	-56	0	9	21,8	0,2	13	29	2	24	47
Power Firms	-31	-7	14	-46	-10	19	-74	-15	34	-0	0	3	-1	1	4	-1	2	14

Delaying the transition non-linearly increases the equity valuation shock across all sectors. The strongest non-linearity can be observed in the automotive and coal sector. For instance, for automotive firms, delaying the transition from 2026 to 2030 increases the mean equity valuation changes by 10 percentage points, while delaying the transition further until 2035 non-linearly increases the losses by an additional 24%.

We observe a similar effect for the transition-related PD changes of firms. We identify a strong nonlinear relationship between delaying the transition and the firm-specific PD changes. This is most prominent in the coal sector, where delaying the transition from 2026 to 2030 leads to mean PD changes from 9% to 13%, while delaying the transition for an additional five years will increase transition-related PD changes to a total of 24%. Similarly, some of the worst affected coal firms (*95^{th} percentile*) see their PD changes increase non-linearly from 22 percentage points (*transition in 2026*) to 29 percentage points for a transition in 2030 and 47 percentage points for a transition in 2035. As a result, expected losses from transition-related credit risk could be minimised when early action is taken. While some of the best-performing firms (5^{th} percentile) in the automotive and oil & gas sectors do not see their PDs affected in a transition, firms that are highly misaligned experience the same non-linearity in their PD changes. This highlights the necessity to distinguish such firms to inform risk management practices or when analysing financial portfolio exposures.

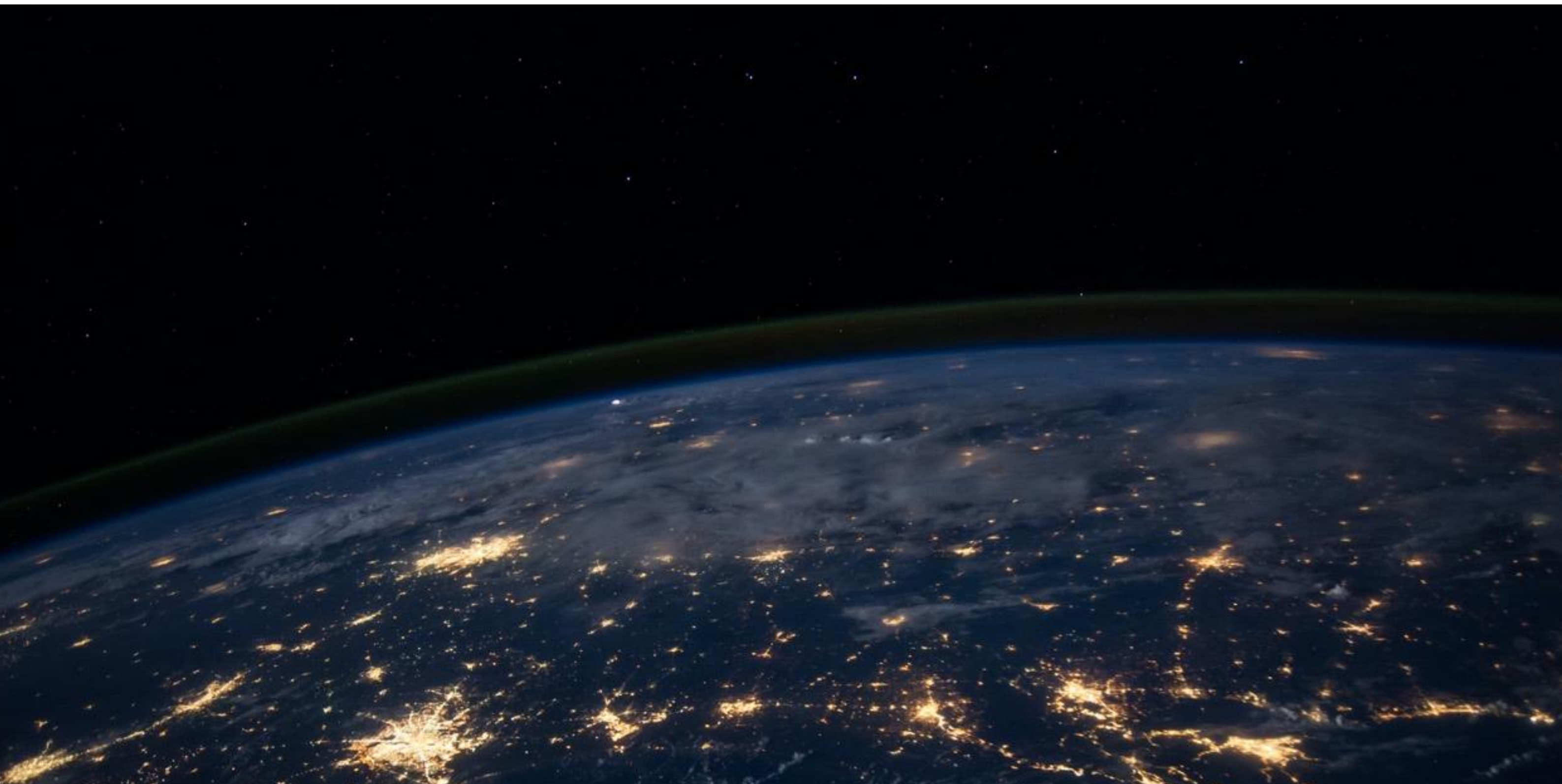
The heterogenous firm-level results highlight that the cost of delayed climate action represents clear distributional consequences. Depending on the unique portfolio composition of FIs, the financial cost stemming from transition risk and delayed climate action, as well as the associated risk-build-up varies significantly. FIs and banks that are invested in or provide credit to firms that are aligned with climate objectives are net beneficiaries of the Paris-aligned transformation, even seeing an overall reduction in expected losses, while FIs that are exposed to misaligned firms might be facing significant financial losses.

Capturing such a heterogeneity in scenario and stress testing models is crucial to inform financial markets and regulators. The failure to distinguish transitioning firms from climate laggards within the same industry in current financial risk management practices is problematic, given the heterogeneity identified above. We argue that the asset-level based approach to measuring transition risk used in this report may serve as a first step to overcome these problems.

4. Limitations and outlook for CSTS

It is important to flag several limitations to the analysis. First, the model does not capture all sectors and asset classes. It thus significantly underrepresents potential losses when considering a broader universe of sectors and potential risks of a delay to other actors (governments, households), as well as network effects that may arise as a result. Second, the model has limitations in terms of the depth of inputs, notably in terms of certain unit costs and the nuance of capturing long-term adaptive capacity (e.g., through R&D). Third, the model uses global scenarios and thus does not fully capture regional decarbonization pathways. Such nuances can hypothetically be captured given the granularity of asset-level data but were not considered for the purpose of this study. Moreover, the stress-tests considered only one type of scenario input and surrounding sensitivity.

The new Climate Stress Testing and Scenarios Project (CSTS) seeks to address these limitations and will further improve the modelling approach described in this report. Advances include an integration of various climate-related physical risk and compounding risk scenarios, expanding sectoral coverage, improving the representation of technological change and other model complexities, as well as accounting for systemic risk more effectively through the representation of amplification mechanisms within the financial sector.



5. Conclusion

This report has attempted to estimate the cost for the financial sector when climate action by companies is delayed. To undertake this analysis, we developed an exploratory bottom-up asset-level climate stress testing framework that translates climate transition shocks affecting individual firms to the shocks affecting the value of financial assets. Using asset-level data we captured the climate transition-related impact on public non-financial firms' equity valuation and probabilities of default for four of the most climate-critical sectors globally: power generation, oil & gas, coal production and the automotive industry. Such a bottom-up approach allowed us to capture the heterogeneity involved in the shocks and to estimate the additional expected financial losses from transition-related increases in market and credit risk. We presented three high-level findings.

1

Analysed firms are insufficiently aligned with the net-zero transition, highlighting that even in a scenario where early climate action is taken by these companies in 2026, the transition is shown to be disorderly with estimated losses of US$ 2.2 trillion for the financial sector.

2

We find that on top of this financial cost, an additional of US$ 150 billion could be added for each year climate action by these companies is further delayed, due to climate transition-related changes in market and credit risk. We find a non-linear relationship between delaying the transition and expected losses, stressing the need for immediate action to avoid the build-up of climate-related transition risks.

3

Transition impacts entail significant heterogeneity in our results across individual firms with clear distributional consequences. The costs fall unevenly across the financial sector. Depending on portfolio or loanbook composition the financial cost from climate-related transition risks and delayed climate action, vary significantly. This also highlights the need for bottom-up stress tests and scenario analysis with sufficient granularity to capture the heterogeneity involved in the transition and to effectively inform financial markets, as well as financial policy design by financial regulators.

ANNEX

1. Detailed Model Description

We define the transition risk of a financial institution *i* associated with a late and sudden scenario *s* relative to the baseline scenario *b (See ANNEX 2. 'Construction of Scenarios')*. Note that in our model we construct a set of scenarios that vary in the introduction of the shock year to estimate the changes in the financial cost stemming from delayed climate action. The transition risk (*TR*) of institution *i* gives the current value at time *t* of the dollar loss that it is estimated to suffer in transition scenario *s* relative to a baseline scenario *b* and is defined as

$$TR_i^{sb,t} = \sum_{a \in \mathscr{A}} TR_i^{sba,t} = \sum_{a \in \mathscr{A}} \sum_{j \in \mathscr{F}} TR_{ij}^{sba,t} \tag{1}$$

where $TR_i^{sba,t}$ represents the dollar loss that *i* could suffer on its portfolio of assets of type $a \in \mathscr{A}$, where $\mathscr{A}$ is the set of assets. Further, $TR_{ij}^{sba,t}$ denotes the transition risk institution *i* faces in scenario *s* on its asset investments of type *a* in firm *j*, where $\mathscr{F}$ represents the set of climate-relevant firms in the real economy.

For this report, we assume that the equity value of the companies[4] in our sample are held by financial institutions through direct shareholding. Hence, we construct a portfolio that holds the total of all current equity assets of climate-critical sectors, without further specifying the composition of individual FI portfolios. A change in the equity value of companies hence results in a loss for the financial sector of $TR^{sb,t}$.

Simultaneously we assume that the total outstanding debt of the companies are held by financial actors through debt instruments such as bonds and loans. Changes in the probability of default of said companies therefore translate into changes of the expected loss for the financial sector. Within this model set up, we can estimate the overall cost to the financial sector under different scenarios.

The *TR* of the financial sector ultimately hinges on the equity value in scenario *x* of each firm *j* that financial institutions have invested in. We model the transition-related impact, expressed as the difference in equity value of a real economic firm *j* under the baseline and a set of late

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[4] Note that in our model the current market capitalisation of companies is not free float adjusted.

and sudden scenarios. More formally, we assume that Firm *j*'s equity value at time *t* in scenario *x* is given by the sum of the discounted profit of firm *j*, i.e.

$$E_j^{x,t} = \sum_{v=t}^{T} \exp^{-r(v-t)} \mathbb{E}_t[\pi_j^{x,v}] \tag{2}$$

Where $\mathbb{E}_t[\pi_j^{x,v}]$ gives the expected profits in scenario *x* at time *v*. For now, we assume that the equity market price each year is linearly dependent on the expected dividends that year. We further assume that dividends for a given year are proportional to the net profits of a firm for this year. Hence, we can estimate the net present equity value of the firm *j* based on its future cash flows. For now, we assume future profits are discounted at the risk-free rate (*we set this equal to the 30Y US treasury yield. Note that in further applications, we aim to allow for a sensitivity test around the discount rate).* Thus, the expected profits can be estimated as:

$$\mathbb{E}_t[\pi_j^{x,v}] \approx \sum_{y \in \mathcal{Y}} \sum_{h \in \mathcal{H}} P_{jyh}^{x,v} \times (NPM_j) \times p_{yh}^{x,v} \tag{3}$$

Where $p_{yh}^{x,v}$ is the unit price of technology *h* in industry *y* in scenario *x* at time *v* as projected by the International Energy Agency (IEA), and where $\mathcal{H}$ represents the set of technologies and $\mathcal{Y}$ the set of industries (*see Table 1*).

Table 1: Set of Industries and set of technologies represented in the analysis:

Set of Industries $\mathcal{Y}$	**Set of Technologies $\mathcal{H}$**
Automotive	Electric
	Hybrid
	Internal Combustion Engine (ICE)
Oil and Gas Production	Oil
	Gas
Coal Production	Coal
Power Generation	Nuclear
	Coal
	Oil
	Gas
	Hydro
	Renewables

Further NPM_j represents the scenario-independent and firm-specific net profit margin that can be used to derive the unit costs of firm *j* associated with producing technology *h* in industry *y*. $P_{jyh}^{x,v}$ gives the production amount of firm *j* of technology *h* in industry *y* in scenario *x* at time *v*. Oftentimes a firm *j* will be active only in one industry in which case the sum over $y \in \mathcal{Y}$ in the equation above contains only one element. The production level $P_{jyh}^{x,v}$ of a firm is assumed to be scenario specific. For instance, in the SDS by the IEA, coal companies are required to significantly lower their production level over time.

To estimate the financial loss from *TR* associated with the set of transition scenarios, we rely on a climate-adjusted market risk model and credit risk model to quantify potential price and market valuation changes for equity, as well as an increased likelihood of credit defaults for outstanding debt.

1.1 Market Risk

For the market risk, the *TR* financial institutions experience due to exposure to firms in climate-critical sectors through assets of type in $a=\{\text{equity}\}$ scenario *s* relative to baseline scenario *b* is given by

$$TR_{ij}^{sba,t}=E_{ij}^{s,t}-E_{ij}^{b,t}, \tag{4}$$

where $E_{ij}^{x,t}$ denotes the equity value of FIs investment in firm *j* under $x=\{s,b\}$ scenario and is given by

$$E_{ij}^{x,t}=\frac{u_{ij}^{t}}{u_{j}^{t}}E_{j}^{x,t}. \tag{5}$$

Hence, institution *i*'s equity value in firm *j* is given by the current equity value of firm *j* in scenario *x*, $E_{j}^{x,t}$ times the number of equity shares *i* holds of firm *j*, u_{ij}^{t} relative to the total number of outstanding shares of firm *j*, u_{j}^{t}. Equation (5) makes clear that institution *i*'s equity investment in *j* changes proportionally to changes in the equity value of *j*. In this analysis we assume that the constructed portfolio holds the total number of outstanding shares of firm *j* to represent the overall financial sector exposure. Ultimately, the changes in market risk for FIs is derived by changes in the discounted cash-flows of climate-critical firms under a set of transition scenarios *s* relative to the baseline scenario *b*.

1.2 Credit Risk

For the transition-related credit risk, we adjust a structural Merton framework to accommodate for climate risks. We model the transition-related changes in credit risk through the application of a structural model which captures the probability of default for a firm based on the value of its assets and liabilities (Chatterjee, 2015). The basic idea is that a firm defaults if the value of its assets is less or equal to the debt of the firm.

To estimate the credit risk for debt financial instruments, including loans and bonds, it is crucial to model the probability of default. To do so, we rely on firm-specific inputs, including the evolution of the firm's equity value under a set of transition scenarios (described above), the default barrier as expressed in the default-free value of liabilities, time to maturity and the asset-value return volatility. More specifically, assuming log-normal asset returns of each firm $j \in \mathcal{F}$, the PD of firm *j* in scenario $x = \{s, b\}$ is, according to the Merton model (Merton, 1974) given by

$$PD_j^x = 1 - \mathcal{N}(DD_j^x) \tag{6}$$

where $\mathcal{N}$ is the cumulative standard normal distribution, and where the distance to default (DD) of firm *j* in scenario *x* is given by

$$DD_j^x = \frac{\log(A_j^{x,t}) + (\mu_j - \frac{1}{2}\sigma_j^2) T_j - log(L_j^t)}{\sigma_j \sqrt{T_j}} \tag{7}$$

where μ_j denotes the expected return of the assets of firm j (and can for simplicity be set equal to the risk-free rate *r*) and σ_j the volatility of *j*'s assets. For now, we assume this is scenario independent. We further assume these are time invariant. Further, T_j represents the average maturity of firm *j*'s liability, which for simplicity, we set equal to 5 years, i.e. the average weighted maturity of syndicated loans in advanced and emerging markets as provided by the IMF (Chen et al., 2019). $A_j^{x,t}$ refers to the scenario-dependent asset value of the company and L_j^t represents the scenario-independet liabilities.

Hence, the transition risk that financial institution *i* experiences in assets of type $a = \{\text{loans \& bonds}\}$ in scenario *s* relative to baseline scenario *b* is given by

$$TR_{ij}^{sba,t} = \mathbb{E}_t[L_{ij}^{sa}] - \mathbb{E}_t[L_{ij}^{ba}] = (PD_j^s - PD_j^b) * LGD_{ij}^a * EaD_{ij}^{a,t} \tag{8}$$

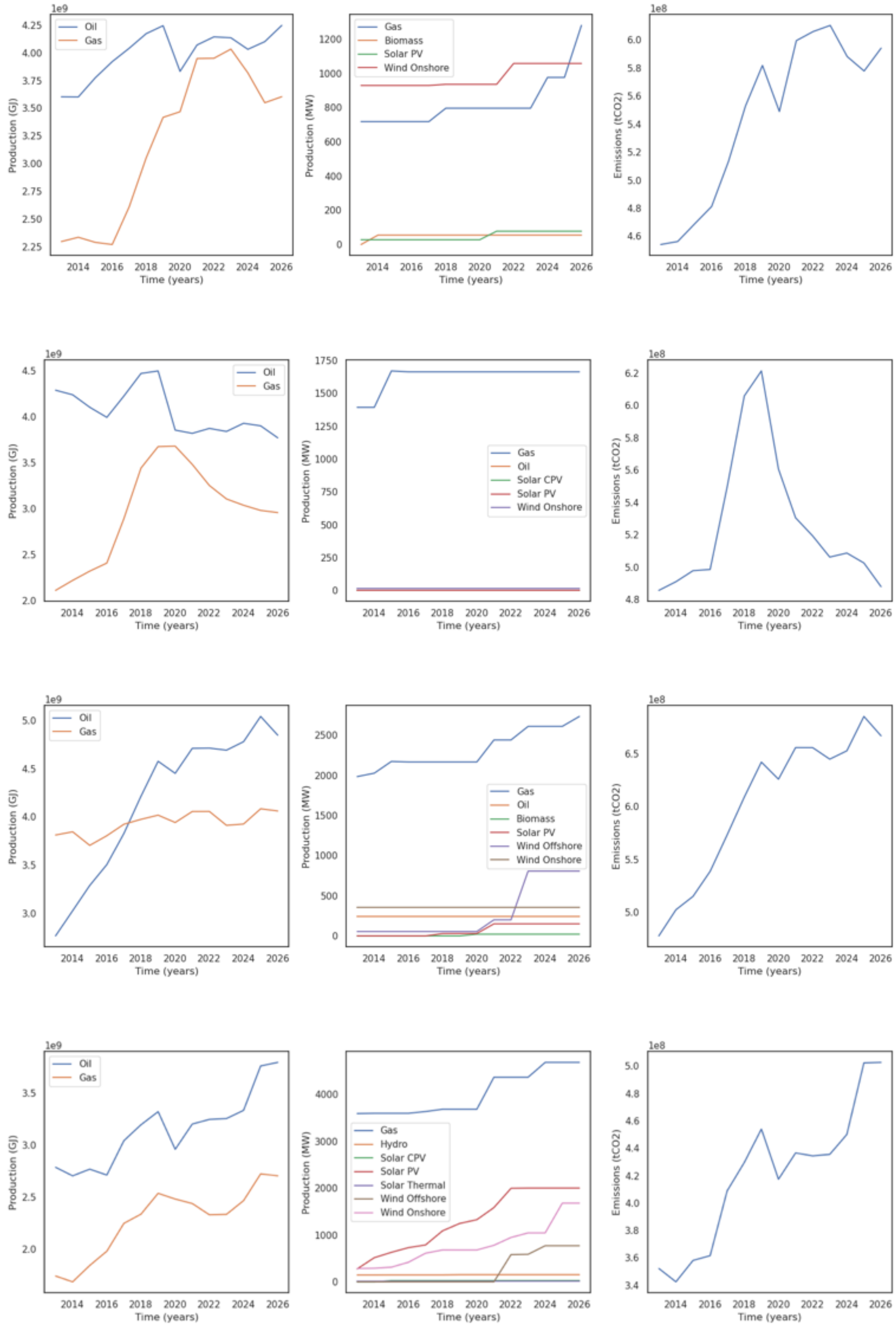
where $\mathbb{E}_t[L_{ij}^{xa}]$ gives the expected loss under scenario $x=\{s,b\}$ given the available information at time *t*. It is given by the multiplication of the probability of default (PD) of firm *j* in scenario *x* times the loss given default (LGD) and the exposure at default (EaD) for institution *i*'s investments in *j* in asset class *a*: ($PD_j^x * LGD_{ij}^{a,t} * EaD_{ij}^{a,t}$). To analyse the credit risk for the loan channel, the expected loss is an essential metric for understanding the impact of climate risks on the loan portfolios of banks. Expected loss is the amount that a bank is expected to lose on its lending exposure in the normal conduct of business and in the current environment and hence for which it needs to make provision. Such a credit risk provision reflects the probability that a counterparty will default and the expected amount the bank will stand to lose. Transition risk in this exercise is measured as the change in expected loss under a set of delayed climate transition scenarios. For now, we assume that the LGD and EaD are not dependent on the scenario *x*. While the LGD is set to 0.6, the EaD in this analysis is set equal to the total outstanding debt of each firm *j* to capture the overall exposure of the financial sector.

2. Construction of Scenarios

Through Asset Resolution we can leverage data on the current t_0=2020 production level of each of the climate-relevant firms $j \in \mathcal{F}$ in each industry *y* and each technology *h*, as well as the carbon intensity associated with the production in technology *h*. Let us refer to the actual production level of the firm *j* in industry *y* and technology *h* at time t_0 as $P^{t_0}_{jyh}$, where we have removed the scenario superscript *x* to signify actual production at time t_0.

Furthermore, Asset Resolution has collected data from sector specific business intelligence data providers that gather from annual reports and other public sources the planned production levels of each firm in each climate-critical industry and each technology for the next 5 years, i.e., we have the following data on production plans: $P^{t_0}_{jyh}, \ldots, P^{t_0+5}_{jyh}$. *Graph 1* below shows an example of this data for a selection of public firms in the power and oil & gas industry. Based on this information, we construct the firm-specific planned production scenario for each technology *h*.

Graph 1: Historical and forward-looking production plans across technologies between 2013 and 2026 with associated absolute carbon emissions for a sample of firms in the power and oil and gas sectors



We identify that a substantial share of the analysed firms in climate-critical sectors are insufficiently aligned with a transition to meet the targets of the Paris Agreement. As shown in *Graph 1* above, large power, oil and gas firms continue to build out carbon-intensive production over the next years, while increasing absolute carbon emission. These firms also build out renewables and more sustainable technologies, but at a slower rate than necessary to comply with the SDS scenario (*see Graph 2*). This results in a steadily growing misalignment with such decarbonisation pathways and increases the transition-related financial risk build-up for exposed FIs.

Given the long-time horizons of the Paris-aligned transition, we then continue the planned production of firm *j* with the stated policies scenario (SPS) given by the IEA, that represents a baseline picture of how global energy markets would evolve if governments made no changes to their existing policies and announced policy intentions. The combination of these two scenario components (*i.e. the planned production and the SPS*) form our baseline scenario *b.* In other words, we assume that a firm produces according to its own technology-specific production plan on the physical production asset-level and then follows the SPS. Based on the current misalignment of these plans, a transition that is in line with the Paris Agreement, will be feasible only after 2026, if firms remain true to their production plans.

We then construct our target scenario, namely the late and sudden scenario *s.* This scenario assumes that firms continue to produce according to the baseline scenario, until the introduction of a "climate action" shock, that shifts the production for firm *j* in each technology *h* onto a Paris-aligned path, to in aggregate comply with the production trajectories and carbon budgets described in the IEAs sustainable development scenario (SDS). The mechanisms of the model work in a way that reflect that the later such transition policies are implemented, the longer firms in climate-critical sectors remain misaligned with the target scenario, and the steeper a potential adjustment in production levels will be. Note that climate action in our model is not restricted to being dependent on strong government intervention, but that transition can also be driven by firms' strategic decisions. We therefore construct a continuum set of target scenarios that vary by the introduction of the shock year. We consider $|\mathcal{S}| = 10$ scenarios, ranging from Carbon Balance (CB) 2026, which induces a production shift in 2026, to CB2035 that assumes late and drastic action only in 2035. The later the introduction of the shock year, the longer firm *j* produces according to its planned production and baseline. In the model mechanics, such delayed climate action leads to a more abrupt and greater magnitude of impact to the firm's profitability to compensate for prior overproduction.

Leveraging off the inputs from the IEA technology production trajectories and information on physical production infrastructure from Asset Resolution, we can project production levels $P^{x,t}_{jyh}$ for a climate-relevant firm $j \in \mathcal{F}$, in scenarios $x \in \mathcal{S}$ for products in industry $y \in \mathcal{Y}$ made of technology $h \in \mathcal{H}$. The scenarios also contain the IEA estimates of product price $p^{x,v}_{yh}$ in the different scenarios.

Importantly, the IEA scenarios specify how much production levels for an industry *y*, $P^{x,t}_{yh}$ as a whole will need to change over time away from carbon-intensive technologies *h* towards greener alternatives to be in line with the stated objective. For instance, under the SDS, the production-level of the automotive industry's ICE cars might have to go down by a certain amount (i .e. $P^{x,t}_{y=automotive,h=ICEcar}\downarrow$) and its production level in electric vehicles might have to go up by a certain amount (i.e. $P^{x,t}_{y=automotive,h=EV}\uparrow$).

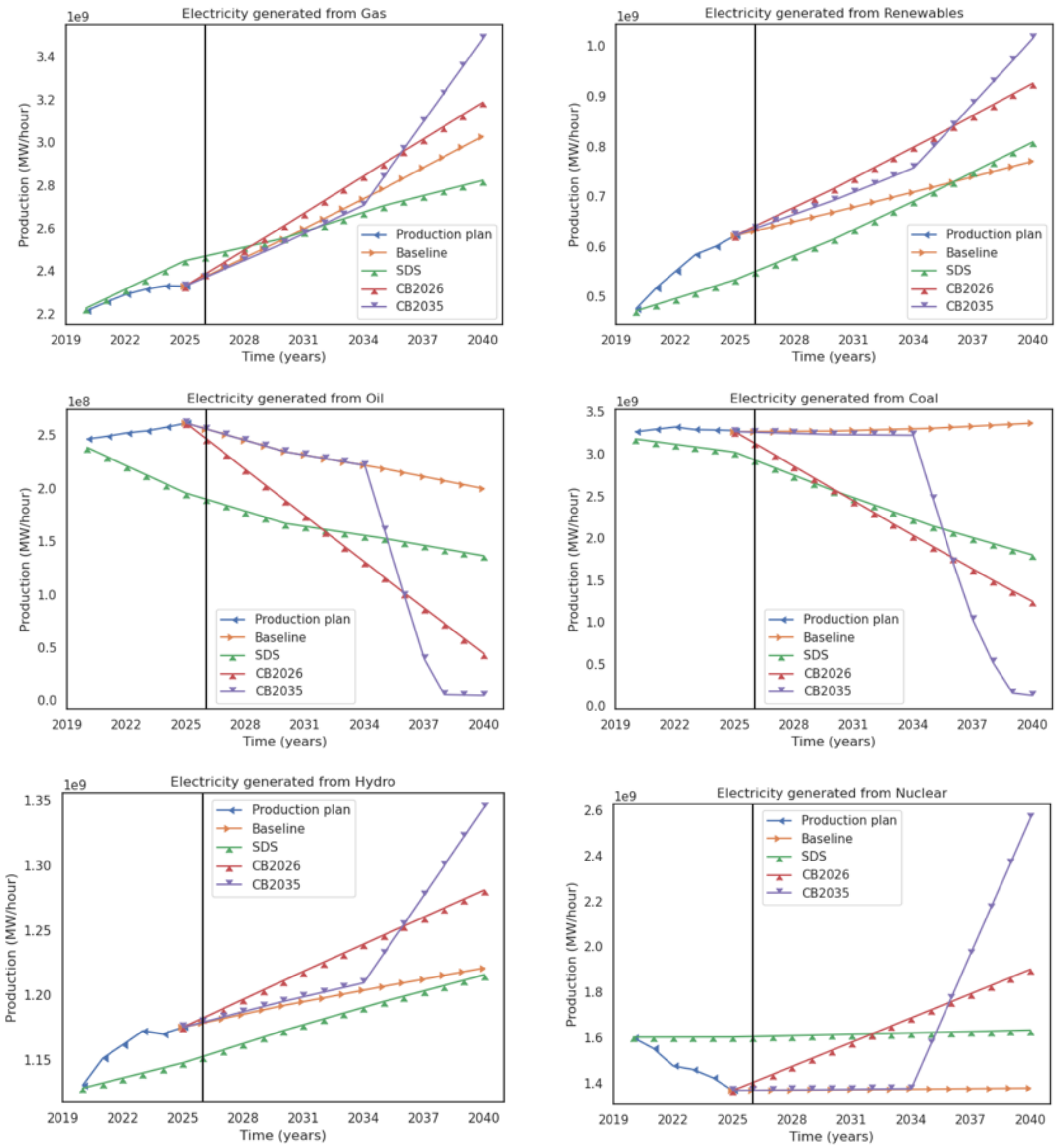
The IEA scenarios do not specify firm-specific transition paths away from carbon-intensive production towards greener alternatives, but instead define them at the level of an industry. We therefore translate the industry-wide scenario to a firm-specific one by assuming that the requisite change towards green production in carbon-intensive production in an industry must be implemented by the firms in the industry according to their market share. Hence, the firm-specific requisite production levels $P^{x,t}_{jyh}$ per technology *h* in industry *y* at time *t* under scenario *x* are given by its total market share in technology *h* at time t_0 as observed in data ($\frac{P^{x,t_0}_{jyh}}{P^{x,t_0}_{yh}}$) times the IEA industry-wide production level $P^{x,t}_{yh}$ in technology *h*:

$$P^{x,t}_{jyh} = \frac{P^{x,t_0}_{jyh}}{P^{x,t_0}_{yh}} P^{x,t}_{yh} \quad \text{, where} \quad P^{x,t_0}_{yh} = \sum_{j \in \mathcal{F}} P^{x,t_0}_{jyh} .$$

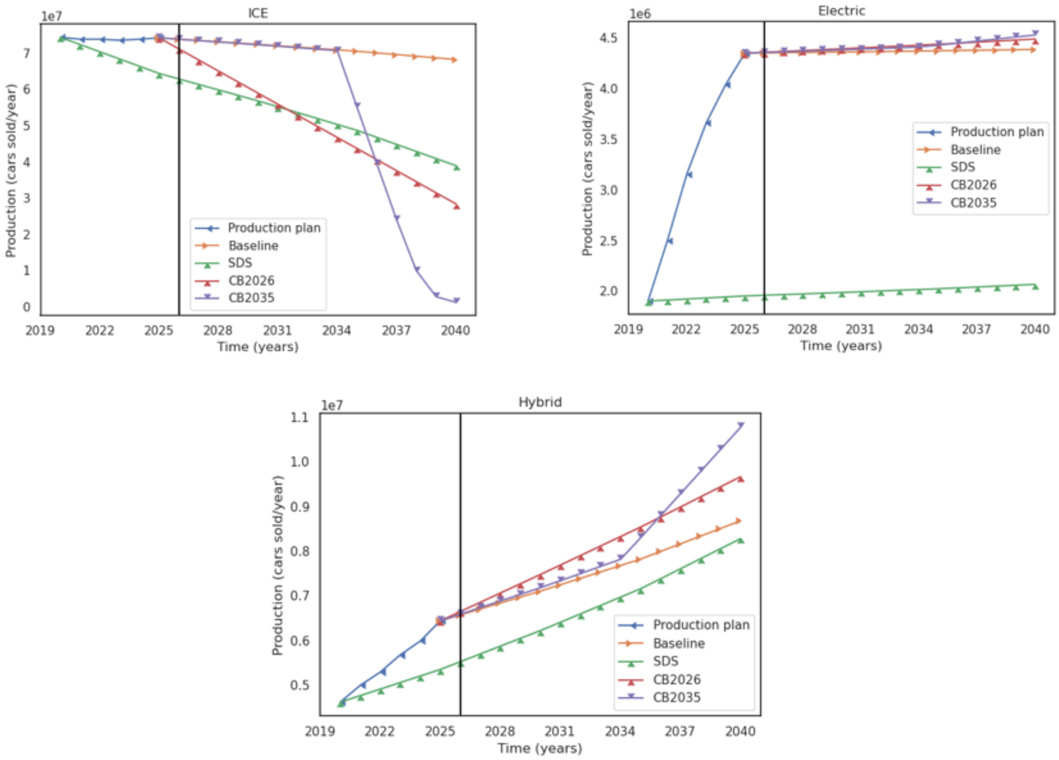
If a firm maintains its market share in a technology *h* over time, it can be seen from the equation above that a firm that has a smaller market share in green technologies today will be at greater transition risk tomorrow if its carbon-intensive technologies are subject to a phase-out according to the IEA scenarios $P^{x,t}_{yh}$. In our model, misaligned firms will therefore not only be faced with higher transition risks, but also miss first-mover advantages in seizing new market shares of sustainable technologies. *Graph 2* below visualises the constructed scenarios on a technology-level across the climate-critical sectors and shows the baseline scenario (production plans and SPS), the misalignment with the SDS scenario and two of the resulting target scenarios (CB2025 and CB2035).

Graph 2: (Mis-)Alignment of firms' production technology mix in climate-critical sectors and Paris-aligned scenario pathways

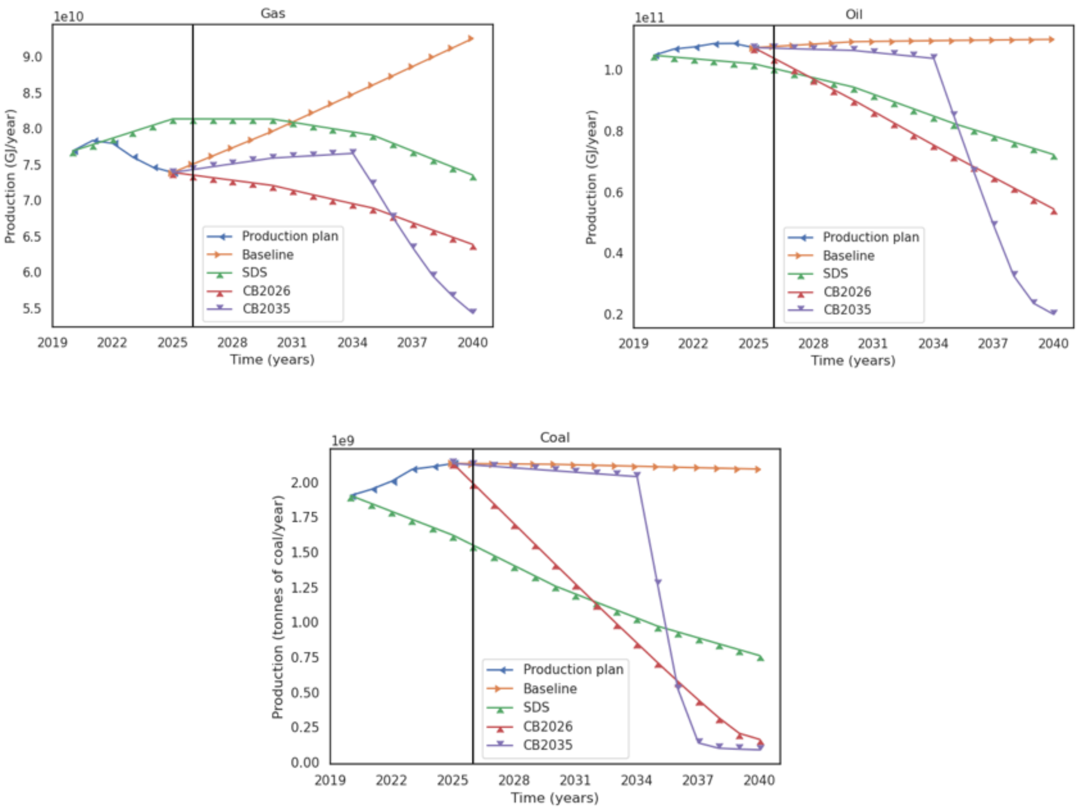
(A) Power Sector



(B) Automotive Sector



(C) Coal, Oil and Gas sector



3. Data

The data used to map physical infrastructure and production capacity are provided by Asset Resolution. They source data from commercial data providers on company production forecasts based on physical company assets. For each sector the datasets include information regarding the location, capacity or production, technology, fuel mixture and ownership of each asset.

Where possible, forward-looking data for key technologies (*e.g. future production plans*) are used in order to provide geography-specific assessments for climate-relevant sectors mapped to the company level. This information allows us to map physical infrastructure and the associated capacity or production in each technology to the ultimate parent company, based on the share of the physical asset each company owns. The data include information on assets in the climate-critical power, oil & gas, coal and automotive sectors.

In our analysis we focus on the public firms within the Asset Resolution dataset, for which we can obtain extensive company financial data to perform a robust firm-level analysis. We source relevant data from *Refinitiv* as of June 2021. That is the average net profit margin over 48 months (*to decrease sensitivities due to COVID-impacts*), the market capitalisation, the total outstanding debt, as well as the average firm-specific historic equity volatility. Our sample comprises 598 unique public companies with a total market capitalisation of US$ 8.7 trillion and outstanding debt of US$ 5.04 trillion. The table below gives an indication of the representativeness of our sample. It is shown that these largest public firms capture a fair share of the estimated global sectorial production.

Table 2: Representativeness of Firm sample, production coverage across sectors and outstanding debt and market capitalisation

	Estimated Global Production	% Share of Global Production captured in Analysis	Number of Ultimate Parent Firms in Analysis	Total market capitalisation (in billion US$)	Total outstanding debt (in billion US$)
Automotive	89 million(cars sold/year)	84%	39	2.199	1.544
Oil & Gas	364 billion (GJ/year)	52%	238	4.265	1.224
Coal	6.5 billion (tonnes of coal/year)	29%	57	191	72
Power (Capacity)	6.3 million (MW/year)	38%	264	2.329	2.203

Declaration of Conflicting Interests

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