Scenario-based equity valuation effects induced by greenhouse gas emissions

Corporate valuations are largely determined by investors' and market participants' expectations. These encompass expectations about the future trajectory of CO_2 prices just as much as expectations about how sharply a company can reduce its greenhouse gas emissions by adjusting technology in response to rising emissions costs. Where expectations shift from a scenario in which Nationally Determined Contributions are implemented to a scenario aligned with the more ambitious Paris Climate Agreement targets, this could involve, in some cases, considerable valuation changes. In particular, it is then likely that companies will be revalued along the lines of their carbon footprint and their ability to bear the associated costs.

The present article introduces a simple indicator which quantifies the emissions-related changes in the valuation of stock corporations resulting from a shift from one scenario to another. Here, a multi-stage dividend discount model is calibrated on firm-specific greenhouse gas emissions and scenario data from a multi-regional integrated assessment model (IAM). The IAM used here models in a detailed fashion the energy systems in the individual regions of the world, amongst other things, and allows for temporary regional differences in climate policy. Under a set of assumptions, the measure presented in this article provides a risk indication for the firm's ability to bear scenario-dependent costs of direct greenhouse gas emissions. In this context, the results for 5,285 stock corporations from various countries indicate that a large percentage of them would sustain only minor emissions-related valuation losses as a result of a shift in expectations towards a transition to a Paris-aligned low-carbon economy. On the other hand, a segment of companies with high emissions costs and limited ability to bear these costs would suffer substantial valuation losses – especially in business areas oriented to fossil fuels. Climate-related valuation changes and the question of climate-related stranding of certain assets are therefore likely to play an important role in financial markets going forward.

Introduction

Climate change and climate policy affect corporate sector

The atmospheric concentration of carbon dioxide (CO_2) has gone up by over 25% in the past 50 years. At the same time, an increase in the global average temperature has been observed. There is now a consensus in the scientific community that the increasing concentration of CO_2 in the atmosphere is attributable to human actions and that there is a causal relationship between the CO_2 concentration and the rise in temperatures. A large number of recognised climate models therefore look at scenarios of future emissions of CO_2 and other greenhouse gases. At the heart of these scenarios is to identify which emissions pathways are associated with which climate impacts and temperature increases.[1]

Consistent with mounting signs of climate change, this scientific consensus is increasingly spilling over to the societal and political debates. It is widely agreed that greenhouse gas emissions need to be reduced in order to mitigate global warming. The outcomes of this consensus have been, in particular, the Paris Climate Agreement (COP21) and, most recently, the UN Climate Change Conference in Glasgow (COP26) and national climate action legislation.

The corporate sector is one of the largest emitters of greenhouse gases. Policy interventions aimed at reducing emissions will therefore also impact strongly on firms. The analysis presented here quantifies the impact of climate policy measures – here, in the form of long-term CO_2 price paths – on corporate valuation. The article will focus on the emissions-related stock market valuation effects that can be associated with a structural transition towards less carbon-intensive production. If, for example, climate policy is aligned with the Paris climate targets, leading to a transition to a low-carbon economy, the results presented here suggest that the valuations of a large proportion of companies will see only little change. For a segment of the firms, however, considerable shifts will occur, and some firms will see elevated insolvency risk (stranded assets).[2] The indicator proposed in this analysis has been kept simple by design. It factors out the firm-specific costs of avoiding emissions. The effects of progressive physical climate change, such as damage caused by extreme weather events, are not taken into consideration, either.

CO_2 price necessary for climate-friendly structural change

A key policy lever is the CO_2 emissions price, which is also applicable to other greenhouse gas emissions (expressed as CO_2 equivalents). This is likely to be the element on which climate-friendly structural change will hinge.[3] At the same time, the CO_2 price path determines the speed at which the relative prices of carbon-intensive products and services shift. The shift in relative prices therefore sets incentives to reconfigure business models and production processes and adapt supply chains. In this context, it is pivotal to head for a use of low-carbon energy sources. In the multi-regional climate-economic model applied here, too, the CO_2 price plays a key role.

Climate-economic models and climate scenarios used

Need for climate scenarios

Recourse is often taken to what are known as multi-regional integrated assessment models (IAMs), which incorporate the climate system, the economy and the energy and land-use systems. They allow scenarios for the climate system to be modelled as a function of climate policy and economic structures – especially regarding the use of fossil and non-fossil energy sources. Drivers here are the various emitters of CO_2 and other greenhouse gases and their emissions trajectories. Such scenarios serve as key pillars of climate policy decisions. It is not sufficient to analyse historical data in order to

1 See, for instance, Rogelj et al. (2019).
2 For more on asset stranding, see p. 68.
3 To wit, in a relevant special report published in 2019, the German Council of Economic Experts called for making the CO_2 price a core element of climate policy. See German Council of Economic Experts (2019).

adequately assess future climate risks: there are no historical precedents for either climate change caused by the burning of fossil fuels or efforts to transition from carbon-intensive to low-carbon economies.

In order to calculate policy-relevant climate-economic scenarios, climate research institutes generally use process-based IAMs which allow for differences in regional developments and which exactly model key sectors. The projections of these models can be used, inter alia, as inputs for central banks' economic models. Harmonised scenarios from such models also form, for instance, the analytical basis for the work carried out within the Network for Greening the Financial System (NGFS), a global network of central banks and supervisory authorities.[4] The baseline scenario in the relevant scenarios is usually the "business as usual" case, characterised by the complete absence of enhanced climate policy efforts. An alternative, somewhat more optimistic baseline scenario of the models consists in full implementation of "Nationally Determined Contributions" by policymakers.[5]

Scenarios calibrated in this manner come to the conclusion that the international community's current Nationally Determined Contributions will not suffice to achieve the Paris Climate Agreement targets.[6]

At centre stage: "Net Zero 2050" climate scenario …

This became clear at the COP26 climate conference in November 2021. It therefore cannot be ruled out that future governments will agree to take more ambitious climate action measures. Therefore, in scenario analyses, the aforementioned more optimistic baseline "Nationally Determined Contributions" scenario is frequently contrasted with a climate policy scenario in which emissions of CO_2 and other greenhouse gases are priced such that they are reduced considerably in keeping with the Paris Agreement. One of these scenarios is "Net Zero 2050". Under this scenario, societies around the world begin today to reconfigure their economies to low-carbon economies in an orderly manner such that, by 2050, net CO_2 emissions are down to zero.

… with endogenous reductions in greenhouse gas emissions

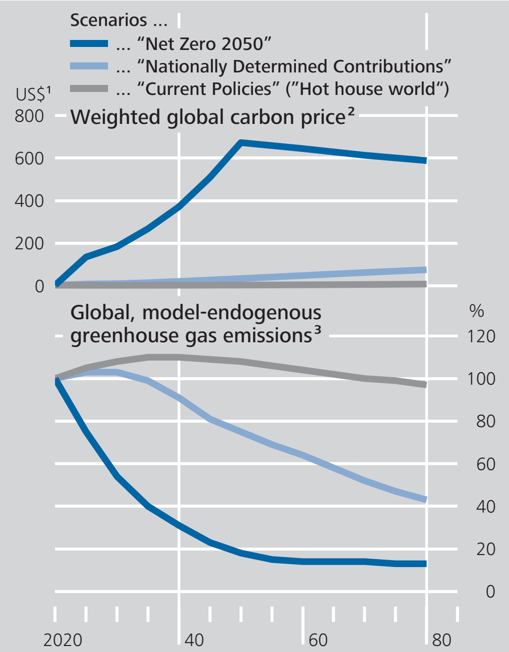
In the IAMs, representative agents maximise their utility while complying with restrictions on cumulative emissions of CO_2 and other greenhouse gases. In the "Net Zero 2050" scenario, their scope is compatible with the 1.5°C temperature target. Regional greenhouse gas emissions are an endogenous result of this maximisation. It is thus implicitly assumed that, in their production plans, companies choose their energy mix to minimise energy costs – depending on the regional availability of resources.[7,8]

Large differences in CO_2 prices between scenarios

The size of the differences between such scenarios is illustrated, in the chart on p. 66, in the time pathways for the CO_2 price and greenhouse gas emissions from a typical simulation of one of the IAMs used in the NGFS. To wit, in the "Net Zero 2050" scenario the global average CO_2 price already surges between 2020 and 2025, while it hovers near zero in the remaining scenarios up until 2030. Global greenhouse gas emissions accordingly continue to rise until 2030, whereas in the "Net Zero 2050" scenario they drop quickly after 2020. Within this Paris-aligned scenario, as in all scenarios used in the NGFS, regionally different CO_2 price trajectories and attendant emissions reductions are permitted (see the chart on p. 67). Here, the different initial conditions regarding

4 See NGFS (2021a, 2021b) as well as the NGFS Scenario Explorer (www.iiasa.ac.at). Since 15 December 2021, the NGFS has been comprised of 105 member institutions and 16 observers.
5 The implementation of Nationally Determined Contributions in IAMs is based on Roelfsema (2020); for a description of the Nationally Determined Contributions, see United Nations Framework Convention on Climate Change (2021).
6 See, for instance, Boehm et al. (2021).
7 In this scenario, there will continue to be a small amount of global CO_2 emissions after 2050, but these will be offset by CO_2 withdrawals elsewhere. Cost-minimising behaviour which also allows for regional differences in CO_2 pricing is a property of the category of "cost-effectiveness models". See, for example, Luderer et al. (2015) and Glanemann et al. (2020).
8 To achieve this temperature target, the trajectory of CO_2 prices is used as a conduit to determine cost-effective pathways of the prices of energy sources and greenhouse gas emissions. See Kriegler et al. (2013), Lontzek et al. (2015), Riahi et al. (2015), Riahi et al. (2017) and Rogelj et al. (2018).

CO_2 prices and pathways of greenhouse gas emissions in selected scenarios



Source: Potsdam Institute for Climate Impact Research (REMIND-MAgPIE). **1** At 2010 prices. **2** Weighted with regional gross CO_2 emissions. **3** 100% corresponds to 54 gigatonnes of CO_2 equivalents in 2020.
Deutsche Bundesbank

the use of the individual energy sources are taken into account.

In the spotlight: REMIND-MAgPIE model

We will refer below to projections for the baseline "Nationally Determined Contributions" scenario and a Paris-aligned "Net Zero 2050" climate scenario in the REMIND[9] model developed by the Potsdam Institute for Climate Impact Research. As in other internationally acclaimed and renowned models of this category of IAMs, this model is basically about projecting a large number of economic, energy-related, physical and climate-relevant indicators over long periods of time – generally until the end of the 21st century. On the basis of these model projections, we will investigate what valuation effects can occur in financial markets if the climate policy expectations "flip over" from this baseline to the "Net Zero 2050" climate scenario.

REMIND-MAgPIE is a global general equilibrium model

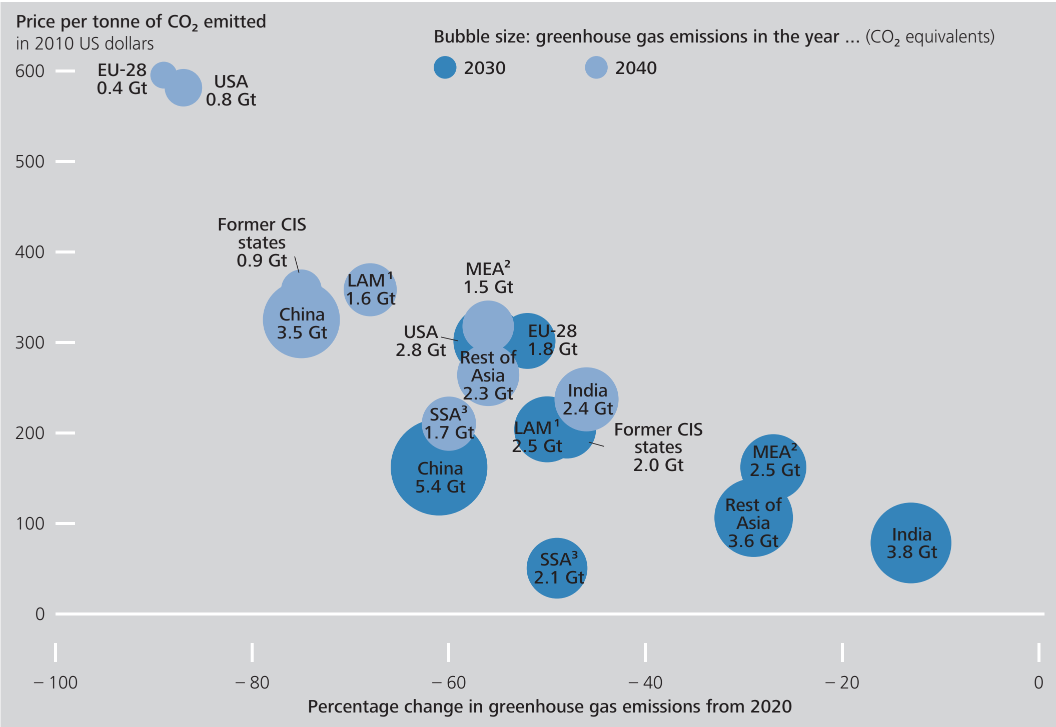
The REMIND model is a global general equilibrium growth model. This closed-economy model with twelve regions consists of a macroeconomic core and process-based modellings of the energy sector with all relevant greenhouse gas emissions.[10] Here, the energy module is connected to the macroeconomic core via energy demand and energy costs. Endogenous technological change all the way to climate-friendly energy production is allowed for via a global learning curve. The REMIND model can be linked up to a land-use model called MAgPIE.[11]

Assumption of globally coordinated climate policy measures

It is assumed in the "Net Zero 2050" scenario that the individual regions of the world begin to coordinate their climate policy approaches in the 2020 to 2025 period, with most regions initially starting out with CO_2 prices at different levels that gradually converge (by 2050) to a common trajectory. The REMIND-MAgPIE model allows an aggregated good, fossil fuels and bioenergy to be tradable across regions. Adequate mechanisms – such as carbon border adjustment mechanisms – permit regional differences in CO_2 prices charged without this leading to shifts in trade relationships. CO_2 price-induced competitive distortion or shifting of emissions to third countries – referred to as carbon leakage – can therefore be ruled out for energy-intensive goods.[12] There is therefore no contradiction between differences in CO_2 prices and coordination of regional climate policies: given that considerable transfers would be necessary in order to achieve the decarbonisation at the same CO_2 prices, initial price dif-

9 For more on the REMIND (Regional Model of Investments and Development) model, see Baumstark et al. (2021).
10 The climate system, including temperature estimation, is not modelled within the REMIND model but in a coupled model. The MAGICC 6 model is used here for NGFS scenarios; see Meinshausen et al. (2011).
11 See Dietrich et al. (2019). Land-use models such as MAgPIE combine economic and biophysical approaches in order to simulate spatially explicit global land-use scenarios (especially pasture, forest and cropland for food and bioenergy purposes) in the 21st century as well as interactions with the environment. In order to identify common transition pathways from energy and land-use systems in connection with the macroeconomic core, the REMIND model is therefore coupled either with land-use emulators or, in an iterative process, with the stand-alone MAgPIE land-use model.
12 In the REMIND model, there is only slight carbon leakage caused by price effects relating to fossil fuels.

Regional CO_2 prices and emissions reductions in the "Net Zero 2050" scenario



Sources: Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. **1** Latin America and the Caribbean. **2** Middle East, Central Asia and North Africa. **3** Sub-Saharan Africa.
Deutsche Bundesbank

ferentiation and gradual convergence are tolerated.[13]

Considerable reduction in emissions intensity necessary to switch to a Paris-aligned emissions pathway

On the basis of the REMIND-MAgPIE model, the chart on p. 68 illustrates the relationship between global greenhouse gas emissions and global GDP (at 2010 prices) for selected climate policy scenarios. It turns out that in a baseline scenario in which climate policy efforts remain unchanged globally ("business as usual"), there is virtually no reduction in emissions despite a certain decline in emissions intensity, which implies that global warming is not mitigated (median rise of 3.1°C by the year 2100).[14]

In the spotlight: comparison of valuation effects under different climate policy expectations

In the alternative baseline scenario, in which it is assumed that the Nationally Determined Contributions pledged by end-2020 are fully implemented, the reduction in emissions intensity – the amount of greenhouse gas emissions over GDP – is stronger, which means that emissions will decline to a certain extent in absolute terms beginning in 2030 (implying median global warming of 2.4°C by the year 2100). Both baseline scenarios can be compared with an ambitious global climate policy aligned with the Paris Climate Agreement targets: as the chart on p. 68 shows, a strong reduction in greenhouse gas emissions and thus in emissions intensity will be necessary to limit median global warming to 1.5°C. In a "Net Zero 2050" scenario, CO_2 prices already go up so sharply in the coming years that greenhouse gas emissions will decline in the current decade from 700g to 290g of CO_2 equivalents per real US dollar of GDP and keep falling to 130g by 2040. Whereas historical reductions in intensity were primarily based on improved energy efficiency, such a rapid reduction is possible only if energy supply is changed over to climate-friendly technologies – mainly based on renewable energy sources.

13 See Bauer et al. (2020).
14 See the chart on p. 73.

Relative decarbonisation in selected scenarios

Sources: World Bank (World Development Indicators), Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations.

Deutsche Bundesbank

Nationally Determined Contributions as a baseline scenario

The scenario of Nationally Determined Contributions shall serve as the baseline scenario below – thereby assuming that it is an accurate reflection of current market expectations.[15] This is against the background of existing empirical evidence which indicates that greenhouse gas emissions influence companies' financial market prices to a certain extent. However, there are no signs to date that corporate valuations are broadly consistent with a Paris-aligned transition scenario.

Climate risks and stranded assets

Properties of stranded assets

"Stranded assets" are currently being increasingly discussed as a possible by-product of climate change. An asset is said to be stranded prior to the end of its useful economic life – as expected at the time of investment – if this asset can no longer yield any economic return and thus loses its entire value. In the context of climate change, losses in value can be caused by physical damage, regulatory intervention or structural change. Value losses can occur – potentially abruptly – if already-made investments are rendered unprofitable by unexpected policy measures or extreme weather events.

With regard to "green" structural change or the transition to a low-carbon economy – much in the spirit of "creative destruction" – it may, however, be necessary to strand certain business models if the goal is the efficient use of funds for necessary investment in financial markets.

"Unburnable carbon"

There is a wide body of literature which studies the potential losses of asset values caused by climate change. Meinshausen et al. (2009) discuss the "stranded assets" hypothesis by showing the limited amount of CO_2 that could be emitted by 2050 in order to have a high probability of keeping global warming below 2°C by 2100. The logical consequence of these calculations is that a substantial portion of existing fossil fuel inventories would have to remain in the ground ("unburnable carbon"). McGlade and Ekins (2015) show that, between 2010 and 2050, one-third of oil reserves, one-half of gas reserves and over 80% of coal reserves would have to go unextracted in order to meet the two-degree goal. In order to have a 50% chance of not exceeding a temperature increase of 1.5°C, according to Welsby et al. (2021), even nearly 60% of oil and gas reserves and 90% of coal reserves would have to remain in the ground.[16] This would render a substantial proportion of fossil fuel assets worthless.

15 In the REMIND-MAgPIE model, economic agents are assumed to have perfect prior knowledge of the scenario in which they are agents. No sudden turnaround in expectations is modelled within the scenarios under review.
16 According to Welsby et al. (2021), global oil and gas production would have to fall by 3% per year by 2050 in order to achieve this target. That would, in turn, make unprofitable many fossil fuel production projects that are either being planned or up and running.

Methodological approach to quantifying emissions-related changes in value and potentially stranding assets

Top-down approach

Various approaches to quantifying climate-related changes in asset values have been proposed in the literature. One of these consists in incorporating projections of the aforementioned macroeconomic climate scenarios into a large macroeconometric model such as NiGEM[17] and, in a first step, identifying country effects for economic output and equity prices within a given transition scenario.[18] In a second step, the resulting trajectories are linked to the results of a sector model in order to assign valuation effects resulting from a switch from a baseline scenario to a more ambitious transition scenario to individual securities depending on the sector of the issuer.

Firm-level approaches

Battiston et al. (2017) and Roncoroni et al. (2021) take another path. They examine risk exposure in institutional portfolios and, on this basis, answer the question as to how climate policy risks might propagate through the financial system, using their own sector classification (referred to as "Climate Policy Relevant Sectors").[19] As regards equity valuation, Battiston et al. (2021) suggest estimating a firm's dividend path in proportion to output. They in turn then model future output as a function of the observed climate scenario. The authors use the comparison between this pathway and the baseline scenario pathway to identify firm-level changes in value.

Scenario-based approach chosen here

We propose an alternative, innovative firm-level approach. As described above, climate-economic scenarios can be used to model the pathways to achieving the Paris Climate Agreement targets. Against this background, we develop a scenario-based price impact indicator based on the costs of direct greenhouse gas emissions attributable to non-financial corporations and then relate these to individual firms' dividend expectations. This indicator also incorporates projected macroeconomic output in the individual regions of the world and the use of individual fossil and non-fossil energy sources. The objective is to quantify the financial market implications of Paris-aligned climate action by taking recourse to projections in IAMs.

Constructing a scenario-based price impact indicator

Dividend discount model as a starting point

Market expectations determine price discrimination based on greenhouse gas emissions

As a rule, market participants' expectations about the climate policy pathways followed by the international community and companies' adaptability determine whether market valuations and financing conditions discriminate adequately between low-emissions and emissions-intensive business models.[20] Against this backdrop, the analysis described here starts by quantifying, in a first approximation, the corporate valuation effects as a result of an assumed switch from an expected implementation of "Nationally Determined Contributions" to the Paris-aligned "Net Zero 2020" scenario. Meanwhile, any imponderables in terms of the evolution of global CO_2 prices and the concomitant uncertainties this creates in financial markets are disregarded here.[21]

The value of companies under the scenarios outlined above can be calculated using a dividend discount model that incorporates long

17 NiGEM (National Institute Global Econometric Model) is a macroeconometric multi-country model developed by the National Institute of Economic and Social Research. See https://nimodel.niesr.ac.uk
18 See Vermeulen et al. (2018), Allen et al. (2020), Banque de France (2021), ECB/ESRB (2021) and Deutsche Bundesbank (2021). In a departure from the assumptions made in the "Net Zero 2050" scenario, Deutsche Bundesbank (2021) assumes that revenue from CO_2 pricing is not used to finance public investment but instead to cut income taxes.
19 See www.finexus.uzh.ch/en/projects/CPRS.html
20 Dunz et al. (2021) and Battiston et al. (2021) demonstrate, for instance, that the pricing of companies' transition risk changes depending on market expectations – in the form of different capital costs, say.
21 See, for instance, Gollier (2021).

An emissions-related price impact indicator

A multi-stage dividend discount model – which allows for the incorporation of scenario-specific projections – was chosen as a basis for the construction of an emissions-related price impact indicator. The relationship between the share price $V_{i,r,s,2020}$ of company i at the base date (here: December 2020) and the future dividends $D_{i,r,s,\tau}$ in the baseline scenario (here: "Nationally Determined Contributions") is shown in equation (1). Here, it is assumed that the baseline scenario is the scenario expected at the end of 2020 in the markets for company i domiciled in region r and whose core business is in sector s:

(1)

$$V_{i,r,s,2020} = \sum_{\tau=2021}^{2024} \frac{D_{i,\tau}^{IBES}}{(1+R_i^{base})^{\tau-2020}} + \sum_{\tau=2025}^{2032} \frac{D_{i,r,s,\tau}^{transition\_base}}{(1+R_i^{base})^{\tau-2020}} + \sum_{\tau=2033}^{2100} \frac{D_{i,r,s,\tau}^{base}}{(1+R_i^{base})^{\tau-2020}} + \frac{D_{i,r,s,2100}^{base}}{R_i^{base}-(g_{r,s,2100}^{Y,base}+\pi)}(1+R_i^{base})^{-80}.$$

Equation (1) expresses the share price as the present value of future dividend flows, as described by the variables $D_{i,\tau}^{IBES}$, $D_{i,r,s,\tau}^{transition\_base}$ and $D_{i,r,s,\tau}^{base}$. The unknown variable for which this equation can be solved is the implied cost of equity (return on equity, R_i^{base}) as a firm-specific discount rate. For the first three years (2021 to 2023), dividend expectations $D_{i,\tau}^{IBES}$ drawn from analyst surveys (sources: IBES, Thomson Reuters) are introduced, which are assumed to be already priced in. For the following year (2024) the dividend expectation is approximated using the three to five-year IBES earnings growth expectation – which does not depend on the chosen scenario, either.[1] In the following assumed eight-year transition period (2025 to 2032), the company's dividends $D_{i,r,s,\tau}^{transition\_base}$ are projected based on an interpolation between the three to five-year IBES earnings growth expectations and the scenario-dependent, partly sector-specific economic output in the twelfth year (plus an inflation assumption).

In contrast to the three-stage dividend discount model,[2] no "steady state" dividend growth is assumed in the subsequent phase (2033 to 2100). Instead, the model assumes a trajectory of dividends $D_{i,r,s,\tau}^{base}$ proportional to economic output in the climate scenario under review up to the year 2100, plus an inflation assumption. Here, economic output refers either to nominal gross domestic product (GDP) or sectoral production in the baseline scenario for the region in which the company is domiciled. If the company is an oil, gas or coal producer or is active in the fields of renewable or nuclear energy, its dividends are projected in proportion to the trajectory of energy production in the respective sector. If it is a cement or steel company, its dividends are projected in proportion to the trajectory of either cement or steel production, respectively.[3]

Projections arising from the REMIND-MAgPIE model are available up to the year 2100 and are accordingly incorporated. For the following period, it is assumed that dividends continue to grow at the rate last projected in the baseline scenario for sector s and/or GDP $g_{r,s,2100}^{Y,base}$ in region r, plus the inflation assumption.

1 Should the latter not be available for a company, it is approximated by extrapolating the dividend growth between years two and three for a further year.
2 See Deutsche Bundesbank (2016).
3 The REMIND-MAgPIE model provides separate, regional emissions pathways for the cement and steel industries, which must be separately taken into account.

The second step involves projecting firm-specific additional costs from greenhouse gas emissions that are incremental to the baseline scenario. The central focus here is the scenario of an orderly transition to a Paris-aligned low-carbon economy ("Net Zero 2050"). The starting point is direct greenhouse gas emissions, expressed in CO_2 equivalents. These data are taken from company reports or estimated by specialised data providers (source used here: ISS-ESG). The emissions data per share $c_{i,0}$ underlying the analysis are for 2019.

In addition to the size of company emissions per share at time τ ($c^{NZ}_{i,r,\tau}$ or $c^{base}_{i,r,\tau}$), the CO_2 price in region r determines the emissions costs per share ($C^{NZ}_{i,r,\tau}$ or $C^{base}_{i,r,\tau}$) in the Paris-aligned "Net Zero 2050" scenario and the baseline scenario:

(2a) $C^{NZ}_{i,r,\tau} = c^{NZ}_{i,r,\tau} \cdot p^{NZ}_{r,\tau}$,

(2b) $C^{base}_{i,r,\tau} = c^{base}_{i,r,\tau} \cdot p^{base}_{r,\tau}$.

Accordingly, the incremental costs per share $\Delta C^{sc}_{i,r,\tau}$ arising for company i in the "Net Zero 2050" scenario are calculated at every future point in time as the difference between (2a) and (2b).

(2c) $\Delta C_{i,r,\tau} = C^{NZ}_{i,r,\tau} - C^{base}_{i,r,\tau}$.

To quantify the future scenario-dependent emissions $c^{sc}_{i,r,\tau}$ for the company ($c^{NZ}_{i,r,\tau}$ or $c^{base}_{i,r,\tau}$), as well as the associated costs, they are projected as a function of the scenario-implied emissions growth rate:

(3)

$$c^{sc}_{i,r,\tau} \equiv c_{i,0} \prod_{n=1}^{\tau} (1 + g^{E,sc}_{r,n}),$$

$$\textit{where}$$

$$g^{E,sc}_{r,n} \equiv \begin{cases} \left(\frac{E^{sc}_{r,t+5}}{E^{sc}_{r,t}}\right)^{\frac{1}{5}} -1 \; for \; E^{sc}_{r,t+5} \geq 0 \; and \; t < n \leq t+5 \\ -1 \; for \; E^{sc}_{r,t+5} < 0. \end{cases}$$

According to equation (3), $g^{E,sc}_{r,n}$ is the rate at which greenhouse gas emissions in future year n increase or decrease. It is determined using the scenario-specific emissions $E^{sc}_{r,t}$ and $E^{sc}_{r,t+5}$, which are available at five-year intervals $[t,\ t+5]$. The emissions of company i change cumulatively between the base date and year τ at the rate $\Pi^{\tau}_{n=1}(1 + g^{E,sc}_{r,n}) - 1$. It is thereby assumed that they evolve in proportion to overall emissions in the observed scenario. With respect to the "Net Zero 2050" scenario, this is compatible with a Paris-aligned decarbonisation.[4] If scenario-specific emissions are negative – due, for instance, to the use of carbon dioxide removal technologies – a complete decarbonisation is assumed ($g^{E,sc}_{r,n} = -1$). This means that no earnings stemming from negative emissions or lateral transfers are permitted at the company level.

Finally, the scenario-dependent dividend path of company i is reduced by the share x_i of the incremental cost from equation (2c) that the company cannot pass on to its customers by assumption. The valuation effect for a company arising from a revision of expectations from the baseline scenario towards the "Net Zero 2020" scenario is shown in equation (4):

(4)

$$\Delta^{v}_{i,r,s,2020} = \frac{1}{V_{i,r,s,2020}} \left(\sum_{\tau=2021}^{2024} \frac{D^{IBES\_NZ}_{i,r,s,\tau} - x_i \cdot \Delta C_{i,r,\tau}}{(1+R^{base}_i)^{\tau-2020}} + \sum_{\tau=2025}^{2032} \frac{D^{transition\_NZ}_{i,r,s,\tau} - x_i \cdot \Delta C_{i,r,\tau}}{(1+R^{base}_i)^{\tau-2020}} + \sum_{\tau=2033}^{2100} \frac{D^{NZ}_{i,r,s,\tau} - x_i \cdot \Delta C_{i,r,\tau}}{(1+R^{base}_i)^{\tau-2020}} + \frac{D^{NZ}_{i,r,s,2100} - x_i \cdot \Delta C_{i,r,\tau}}{R^{base}_i - (g^{Y,NZ}_{r,s,2100} + \pi)} (1+R^{base}_i)^{-80} \right).$$

In equation (4), the bracketed term provides the present value of the dividends net of

4 Although compliance with the Paris Agreement climate targets is not necessarily limited to a reduction in direct (scope 1) company emissions, for the purposes of this analysis scope 1 decarbonisation in proportion with emissions reduction in the "Net Zero 2050" scenario is nevertheless defined as Paris-aligned.

the share of incremental costs that cannot be passed on $(x_i \cdot \Delta C_{i,r,\tau})$, taking into account the dividend path described by the variables $D_{i,r,s,\tau}^{IBES\_NZ}$, $D_{i,r,s,\tau}^{transition\_NZ}$ and $D_{i,r,s,\tau}^{NZ}$. To the extent that output growth at time τ in the scenario under review differs from that in the baseline scenario, differing dividend growth rates are accordingly accounted for. For the period following 2100 in the Paris-aligned scenario, it is assumed that dividends continue to grow at the rate last projected in this scenario for sector s and/or the GDP $g_{r,s,2100}^{Y,NZ}$ in region r, plus the inflation assumption.

Similarly, short-term dividend expectations $D_{i,\tau}^{IBES}$ taken from analyst surveys, which are assumed to be already priced in, are likely to be revised in a more ambitious climate policy scenario. In the valuation approach presented here, an adjustment is carried out for the growth differential in economic output $(g_{r,s,\tau}^{Y_{NZ}} - g_{r,s,\tau}^{Y_{base}})$ at time τ between the scenario under review and the baseline scenario. It is thus assumed that short-term dividends $D_{i,r,s,\tau}^{IBES\_NZ}$ do not grow at rate $g_{i,\tau}^{IBES}$ but instead at the adjusted rate $g_{i,r,s,\tau}^{IBES\_NZ}$:

(5) $D_{i,r,s,\tau}^{IBES\_NZ} = D_{i,r,s,\tau-1}^{IBES\_NZ}(1 + g_{i,r,s,\tau}^{IBES\_NZ})$.

This rate is calculated as the sum of $g_{i,\tau}^{IBES}$ and the aforementioned growth differential:

(6) $g_{i,r,s,\tau}^{IBES\_NZ} = g_{i,\tau}^{IBES} + (g_{r,s,\tau}^{Y_{NZ}} - g_{r,s,\tau}^{Y_{base}})$.

If the company's business is in one of the aforementioned energy sectors or the steel or cement industry, $g_{r,s,\tau}^{Y_{NZ}}$ reflects the sectoral production growth rather than GDP growth.

Scenario-based calculation of value based on a dividend discount approach

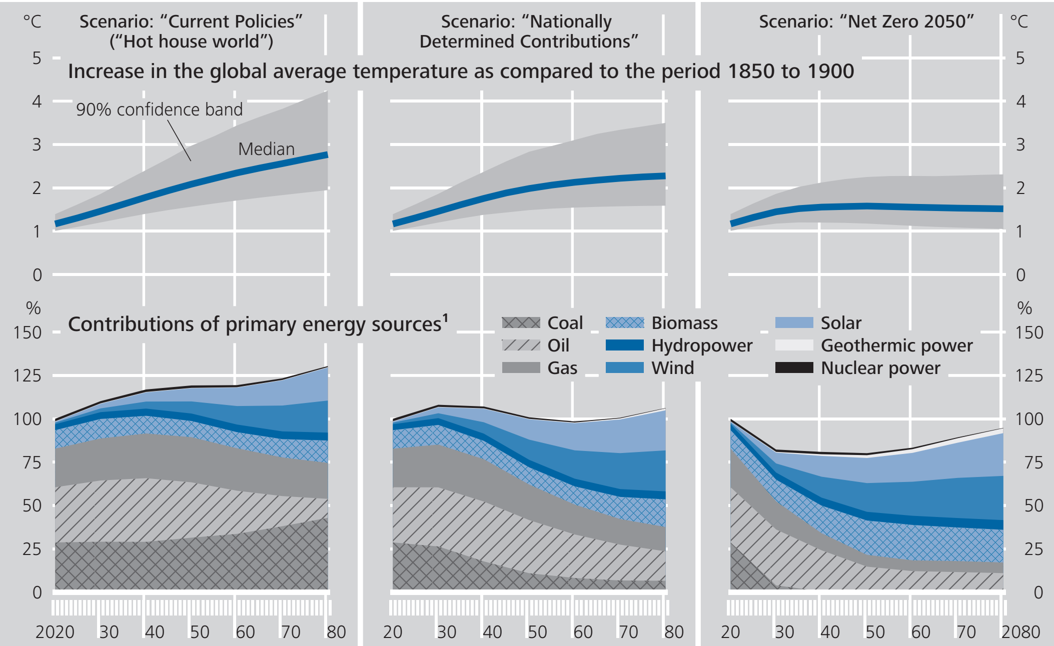
horizons. The focus here lies on the change in the value of individual firms as a result of the switch, outlined above, in market participants' expectations regarding climate policy. The company's equity price as at the base date (here: end-2020) is used as its reference value. This is assumed to correspond to the present value of the future dividend flows if the end-of-2020 pledges (Nationally Determined Contributions) are implemented. This share price is put in relation to the company's equity value if the "Net Zero 2050" scenario is implemented. The price impact indicator analysed here describes the difference between these two figures. Such a measure of the difference in value between scenarios is likely to be relevant to investors, too, when quantifying potential price adjustments for individual companies or the risk of a stranding of assets (see also the box on pp. 70 ff.).

Assumption regarding production technology and elasticities of substitution …

For this indicator to be calculated for every stock corporation, several assumptions must initially be made. It is assumed, for instance, that companies are able to substitute energy sources in line with the production technology pathway projected in the REMIND-MAgPIE model and switch to environmentally friendly technologies for their energy usage.[22] Ultimately, greenhouse gas emissions can be perceived as the result of a cost-driven energy choice made by the representative firm. As CO_2 prices rise, firms will tend to replace increasingly expensive emissions-intensive energy sources with lower-emissions alternatives. Put simply, companies' optimisation calculus will be to decarbonise as long as the firm-specific cost of avoiding the last tonne of carbon emissions is lower than the CO_2 price.

22 For the gross domestic product of each region, this model assumes a (nested CES) production function with constant substitution elasticities, with energy as a factor of production consisting of inputs from the buildings, industry and transport sectors. These are, in turn, dependent on their own elasticities of substitution between individual fossil and non-fossil energy sources.

Temperature pathways and contributions of primary energy sources



Sources: Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. **1** 100% equates to global primary energy production in 2020 (560 exajoules). In the study of Baltzer, Bertram, Hilaire, Johnston and Weth (forthcoming) referenced here, the contributions of the primary energy sources serve as an indicator to capture the output and dividend growth of companies that depend on the respective primary energy sources. The contributions of the primary energy sources are based on the direct equivalence method, where a unit of secondary energy from non-fossil sources equates to a unit of primary energy. This method is used in studies on long-term scenarios, including several IPCC reports.

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.. and the dividend path

A further assumption relates to the expected dividend path. The approach chosen in this analysis takes account of short-term firm-specific dividend expectations gleaned from surveys as well as long-term gross dividend expectations, which are assumed to evolve in line with modelled economic output. The estimated cost of the company's direct greenhouse gas emissions is deducted from these long-term gross dividends[23] to yield a net dividend path.

Assumptions on the region

The present analysis assumes that region-specific progress in reducing the intensity of emissions is reflected at the company level. The companies studied in this analysis are domiciled in 75 countries from various regions of the world, where their businesses are subject to the prevailing national climate policies. In order to calculate the indicator, it is assumed that the companies work under the regional circumstances presumed in the REMIND-MAgPIE model. A company is assigned to one of the twelve regions based on where the parent company is headquartered. It is thus assumed, for simplicity, that this firm's greenhouse gas emissions will also all take place in the region in which the company is headquartered.

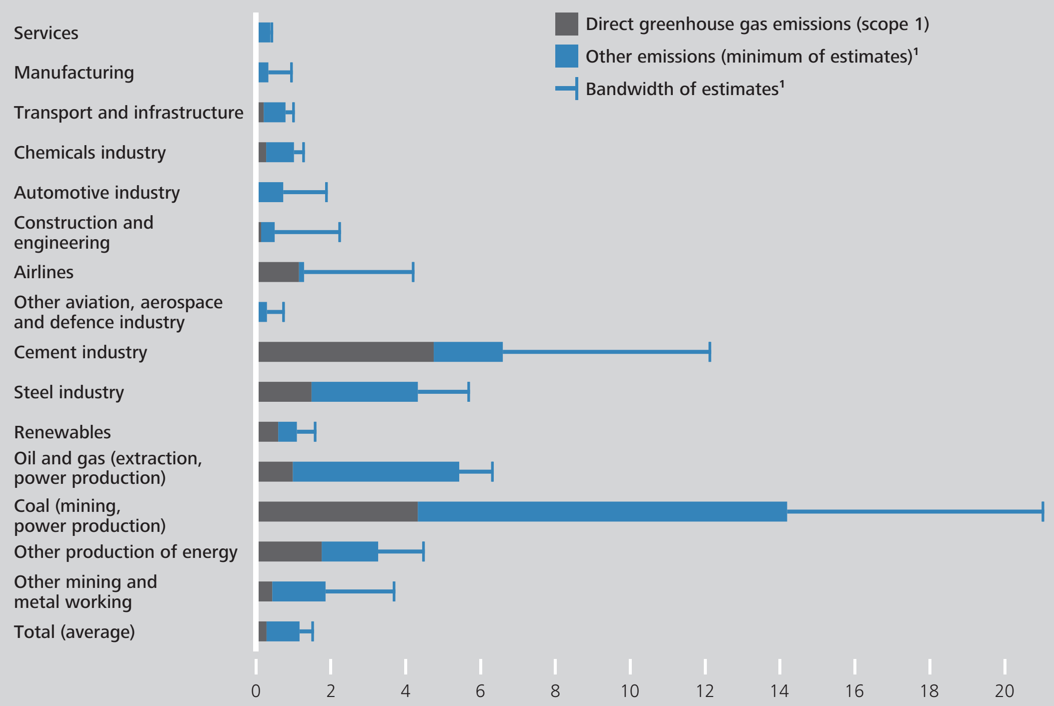
Assumptions on cost pass-through

Finally, the baseline scenario assumes that companies are not, or only partially, able to pass on higher CO_2 prices to consumers. In order to quantify the bandwidth of potential effects, this analysis differentiates between two cases: first, the case without cost pass-through and, second, the case with an 80% pass-through. In the first case, any emissions costs incurred will reduce profits and consequently dividends as well. If the cost of emissions is already reflected in dividend expectations in the baseline scen-

23 The required firm-specific emissions pathway starts with the company's current (reported or estimated) emissions and is assumed to evolve in line with scenario-specific decarbonisation. The company's future cost pattern is determined by developments in CO_2 prices as well as the growth rates of the modelled emissions. Progress in reducing emissions intensity (see the chart on p. 68) is consequently imposed for the companies under review.

Sectoral emissions intensities*

Thousands of tonnes of CO_2 equivalents per €1 million in revenues



Sources: ISS-ESG, Trucost, Thomson Reuters and Bundesbank calculations. * A total of 5,285 stock corporations are analysed. Sector averages calculated based on unweighted company-specific emissions intensities. **1** Bandwidth of estimates supplied by data providers ISS-ESG and Trucost for indirect greenhouse gas emissions (scope 2) and emissions relating to the product or supply chain (scope 3).

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ario, only that percentage of the costs that exceeds the costs in the baseline scenario will have to be deducted from dividends in the "Net Zero 2050" scenario.

Ultimately, two factors determine the company's net dividend path: the deviation of the output paths from the baseline scenario and the incremental emissions-related costs as a result of the remaining emissions (see the box on pp. 70 ff.). Depending on data availability, the net dividend paths also reflect the degree to which companies generate revenues from the sale of fossil energy sources or electricity produced from such sources.[24]

Firm-specific discounting of dividends

If the scenario-specific net dividends are discounted using the same interest rate (in this case, a firm-specific interest rate) as in the baseline scenario, valuation effects can be derived by comparing the resulting present value with the actual equity price. We determine this present value based on the firm-specific implied cost of capital, as required by investors at the base date using the baseline scenario and the equity price at that date. The resulting firm-specific changes in value are subsequently aggregated and evaluated at the sectoral and macroeconomic level.[25]

Data

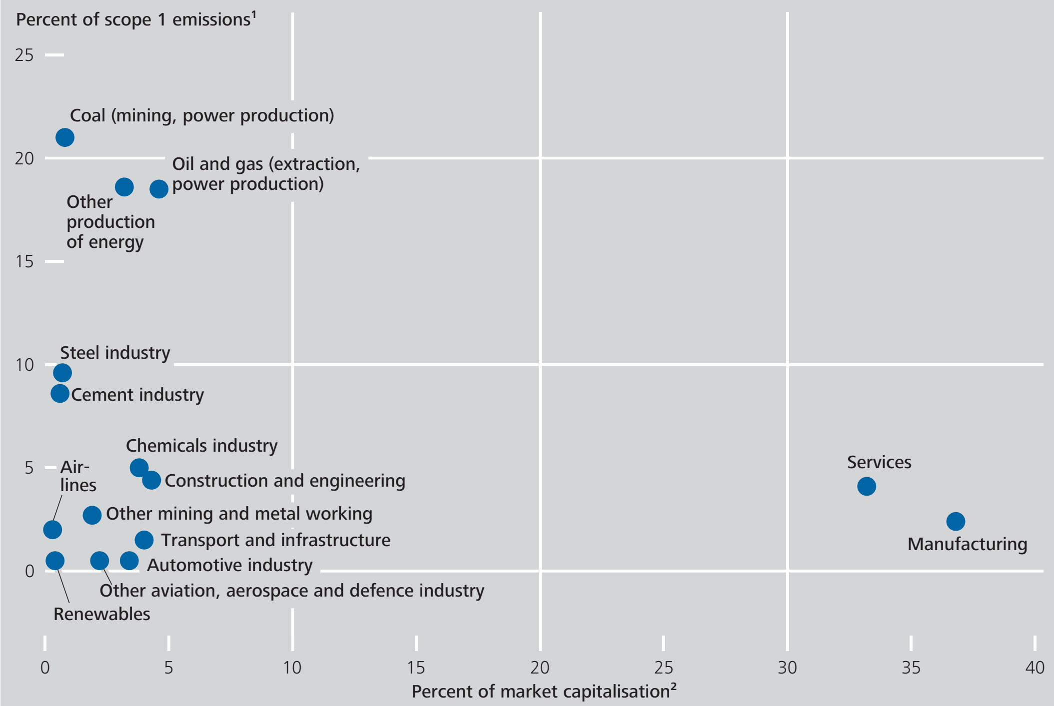
The present analysis covers 5,285 stock corporations worldwide

A useful guideline when measuring companies' greenhouse gas emissions is represented by the classification standards used in the Greenhouse Gas Protocol.[26] According to this protocol, dir-

24 The projected growth of companies' energy source-specific revenues are, in turn, based on the scenario-dependent contributions of individual energy sources to the total primary energy production in the region that includes the country in which the company is headquartered. For the globally aggregated contributions to primary energy production, see the chart on p. 73.
25 This path is taken based on the method used by Baltzer et al. (2022) (forthcoming).
26 For more on the Greenhouse Gas Protocol, see World Resources Institute (2004) and https://ghgprotocol.org/

Sector contributions to greenhouse gas emissions and stock market capitalisation*

%



Sources: ISS-ESG, Thomson Reuters and Bundesbank calculations. * The analysis covers a total of 5,285 stock corporations. **1** 100% represents these companies' total direct greenhouse gas emissions (scope 1 emissions for 2019) in the amount of 9.4 gigatonnes of CO_2 equivalents. **2** 100% of these companies' stock market capitalisation is equal to €44.6 trillion (end-2020).
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ect emissions (known as scope 1 emissions) from the production process or the services the company provides are distinct from indirect emissions (scope 2) that come about as a result of the purchase of electricity or heat. A further distinction (scope 3) covers emissions from upstream and downstream stages of the supply chain or in connection with the use of the product.

Firm-specific data on greenhouse gas emissions are provided by various suppliers that base their information on company reports or estimations. On this basis and using additional data at the firm level, the above-mentioned price impact indicator is calculated for a total of 5,285 non-financial stock corporations from 75 countries. These companies account for more than half of global stock market capitalisation. The percentage of direct greenhouse gas emissions they represent amounts to between 17% (9.4 billion tonnes of CO_2 equivalents) and 20% (10.5 billion tonnes) of total global emissions, depending on the data supplier. The following analyses are based on information gleaned from company reports and estimates provided by ISS-ESG, which supplies emissions data for all the companies observed here.

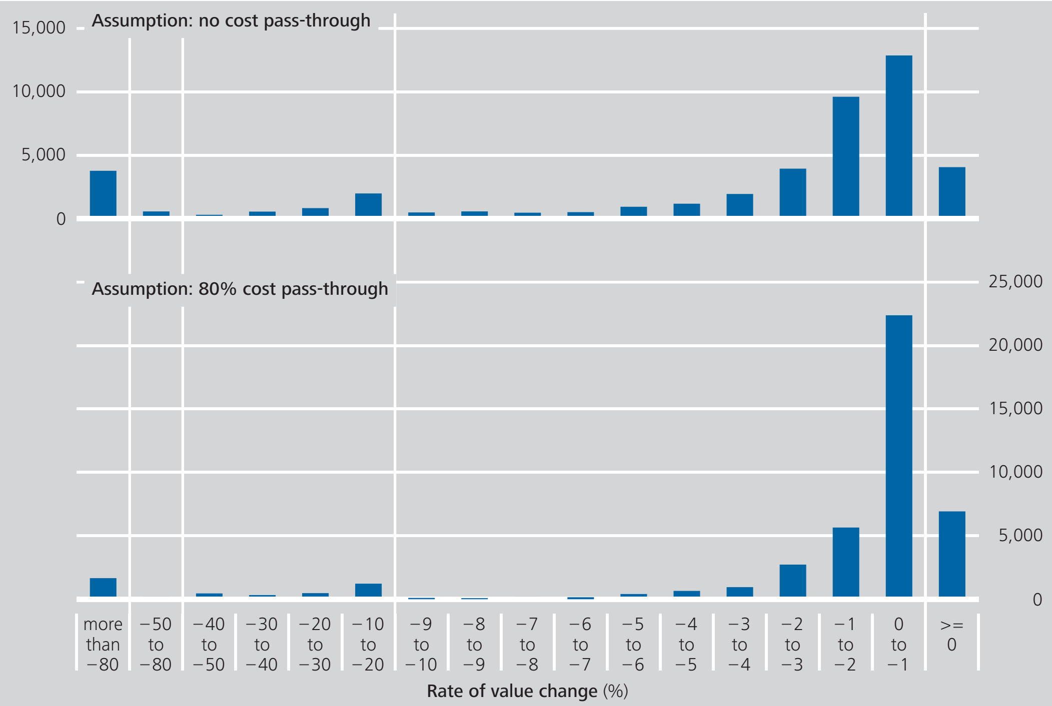
The chart on p. 74 depicts average emissions intensities for individual sectors (greenhouse gas emissions in 1,000 tonnes of CO_2 equivalents per €1 million in revenues). It shows, first, direct emissions (scope 1) as reported by the companies or estimated by ISS-ESG. Second, it depicts the bandwidth of sector averages of the intensities of indirect emissions (scope 2) and product or supply chain-related emissions (scope 3) based on estimates provided by two data suppliers. In most sectors, this imprecision in terms of these emissions is considerable.

Definition of the greenhouse gas emissions analysed

When constructing the price impact indicator presented here, only direct greenhouse gas emissions (scope 1) as at the base date are

Distribution of stock corporations' valuation effects*

Share capital in € bn (end-2020)



Sources: ISS-ESG, Thomson Reuters, Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. * Assumption: Paris-aligned decarbonisation of companies (scenario: "Net Zero 2050", baseline scenario: "Nationally Determined Contributions").

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used. That means that the focus lies on that part of companies' carbon footprint where data reliability is greatest. Another advantage is that direct emissions can be aggregated without double counting.[27]

Importance of sectors in terms of greenhouse gas emissions and market capitalisation

Weighting of companies by stock market capitalisation and greenhouse gas emissions often diverge

In many cases, the size of a firm's carbon footprint as measured by direct greenhouse gas emissions does not reflect its importance in financial markets (see the chart on p. 75). Looking ahead to the results, that means that losses that depend on the level of emissions have a massive impact on part of equities, but this part is fairly small in relation to total stock market capitalisation. This applies to companies in the coal, gas and oil industry, for instance, as well as to other energy industry companies and companies in the cement and steel industries.

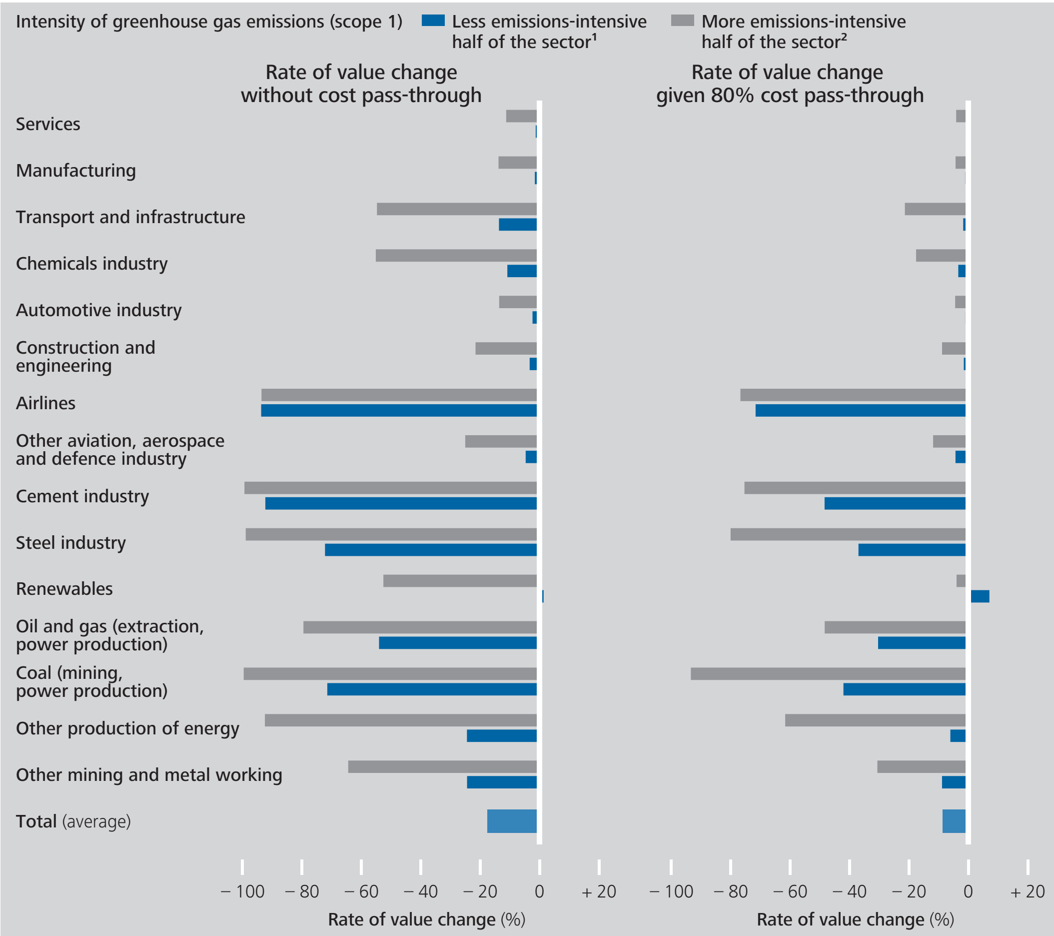
Companies assigned to energy sectors based on percentage of revenues from energy sources

A subset of 502 stock corporations can be assigned to the above-listed energy sectors based on available information on the revenue share generated from the respective energy source (source: ISS-ESG). If, say, the extraction of coal or the production of electricity from coal accounted for more than 50% of revenues in 2019, then that company is assigned to the coal sector. The same is done for companies whose business models are tied to other fossil or non-fossil energy sources, where companies active in the oil and gas business and companies focusing on renewables are aggregated in each case.

The companies assigned to the sectors listed above emit direct emissions totalling 7.5 gigatonnes of CO_2 equivalents, accounting for around 80% of all the company emissions

27 Double counting would occur, for instance, if an electricity supplier's direct emissions and an electricity user's indirect emissions were added together.

Emissions-related price impact indicator in a sectoral breakdown*



Sources: ISS-ESG, Thomson Reuters, Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. * Unweighted sectoral averages of value change rates are calculated for a total of 5,285 stock corporations. Sector allocations are made based on information contained in the NACE and GICS classification systems. In some cases, companies were, as an exception to this rule, allocated to the sectors Coal, Oil and gas as well as Renewables if extraction of or energy generation using the respective primary energy source accounts for more than 50% of the enterprise's total revenues according to ISS-ESG. **1** Includes all companies allocated to the respective sector whose scope 1 emissions intensity is smaller or equal to the sector median. **2** Includes all companies allocated to the respective sector whose scope 1 emissions intensity is greater than the sector median.

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under review. By comparison, their weight in the total stock market capitalisation under observation is small, at €4.7 trillion, or just under 10%. Low-emissions companies in manufacturing and the services sector account for the largest share of market capitalisation, at around €16 trillion each.

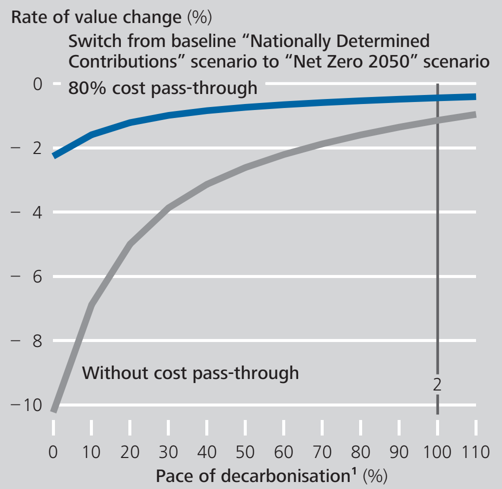
Results

Distribution of valuation effects

As described in the box on pp. 70 ff., shifts in the value of the companies under analysis are expressed as the scenario-based present value changes of the shares in relation to the actual share price. In total, 5,285 stock corporations are valued relative to their share price at the end of 2020 and the dividend expectations at this point in time. These valuation effects can be presented in the form of a loss distribution. The chart on p. 76 shows – broken down by degree of cost pass-through – for certain intervals in the rates of value change the sum of the respective market capitalisation attributable to them (before the valuation change, as of end-2020).

The case of a Paris-aligned decarbonisation with correspondingly high CO_2 prices shows that, given full pass-through of the incremental

Emissions-related price impact indicator for a fictitious company*



Sources: Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. * Assumptions: Fictitious European stock corporation with an assumed return on equity of 8.5% and dividends (2021) in relation to direct greenhouse gas emissions (2019) of €1.70 per kg of emitted CO_2 equivalents. **1** Company decarbonisation relative to the emissions pathway in the "Net Zero 2050" scenario: 100% represents a proportional (Paris-aligned) decarbonisation, 0% represents the locus where companies' emissions remain unchanged at their 2019 level. **2** Cut-off at 100%: the present analysis looks at reductions in emissions in line with the "Net Zero 2050" scenario.

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costs from direct greenhouse gas emissions, shares to the tune of just over €35 trillion (or 78% of the total market capitalisation under observation) are left unscathed by emissions-related share price losses of more than 4%. At the same time, however, more than one-tenth of the total market capitalisation (€4.7 trillion) suffers losses of more than one-half of company values as a result of higher emissions costs and deviating value added paths.

Assuming instead a cost pass-through of 80%, share price losses are limited to less than 4% for 87% of market capitalisation (€38.6 trillion). At the same time, shares to the tune of €1.9 trillion suffer losses of more than 50%.

The price impact indicator calculated at the company level can be aggregated for individual sectors. In the chart on p. 77, each analysed sector is split into a more emissions-intensive and a less emissions-intensive half of companies. For each of these halves, unweighted loss ratios (in negative territory) are determined. Positive average value changes are not fundamentally out of range, though; they do occur in some cases for renewables.

It is evident that emissions intensity is one of the factors that determine the size of the valuation effect. The "greener half" is associated with smaller value losses for the stocks under observation. However, in several sectors, this relationship is overlain by the influence of deviating value added paths.

A theoretical example

The price impact indicator presented here is sensitive to changes in individual assumptions. The results outlined so far are limited to the case where all companies reduce their emissions in line with the "Net Zero 2050" scenario. This Paris-aligned response of emissions is depicted using a cut-off point at 100% in the adjacent chart.[28] This chart exemplifies, for a notional company, the sensitivity of the price impact indicator to the percentage of emissions costs that can be passed through and as a function of the pace of decarbonisation relative to the scenario pathway.

While the results explained above refer to a case in which the companies adapt their energy mix in line with the substitution elasticities used in the REMIND-MAgPIE model and decarbonise correspondingly (in a Paris-aligned manner), individual companies might reduce their emissions to different degrees. As explained (see p. 72), the individual pace of decarbonisation is likely to depend on both the expected CO_2 price pathway and on the individual cost of avoiding emissions. If, meanwhile, the focus lies exclusively on emissions costs arising under the price projections in the Paris-aligned scenario, it is clear that value losses are higher the slower the pace of decarbonisation.

28 Paris-aligned decarbonisation is taken to mean that the company's emissions develop in line with the emissions in the "Net Zero 2050" scenario.

Scenario-based value indicator for transition risk: quantifying stranding

Definition of stranding in this approach

The valuation approach presented here can be used to derive not only an emissions-related price effect, but also a measure for company "stranding". In what follows, this is defined as the case where, after taking into account deviating value added paths, the incremental costs of emissions will exceed the expected or projected gross dividends as of a certain future point in time.

Distribution of stranding over time

This definition can be applied to the companies under review in the Paris-aligned scenario. The adjacent chart illustrates that the vast majority of stranding, both as measured by the number of companies and by their stock market capitalisation (end-2020), occurs in the five years to 2025. This is also true if 80% of the incremental costs of greenhouse gas emissions can be passed through, although this assumption sees a somewhat larger percentage of companies stranding in the years after 2025 than is the case if the company has to bear all emissions-related costs.

Stranding in a sectoral perspective

Stranding stock market capitalisation can also be shown at the sector level. The table on p. 80 indicates that even given decarbonisation in line with the Paris-aligned "Net Zero 2050" scenario, the incremental costs from the remaining emissions and deviating output pathways can leave several sectors hard hit. This is particularly true if no cost pass-through is possible. Unsurprisingly, particularly badly affected sectors include the carbon-intensive cement and steel sectors as well as companies whose business centres on fossil energy sources – driven in part by projected sectoral output trajectories. According to the calculations, stranding stock market capitalisation amounts to €4.4 trillion without cost pass-through and €1.7 trillion with 80% cost pass-through. Leaving aside stranding and taking into account all 5,285 stock corporations under review, the aggregate capitalisation-weighted loss ratio amounts to 12.4% (without pass-through) and 6.0% (with 80% pass-through).

Stranding companies and losses in market capitalisation under a Paris-aligned decarbonisation*

Sources: ISS-ESG, Thomson Reuters, Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. * Scenario: "Net Zero 2050". **1** Pass-through of incremental emissions-related costs to the clients of the companies under review. **2** The stranding of a company is defined here as the point in time at which the expected dividends no longer cover the incremental emissions-related costs which cannot be passed on to the company's clients.
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Constraints

Measurement uncertainties …

One constraint to consider is that the price impact indicator presented here does exhibit some measurement imprecision. The starting point for the quantification carried out in this article is that, first, market participants currently expect the "Nationally Determined Contributions" scenario to be implemented.

Stranding stock market capitalisation by sector

Scenario: "Net Zero 2050", baseline scenario: "Nationally Determined Contributions"

Sector	Losses in stock market capitalisation caused by stranding[1]			
	Absolute, in € billion		As a percentage of respective (sector-specific) market capitalisation	
	Without cost pass-through[2]	80% cost pass-through[2]	Without cost pass-through[2]	80% cost pass-through[2]
Services	− 300	− 68	1.9	0.4
Manufacturing	− 127	− 19	0.8	0.1
Transport and infrastructure	− 211	− 67	26.7	8.4
Chemicals industry	− 392	− 54	23.3	3.2
Automotive industry	− 9	− 2	0.6	0.1
Construction and engineering	− 64	− 16	3.4	0.8
Airlines	− 111	− 98	98.4	86.9
Other aviation, aerospace and defence industry	− 137	− 66	13.2	6.3
Cement industry	− 245	− 157	97.7	62.7
Steel industry	− 236	− 145	71.4	44.3
Renewables	− 30	0	17.1	0.0
Oil and gas (extraction, power production)	− 1,256	− 246	61.6	12.1
Coal (mining, power production)	− 190	− 146	54.3	41.6
Other production of energy	− 901	− 491	62.7	34.1
Other mining and metal working	− 191	− 79	23.0	9.5
Total	− 4,401	− 1,653	9.9	3.7

Sources: ISS-EEG, Thomson Reuters, Potsdam Institute for Climate Impact Research (REMIND-MAgPIE) and Bundesbank calculations. **1** Stranding is defined here as a case in which, at a future point in time, the incremental emissions-related costs exceed the projected gross dividends. **2** Cost pass-through is understood as the incremental emissions-related costs being passed on to the companies' clients.

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… in the formation of expectations

This assumption is supported by indications in the empirical findings that greenhouse gas-related risks are already reflected in financial markets to a certain extent.[29] It cannot be ruled out, however, that markets assume these commitments will not be honoured in some regions of the world. If, for example, one were to choose a less optimistic "Current Policies" scenario as the baseline scenario (see the charts on pp. 66 and 68), the value adjustments resulting from a flipover to a "Net Zero 2050" scenario would be more significant still. Second, another factor to consider alongside this imprecision is that the price impact indicator assumes a shift in expectations towards a Paris-aligned scenario. As is usual in scenario analyses, it is silent on whether, or with what probability, this will happen at the global level. When interpreting the price impact indicator, it should furthermore be considered that the future (global) climate policy stance is subject to a high degree of uncertainty. This uncertainty also has a knock-on effect on market participants' expectations formation about the future CO_2 price pathway.

Model uncertainty surrounding technologies, substitution elasticities and emissions avoidance costs, …

There is also uncertainty about how flexibly economic agents will respond to a rise in CO_2 prices and whether the substitutability among energy sources assumed in the REMIND-MAgPIE model and the assumption of technological learning adequately captures their behaviour. In particular, no data are available on individual companies' current and future emissions avoidance costs, which, along with the CO_2 price, will determine the decision to decarbonise. This means the question of decarbonising certain production processes also remains subject to uncertainty.

Basing the regional allocation of companies' greenhouse gas emissions on the country in which the parent company is headquartered is

29 See, for example, Bolton and Kacperczyk (2021) or Görgen et al. (2019).

… the country in which the company is headquartered …

another source of inaccuracy. This means, for example, that manufacturing sites of companies which produce worldwide but are headquartered in Europe are assigned in their entirety to Europe and subject to the projected European CO_2 prices.

… and the scope for pass-through

The resulting valuation effects are, moreover, very much determined by the extent to which emissions costs can be passed on. The scope for companies to pass through costs depends on their competitive position in sales markets, say. Where a company has sufficient market power, it can, in extreme cases, avoid the burden of emissions costs altogether. If, however, producers of intermediate goods manage to pass the attendant emissions costs through to a (downstream) company, the latter might, depending on its competitive position, face costs beyond those associated with its own direct emissions.

Valuation effects possibly overstated due to CO_2 hedging

Another source of imprecision in the indicator of the financial implications of higher CO_2 pricing comes from the extent to which companies have frontloaded the costs of foreseeable emissions as protection against mounting emission costs over the coming years.[30] If a company has already purchased enough emissions allowances for the coming years, it will not incur any additional emissions costs no matter how tightly emissions rights are capped in this period and how strongly the CO_2 price will rise. Hence, the company will only have an incentive to reduce its greenhouse gas emissions once the hedging period has elapsed. As a result, the valuation effects determined here could overstate the company's actual emissions-related loss in value, provided it already has sufficient emissions allowances. It is therefore in the absence of such hedging strategies that the proposed emissions-related price impact indicator can be understood as a point of reference in terms of a shift towards Paris-aligned CO_2 pricing.

Summary

Quantification of valuation effects due to a shift in climate policy expectations

The present article proposes an approach for quantifying valuation effects resulting from a shift in climate policy expectations. Its focus is on the difference between a scenario based on the implementation of Nationally Determined Contributions (consistent with global warming of 2.4°C) and the scenario of an orderly transition to a Paris-aligned low-carbon economy (consistent with global warming of 1.5°C). This analysis looks at the incremental costs arising from greenhouse gas emissions as well as from scenario-dependent deviations in the output pathways; no other shifts in costs are taken into account. Valuation effects resulting from ongoing physical climate change are disregarded as well.

Valuation method applied for 5,285 stock corporations worldwide

The valuation method selected here is applied for 5,285 stock corporations from all over the world at the firm level. Together, they account for more than half of the global stock market capitalisation and are responsible for 17% to 20% of global greenhouse gas emissions. The potential price adjustment for individual companies as a result of changed expectations is modelled using a multi-stage dividend discount model. This traditional valuation model is calibrated on firm-specific greenhouse gas emissions and scenario data from a multi-regional integrated assessment model (REMIND-MAgPIE), which, amongst other things, models the energy systems in individual regions of the world in detail and allows for temporary regional differences in climate policy.

This scenario-based valuation approach for transition risks is driven by various factors. First of all, the company valuation in the baseline

30 In an emissions trading scheme, frontloading can be perceived as an issuer strategy to purchase emissions allowances when their prices are low in such a quantity that, together with the emissions allowances allocated for free, they are sufficient to cover the expected greenhouse gas emissions in the hedging period. The price of emission allowances in the European Emissions Trading System (ETS) in mid-2017 was still €5 per tonne of CO_2 emitted, compared with around €80 at the end of 2021.

scenario is pivotal. Here, in addition to the equity price and the individual dividend expectations, the respective Nationally Determined Contributions are taken into account. This information is used to compute the firm-specific implied cost of capital, which is one of the decisive factors in the price impact analysis. Moreover, the most significant factor for the majority of companies is the CO_2 price trajectory in their particular region: together with the projected greenhouse gas emissions, this is what determines how the company's emissions costs in a Paris-aligned scenario evolve relative to its emissions costs in the previously defined baseline scenario. These incremental costs lower the projected firm-specific and scenario-specific dividends. In addition, scenario-specific output pathways are incorporated for selected sectors.

Scope for cost pass-through determines bandwidth of potential losses

The cases analysed – first, where 80% of the incremental emissions-related costs are passed through and second, where the company bears all emissions-related costs – serve to estimate the bandwidth of potential losses. It is found that, in the case of a Paris-aligned decarbonisation by the companies, the vast majority of them, along with their stock market capitalisation, are only expected to suffer small losses in value even if CO_2 prices rise strongly. By contrast, considerable losses in value will be sustained by a segment of stock corporations that are responsible for very high greenhouse gas emissions while expected dividends are relatively small by comparison. In addition, companies whose business activities are centred around fossil fuels will be strongly affected; they may face the risk of stranding even if they reduce emissions in compliance with the Paris Agreement.

Changes in value associated with transition risks

The measure presented in this article provides a risk indication for the firm's ability to bear emissions costs under a given scenario. This type of indicator can help to better quantify price adjustments associated with transition risks and the risk of climate-related stranding of certain assets.

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