An investor's guide to net zero by 2050

Understanding the investment risks and opportunities created in what may be the largest redeployment of capital in history

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Report at a glance

Achieving the goal of the Paris Climate Accord, and 'greening' the world's capital stock, is arguably humanity's greatest challenge. The transition has the potential to be the largest redeployment of capital in history and it could be just as, if not more, transformational than the Marshall Plan** or China's rise in the 1990s/2000s. Get it right and the payoff to society, and far-sighted investors, can be enormous.

In this report BNY Mellon Investment Management and Fathom Consulting show that a capital investment of around $100 trillion in lower-carbon infrastructure will be required for the world to comply with the Paris climate goal of limiting warming below 2.0 °C and achieve net zero** emissions by 2050. We also show that this investment and, by extension, these targets are within reach. Analysis of investment needs by sector and by country shows that the net zero transition should offer significant opportunities to informed investors. However, despite this positive outlook, one primary obstacle to achieving net zero by 2050 is that around $20* trillion of polluting assets will need to be scrapped or retrofitted: these are referred to in the report as 'stranded assets'.

* All dollar currencies in the report are US$.

** Glossary can be found on page 39.

Executive summary

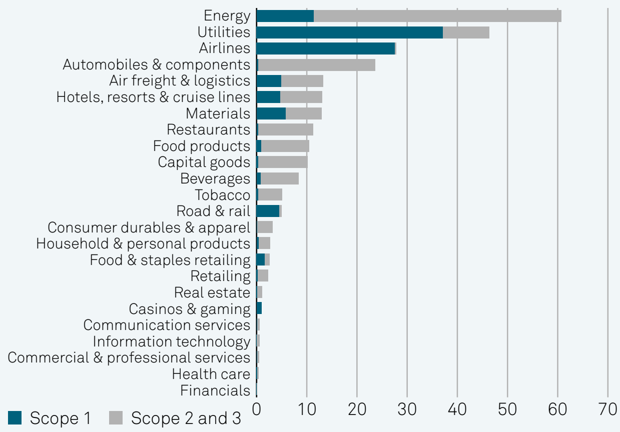
The primary finding of this report is that investment of around $100 trillion spent on 'greening' the world's capital stock is required for the world to comply with the Paris climate goal of limiting warming well below 2.0 °C and achieve net zero emissions by 2050. The unprecedented scale of investment required should bring significant opportunities for businesses and investors. However, despite the recent increase in ESG (environmental, social and governance) and sustainable investing**, spending on 'greener' capital stock must be scaled up significantly if the Paris goal is to be met.

Most of the investment required will either add to the world's existing capital stock to support future economic growth or replace existing assets as they naturally depreciate. Thus, most of the investment in low-carbon alternatives will simply take the place of investment that would otherwise have been spent on growing the economy or renewing polluting assets.

But this $100 trillion investment includes around $20 trillion worth of assets that may need to be scrapped or retrofitted before the end of their useful life. These assets are 'stranded'. The longer that the transition is delayed the larger this amount will be. The energy, utilities and airline sectors face some of the most significant costs in scrapping polluting assets, part of the higher 'transition risks' confronting these sectors. But investors should be aware that simply selling stocks in high-emitting sectors such as these may not be an effective strategy; energy and utility companies remain essential to the global economy and need capital to survive and re-align with net zero.

CARBON TAX EFFECT

% reduction in EBITDA due to $50/ton carbon tax*



* Assuming tax is fully absorbed by company on its scope 1 emissions and 50% absorbed on its scope 2 and 3 emissions. Uses financial and emissions data between 2018 and 2020.

Note: carbon tax effect is calculated using publicly-available financial data and greenhouse gas emissions data accessed via Refinitiv Eikon.

Source: Refinitiv Eikon / BNYM / Fathom Consulting. As of September 2022.

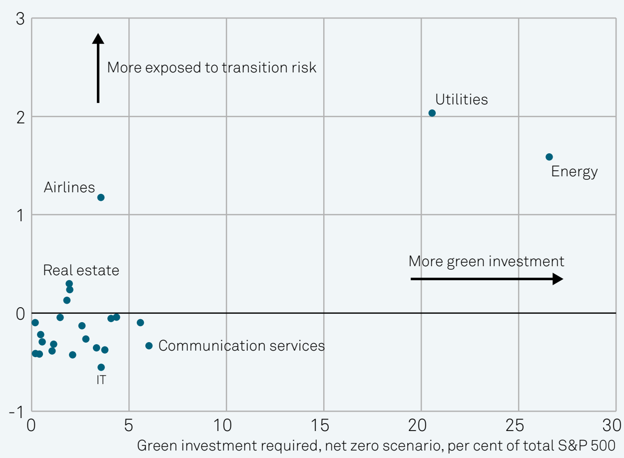
We estimate that half of all corporate investment required for net zero by 2050 must be spent by firms in the energy and utilities sectors, even though these sectors face significant transition risks and are responsible for a large share of global CO_2 emissions. But rather than shun these sectors completely, to help facilitate the transition ESG or impact investors might consider investing in those companies with credible decarbonisation and green investment** plans.

> **"Most of the investment in low-carbon alternatives will simply take the place of investment that would otherwise have been spent on growing the economy or renewing polluting assets."**

In terms of geography, more than half of the $100 trillion investment is required in emerging markets (EMs) where accessing capital is more difficult and expensive than in advanced economies (AEs). However, since EMs generate a larger share of total global emissions, the investment needed to reduce them tends to be correspondingly lower. By implication, investors should be able to achieve more decarbonisation per dollar spent in an EM than in an AE.

GREEN INVESTMENT REQUIRED AND TRANSITION RISK, S&P 500

Transition risk score



Source: Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

** Glossary can be found on page 39.

Beyond corporate sector investment, households and governments may also need to invest in green assets**, such as electric cars and green heating systems. This need will create opportunities for private sector companies that respond to this demand, as already seen in electric vehicle (EV) demand.

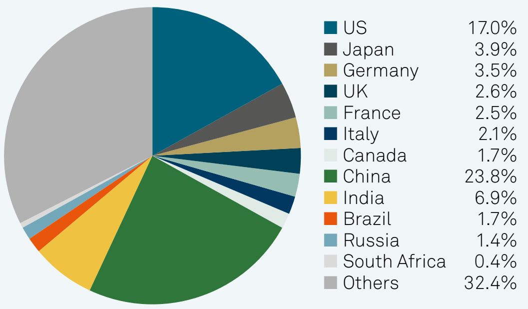
Similarly, investment in new technologies and green capital** can reduce costs for the companies making this investment. The real market and trading opportunities could however arise from the demand this investment may create for corporates in other sectors. For example, investment by companies in the utilities and energy sectors may significantly boost demand for capital goods, intermediate goods and the raw materials and minerals needed in their production.

While most of the heavy lifting will be done by the private sector, policymakers have a vital role to play in overseeing the transition: setting clever and reliable policy can encourage private sector investment. They can also put in place financial support for those left behind (such as coal miners who lose their jobs) and, by so doing, generate political goodwill for transition-related initiatives.

While it is eminently feasible, solving climate change and making the requisite investments for that to happen are arguably humanity's greatest challenges, given the scale of the changes and effort required from all cohorts of society. It will require an unprecedented level of coordination and cooperation. Get it right, and the payoff to society will be enormous — not least by avoiding the potentially catastrophic consequences and costs of climate change. The potential returns to far-sighted investors and corporates can be significant too.

BREAKDOWN OF GLOBAL GREEN INVESTMENT REQUIRED*

% of total

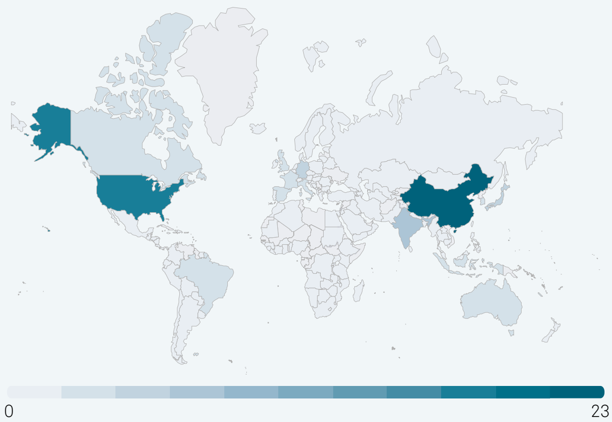


* Net zero 2050 scenario G7, BRICS and others.

Source: BNYM / Fathom Consulting. Date as of September 2022.

GLOBAL GREEN INVESTMENT REQUIRED, BY LOCATION*

% of global total

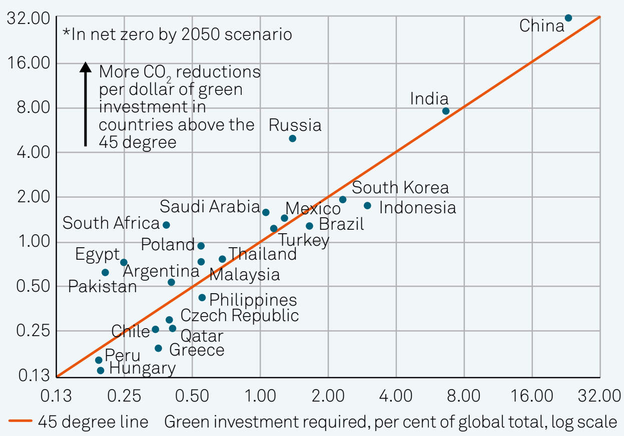


* Net zero 2050 scenario.

Source: BNYM / Fathom Consulting. Date as of September 2022.

EMS GREEN INVESTMENT REQUIRED* VS CO_2 EMISSIONS

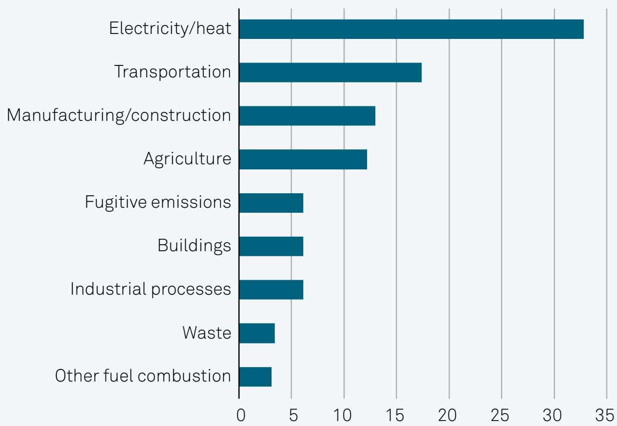
CO_2 emissions in 2019, % of global total, log scale



Source: Penn World Table / Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

GLOBAL GREENHOUSE GAS EMISSION BREAKDOWN BY ACTIVITY

% of total, 2019



Source: CAIT / IPCC / BNYM / Fathom Consulting. Accessed as of September 2022.

** Glossary can be found on page 39.

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** Glossary can be found on page 39.

Section 1: the big picture

KEY TAKEAWAYS

- Capital investment of around $100 trillion is required to achieve net zero by 2050.
- This apparently huge sum is achievable: it equates to around a fifth of the total anticipated global investment over the next 30 years, or 3% of cumulative GDP.
- This investment is not the cost of preventing climate change – most of it will either grow the world's capital stock, supporting future economic growth, or replace existing 'dirty' capital with clean infrastructure when that capital reaches the end of its useful economic life.
- There will be costs, however: most notably around $20 trillion worth of 'stranded' capital may need to be abandoned early or retrofitted.
- For all the recent growth in interest in ESG investing and the trillions of dollars that have been committed to align with the Paris goal, the world is still not on track to achieve net zero by 2050: 'green' investment needs to be scaled up significantly from current levels.

NET ZERO INVESTMENT IN CONTEXT

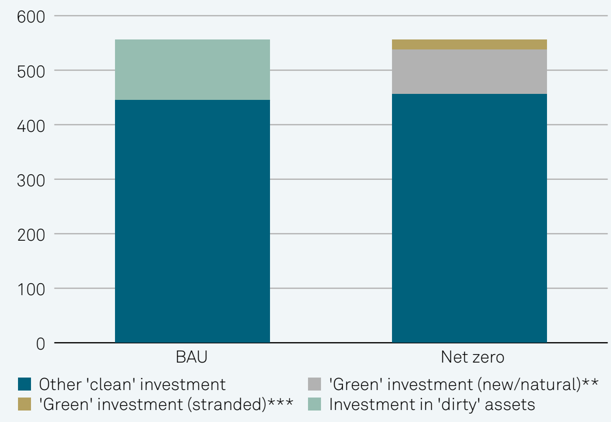
Globally, an investment of around $100 trillion is essential to hit net zero by 2050. At first glance, this is a huge number – roughly equivalent to one year's global GDP – which might seem unachievable. But between now and 2050, the $100 trillion 'green' investment accounts for less than a fifth of total projected investment in capital assets, or just 3% of cumulative GDP. Moreover, the amount of gross investment between now and 2050 is little changed when business-as-usual (BAU) is compared to a net-zero scenario, as reflected in the chart below. The main difference is the type of investment that gets done. When framed in this way, net zero appears far more attainable.

It is important to be clear that this $100 trillion is not the cost of achieving net zero; it is largely investment that would otherwise have been spent on creating or renewing polluting capital.[1] More than four fifths of this should either replace existing 'dirty' capital stock with 'clean' capital once it has depreciated naturally or create the new capital stock needed to support growth in the world economy over the next 30 years. A little less than a fifth of this investment should replace existing "dirty" capital which will need to be scrapped or retrofitted before the end of its useable life. (Dirty or polluting capital refers to assets that are either powered by fossil fuels or that create greenhouse gas emissions themselves.)[2]

Still, the investment needs are huge, but we believe they are within reach and would be transformational. The price of clean technologies (and capital), such as renewable energy and electric vehicles (EVs), has fallen significantly in recent years, in some cases below the cost of the equivalent high-carbon technology (and capital).
Some, perhaps a lot, of this investment would be inevitable regardless of today's net zero targets. The case for green investment may become more compelling as the cost of green technologies, both new and established, continues to fall in the coming years.

GLOBAL INVESTMENT REQUIREMENTS*

USD, trillions



* Cumulative investment between now and 2050 under business-as-usual (BAU) and net zero scenarios.

** Green investment replacing naturally depreciated existing "dirty" capital and supporting new economic growth.

*** Green investment replacing/retrofitting stranded assets.

Source: BNYM / Fathom Consulting. Date as of September 2022.

[1] A 'cost' is something that involves the use of economic resources that therefore cannot be used elsewhere. This investment is by contrast a transfer of resources from the production of polluting capital to clean. The true transition cost is the impact on GDP or consumption per head of making that change. We do not focus on that question in this paper, nor do we try to estimate physical costs. Instead, we estimate the investment required to change the composition of the world's capital stock to be consistent with hitting the net zero target by 2050. Appendix VII describes some of the literature and approaches to assessing the cost of net zero.

[2] In reality, some "dirty" capital stock is likely to exist in 2050 even if the world reaches net zero by then; the emissions generated by these assets are likely to be captured and stored underground (also known as carbon capture and storage – or CCS). The amount of spending on this technology is highly uncertain and will depend on the price and scalability of this technology in future and on the cost of other low-emission forms of economic activities. For simplicity, in this paper we say that the amount of "dirty" capital in the 2050 net-zero scenario is zero, even though there will be some that will be made 'clean' using CCS. The $100 trillion investment figure is unchanged by this detail.

There is more good news: our analysis shows that much of the net-zero-related investment can take place gradually, while still meeting climate goals, and that most "dirty" capital** can be replaced by clean capital** once it has fully depreciated and reaches the end of its useful life. In these cases, the transition may not hurt corporations economically, as investment would simply be redirected from renewing polluting assets to investing in green assets (or retrofitting).

But reaching net zero by mid-century will have costs too. Significantly, our analysis shows that around $20 trillion worth of polluting assets may need to be scrapped or retrofitted before they have fully depreciated. This is one of the key costs, although not the overall 'cost', of the net zero transition.[3] Some corporates must either absorb significant losses or will need to be compensated for these necessary losses. This is the greatest challenge in meeting the Paris climate goal. Our analysis also shows that the amount of assets that are stranded rises the longer the transition gets delayed.

For the sake of clarity, this capital investment is only one factor, albeit a significant one, in the overall net zero transition. It is not the 'cost' of achieving net zero. (For more on the cost of achieving net zero by 2050 see Appendix VII). Nor should it be confused with the value of assets managed by investment firms that have committed to achieving the objective of the Paris climate agreement (a figure also in the hundreds of trillions of dollars – $130 trillion in the case of the Glasgow Financial Alliance for Net Zero, GFANZ).

OUR METHODOLOGY

We simulate two economic scenarios: business as usual (BAU) and net zero 2050. We compare the capital stock, of both clean capital and "dirty" capital, in 2050 in each scenario to infer the amount of green investment that is required. This approach also tells us the amount of "dirty" capital that would not have fully depreciated in the net-zero scenario by 2050 telling us the value of stranded assets**.

There are several modelling uncertainties in each scenario, including GDP growth estimates, capital depreciation rates, the capital stock to GDP ratio and the ratio of clean capital to total capital. There are also different ways to interpret the model output, giving different estimates of the total sum of green investment required. The central estimate of Fathom's preferred method points to green investment of $125 trillion, while that of BNYM points to an estimate of $93 trillion. The reality is that there is no 'right' or 'wrong' estimate, and with so many uncertainties it would be foolish to place too much store in any particular number. We have confidence that these figures point us to the right ballpark and hence we settle on a joint $100 trillion estimate.

We explain our modelling technique, and the two interpretations, in more detail in Appendix I of this paper.

We also explain the modelling uncertainties in more detail and have run a sensitivity analysis (see Appendix II) to show the green investment needs using different assumptions.

Table 1: Key data and assumptions used in central scenario	
Capital to GDP ratio (K/Y)	4.1
Depreciation rate	4.5%
Current clean to "dirty" capital ratio	80% – 20%
Real GDP growth, net zero 2050	1.9%
Real GDP growth, BAU	2.0%
Current global GDP, US dollar trillions	87

Source: BNYM / Fathom Consulting. Date as of September 2022.

UNCERTAINTIES

Forecasting the size of investment required to achieve net zero by 2050 and the value of assets that become stranded depends on several unknown factors. In addition to standard modelling uncertainty, there is much uncertainty related to future technological progress and whether the new technologies that emerge will complement or replace existing infrastructure. The level of investment required to adopt such technologies will vary significantly according to the how this unfolds.

For example, widespread adoption of hydrogen as a fuel and means of electricity storage would mean that much of the existing gas power plant and pipeline infrastructure could simply be repurposed. By contrast, if industrial-scale lithium-ion batteries become the primary source of electricity storage, much of the gas infrastructure would be rendered useless and scrapped, resulting in a different level of investment to reach net zero. The ability to use existing aircraft will depend on which low-carbon aviation technology becomes established.

This might explain why there is such a wide range of estimates from the various organisations that have tried to estimate the green investment** needs to hit net zero by mid-century. Definitional issues complicate things too. For example, there is no consensus on precisely what should be considered 'green' investment. The European Union (EU) recently classified natural gas and nuclear energy as 'sustainable', sparking an intense debate over whether these could truly be considered either 'green' or 'sustainable'. Such unknowns cause difficulties in predicting the level of investment required. For clarity, this study considers 'green' investments as investments that specifically contribute to reducing greenhouse gas emissions relative to a business-as-usual scenario. The chart on page 8 shows how the value of economy-wide investment can vary significantly if only a single model parameter is changed. Table 2 shows the range of model-implied investment figures given different combinations of model inputs (see Appendix II for more detail and the results of the sensitivity analysis).

[3] Overall 'transition costs' refers to the impact on GDP or consumption per head of making the transition to a green economy. These are hard to project since the cost of abatement and green technologies is highly uncertain. Also, the cost of preventing climate change should also be compared to the counterfactual – i.e. the cost of climate change itself in a business-as-usual scenario. For more information and a summary of the literature on estimates of these costs see Appendix VII. Determining the value of the transition cost or the cost of climate change itself is beyond the scope of this report and will be addressed in subsequent publications.

** Glossary can be found on page 39.

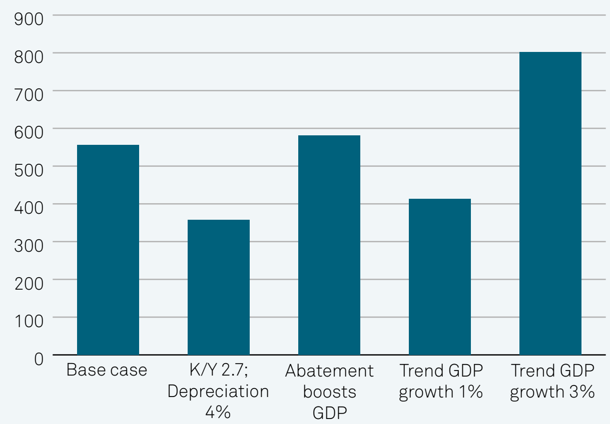
The variation in projections demonstrates the difficulties in assessing the required amount of financing to achieve net zero: they haven't all been classed in the same way and there is no consensus on what constitutes 'green' or 'transition-specific' investment. All estimates, however, agree on one thing: a huge and unprecedented amount of investment is needed to achieve net zero by the middle of the century.

CURRENT STATE OF PLAY

While there is uncertainty about the precise amount of green investment needed over the next 30 years, we can be certain that the current amount of green investment falls well short of what is needed.

In its *Net Zero by 2050* report, the International Energy Agency (IEA) shows that annual clean energy investment needs to be scaled up four-fold, from around $1 trillion. It has separately noted that investment in fossil fuels currently exceeds the limits for the world to be consistent with this target.[4] A report by BloombergNEF indicated that a combined total of $920 billion was spent on clean energy and climate technology in 2021.[5] The UK CCC's balanced pathway to net zero investment indicates that UK green investment needs to increase five-fold from current levels.[6]

GROSS INVESTMENT NET ZERO SCENARIO, SENSITIVITY
USD, trillions



Source: BNYM / Fathom Consulting. Date as of September 2022.

Table 2: Range of model estimates	
Cumulative values between now and 2050, USD trillions, 2020 prices	
Economy-wide investment	$396.6 – $597.0
Green investment	$61.4 – $166.1
Stranded assets	$4.2 – $22.4

Source: BNYM / Fathom Consulting. Accessed as of September 2022.

Model output ranges following adjustments to capital stock to GDP ratio, depreciation rates, GDP growth rates and the clean capital share of total capital. For more details, including the model variables changed see Appendix II.

Table 3: Estimates of investment needed to meet net zero by mid century

Organisation	Projection (USD, trillions)
International Energy Agency[i]	Well in excess of 110
Mark Carney[ii]	100
OECD[iii]	96.6
IMF[iv]	12 – 174
McKinsey[v]	275
UK Climate Change Committee (UK CCC)[vi]	90
Fathom / BNYM	100

Source: BNYM / Fathom Consulting. Date as of September 2022.

[i] See IEA (2021). This report estimates that annual clean energy investment worldwide will need to be scaled up more than threefold to around $4 trillion by 2030 and maintained at that level until 2050 for the world to achieve the net zero goal by the middle of the century. That would equate to energy investment alone of more around $110 trillion; while that figure that includes energy, infrastructure and end-use, it does not include other types of clean investment such as retrofitting of buildings and transport equipment, including cars, ships and planes. In other words, total green investment well in excess of $100 trillion will be needed.

[ii] See Carney (2021). Do not confuse with the $130 trillion of assets under management of the members of the Glasgow Financial Alliance for Net Zero (GFANZ, a group of asset managers committed to achieving the Paris climate goal, led by Mr Carney). The latter is a stock of financial assets under management that has so far committed to align with the Paris climate goal, while the former is a flow that needs to happen over the next 30 years.

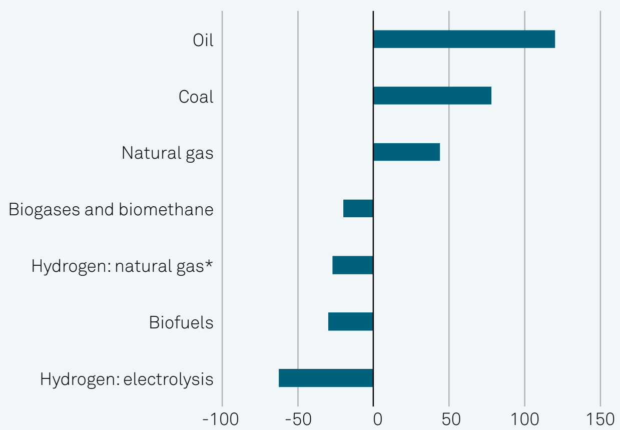
[iii] See page 2 of IMF (2021). The report states that achieving net zero carbon emissions will require additional global investments... amounting to $12 to $20 trillion. It also states that these estimates may be conservative and cites research which says: investment in the energy sector alone may rise from around $1.7 trillion today to between $31. trillion and $5.8 trillion, on average, over the next three decades.

[iv] See page 15 of OECD (2017).

[v] See McKinsey Global Institute (2022).

[vi] See Committee on Climate Change (2020). We use UK CCC estimates of UK net zero investment needs to estimate a global investment figure (scaling the UK's figure up proportionally to its share of global GDP) – the global figure is not an actual forecast from the UK CCC. This is not a forecast and we have done this for illustrative purposes only. Other countries may need to do more or less green investment than the UK relative to the size of their economies.

OVER/UNDER INVESTMENT BY FUEL SUPPLY
2021 vs annual average required in net zero scenario, USD, billions



* With carbon capture, utilisation and storage (CCUS).

Source: BNYM / IEA / Fathom Consulting. Accessed as of September 2022.

[4] In terms of specifics, annual electricity generation should be scaled up from just over $500 billion per year to $1.6 trillion by 2030, modernisation of electricity networks rises from $260 billion to $800 billion per year, annual nuclear investment more than doubles from current levels, investment in hydrogen, hydrogen-based fuels and bioenergy increase from very low levels currently to $140 billion per year by 2050 and spending on transport increase from $150 billion per year to more than $1.1 trillion by 2050, stemming from the upfront cost of electric cars compared with conventional vehicles.

[5] Energy Transition Investment Trends 2022 | BloombergNEF (bnef.com).

[6] Since the UK economy has already decarbonised more than many others, it is possible that other countries will need to scale up their transition-related investment by even more.

The finance being made available for the transition seems to be falling short too. The Climate Bonds Initiative, a not-for-profit organisation seeking to mobilise climate finance, estimates that less than $500 billion of green bonds** were issued in 2021, with only a fraction of those 'certified'. Moreover, the chart below shows that the number of climate-designated funds accounted for around 0.5% of all funds identified in 2020. As a share of assets under management (AUM), the ratio was just 0.2%.

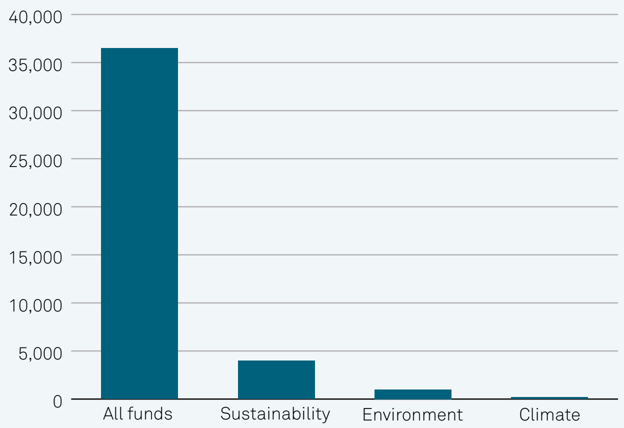
Admittedly, climate labelling may underestimate the true level of Paris-aligned investment, since transition-facilitating investment will be taking place in companies owned by pension funds that do not have a specific climate and sustainability label. Also, the number of sustainable, environment- and climate-related funds may have increased since COP26, when many investors made net zero pledges. But still, investors can do more to ensure that the funds they manage are aligned with the Paris climate goal, and that the companies in which they invest are making the investments necessary to turn these pledges into reality.

FINANCING THE TRANSITION

Scaling up investment from current levels and mobilising the resources to achieve these targets will be a huge challenge – especially in emerging markets (EMs).

The UK and other advanced economies (AEs) are betting that the bulk of the funding burden will be borne by the private sector. This should be possible in AEs with favourable policy environments, but may be out of reach for EMs, where the cost of private capital is typically higher and policy environments may be less favourable. According to the IEA, they will require around 40% of what they define as 'global clean investment' over the next three decades but hold just 10% of global wealth. Our own calculations, detailed later in this paper, suggest that more than half of all green, net-zero-specific investment will be needed in EMs.

INVESTMENT FUNDS BY LABEL
Number of funds



Source: BNYM / Fathom Consulting. Accessed as of September 2022.

The IEA also estimates that overall clean energy financing in EMs will have a 70/30 private/public split, up from around 60/40 today, and that reliance on debt financing and international capital will increase too. Creating the right policy environment to attract international capital will be key. ESG and sustainable finance considerations could help too as international financiers have an opportunity to boost their green credentials by providing this financing. We also show later in this paper that each dollar of green investment in an EM may achieve more decarbonisation than the equivalent amount spent in an AE, a point that impact investors should consider.

The slew of recent net zero commitments by the asset management industry can spur private sector investment. But these commitments are not a panacea. The GFANZ (Glasgow Financial Alliance for Net Zero) alone oversees $130 trillion of assets,[7] but even if all these assets were invested in companies whose investments were aligned with net zero, this would fall short of the financing required by net zero 2050. Besides, not all the funds they manage can be dedicated specifically to net zero. These asset managers will be investing in the general economy and while they have pledged to invest in a net-zero consistent way, their remit is not to solve climate change.

One obstacle preventing more capital from being deployed to achieve the Paris climate goal is the absence of good quality climate-related data. But this is starting to change, with organisations (including Fathom Consulting) producing tools and metrics that can be used by asset managers to identify climate-related transition risks and measure company performance against the Paris goals in a potentially clearer and more transparent way.

The bottom line is that not all this investment will be done by the listed equities or the corporate sector. They may do a lot of the heavy lifting but much of it will need to be done by households and governments, by, for example, purchasing electric cars, buying new, green heating systems and insulating their homes and buildings. Funding for this should come from a range of sources including earnings, tax revenues and bank loans. Clever and clear-sighted policy can facilitate this process.

[7] GFANZ. 8th November 2021.

** Glossary can be found on page 39.

Section 2: investment requirements by country and sector

KEY TAKEAWAYS

- More than half the estimated $100 trillion of global green investment required must take place in emerging markets (EM) to meet net zero targets.
- More investment will be needed in the BRICS[8] than in the G7.
- Around a quarter of all global green investment will need to take place in China.
- Around a third of investment will need to be spent in the US and EU combined.
- Investment in EMs can achieve more in reducing CO_2 emissions than an investment of equal value in advanced economies – this is a crucial consideration for ESG or impact investors.
- We estimate that nearly half of all corporate investment is required in the energy and utilities sectors – even though their combined market capitalisation is just 6% of the total.
- The market capitalisation to fixed asset ratio for these two sectors is a lot lower than the market average.
- This can be explained by the fact that they are asset-intensive industries, but transition risks may also be a factor.

NET ZERO INVESTMENT NEEDS BY COUNTRY

The table below compares the green investment needs of the world's 20 largest countries (and the EU) alongside a selection of other economic data.[9] The data and methodology used are explained in Appendix III of this paper.

Table 4: Green investment, net zero 2050 scenario, % of global total

Rank	Country	Required investment spending	Current GDP, USD, market exchange rates	Current CO_2 emissions	Current capital stock, USD, market exchange rates
1	China	23.8	16.4	30.7	17.4
2	US	17.0	24.5	14.8	19.1
	European Union	16.2	17.9	8.5	22.4
3	India	6.9	3.2	7.3	2.9
4	Japan	3.9	5.9	3.3	6.7
5	Germany	3.5	4.5	2.1	4.8
6	Indonesia	3.1	1.3	1.7	1.7
7	UK	2.6	3.3	1.1	3.7
8	France	2.5	3.1	0.9	4.2
9	South Korea	2.4	1.9	1.9	2.2
10	Italy	2.1	2.3	1.0	3.9
11	Australia	1.9	1.6	1.2	1.7
12	Spain	1.8	1.6	0.8	2.3
13	Canada	1.7	2.0	1.7	2.1
14	Brazil	1.7	2.1	1.3	2.2
15	Russia	1.4	1.9	4.8	2.2
16	Mexico	1.3	1.5	1.4	1.5
17	Turkey	1.2	0.9	1.2	0.8
18	Saudi Arabia	1.1	0.9	1.5	0.9
19	Iran	1.0	0.8	1.9	1.0
20	Netherlands	0.9	1.0	0.5	1.2

Advanced economy   Emerging market

Source: Penn World Table / Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

[8] The BRICS: Brazil, Russia, India, China, South Africa.

[9] The table also includes each country's share of global GDP in international dollars, first using purchasing power parity exchange rates, and again in US dollars at market exchange rates; its recent share of global CO_2 emissions and its share of global capital stock (in US dollars at market exchange rates).

FINDING 1

China may need more green investment than any other country

Our analysis finds that just under a quarter of total green investment should be required in China. There are a few reasons for this. First, the country is large and already accounts for more than 15% of global GDP. Second, it is expected to grow faster than most other economies between now and 2050, even using Fathom's somewhat conservative estimates of GDP growth – more investment, including green investment, will be needed to support this growth. Third, a higher-than-average share of electricity production in China comes from fossil fuels and the country also has an above-average CO_2 intensity of GDP. This means that more effort, and investment, will be needed relative to the size of its economy.

FINDING 2

More than half the estimated $100 trillion global green investment will be needed in EMs

Nearly 50% of the investment is required in the 24 countries included in the MSCI emerging markets index. (There are additional emerging markets which are not included in this index which will probably require significant investment spending, such as Iran, Hong Kong, Bangladesh, Vietnam, Nigeria). Our analysis also shows that slightly more green investment is needed in the BRICS than in the G7; China and the US account for most of the spending in each of those two groups.

FINDING 3

Relative to the size of their economies, EMs require more green investment than others

There are two main reasons that EMs' need for green investment is disproportionate to the current size of their economies:

- Many EMs are set to grow faster than AEs over the next decade, and will need to grow their capital stock (including green capital) faster to support this growth, relative to AEs.
- Many EMs are further behind in their transitions than AEs and so require more investment to green their existing capital stock.

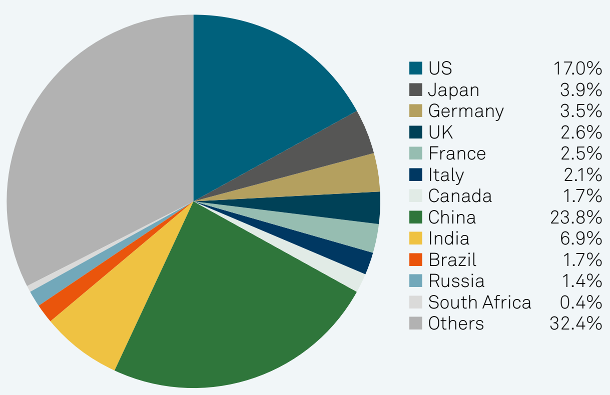
The scatterplot below shows the share of global GDP and the share of the $100 trillion in global green investment needed by each of the 24 countries in the MSCI EM index. The average country should sit on the 45-degree line: that would indicate that the share of green investment that they need is equal to their share of global GDP. Countries below the line require a larger share of the global green investment relative to their current GDP.

Russia and Brazil are notable exceptions, sitting above the line. In Russia's case this can be explained by its below-average trend GDP growth, due to its ageing population and quite likely exacerbated by the current international sanctions. Brazil's trend GDP growth isn't particularly rosy either, but its position above the 45-degree line can be explained by its relatively low share of electricity generation from fossil fuels, meaning that it doesn't need to invest a lot to decarbonise this already largely decarbonised sector.

India, China, South Korea and Indonesia are expected to grow faster than the global average and currently use a lot of coal for electricity generation. Consequently, they may require a larger share of green investment than their current share of global GDP.

BREAKDOWN OF GLOBAL GREEN INVESTMENT REQUIRED*

% of total

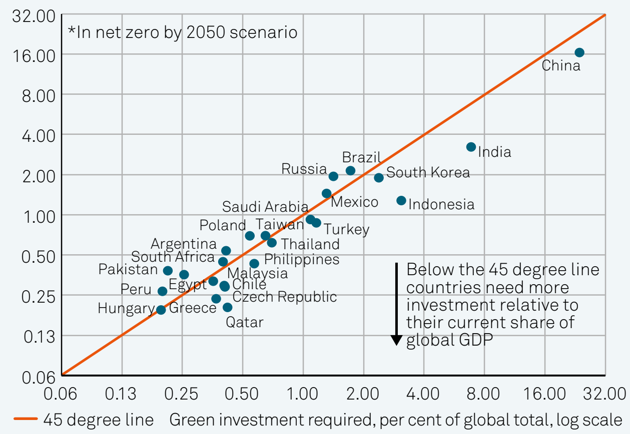


* Net zero 2050 scenario G7, BRICS and others.

Source: BNYM / Fathom Consulting. Date as of September 2022.

EMS GREEN INVESTMENT REQUIRED* VS GDP

GDP in 2019, market prices, % of global total, log scale



Source: Penn World Table / Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

FINDING 4

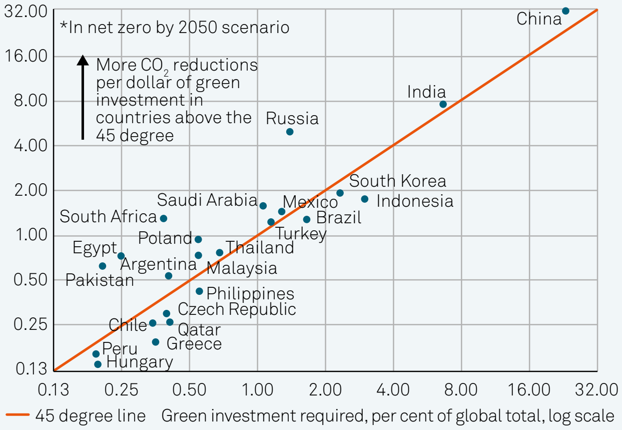
Investors can achieve more decarbonisation per dollar spent in EMs than AEs

Countries that sit on the 45-degree line in the chart to the right have net-zero investment needs are roughly proportional to their current contribution to annual global CO_2 emissions. Countries above the 45-degree line currently emit a larger share of global CO_2 than the share of green investment they need to make. Investing in these countries would potentially achieve more bang per buck in reducing emissions than in the countries below the line. For ESG and impact investors seeking to achieve positive tangible climate outcomes from investments, this is a key consideration. (See more in section 4.)

Note, though, that this analysis considers current emissions, not projected emissions. Some countries, such as India, are expected to grow fast and continue industrialising, and consequently will emit an increasing share of global CO_2. By contrast, countries such as Russia are already comparatively industrialised and aren't expected to grow as fast.

EMS GREEN INVESTMENT REQUIRED* VS CO_2 EMISSIONS

CO_2 emissions in 2019, % of global total, log scale



Source: Penn World Table / Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

NET ZERO INVESTMENT NEEDS BY SECTOR

We now turn to a breakdown by sector of the required corporate 'green' investment spending needs for the Paris climate goal to be met.[10] Table 5 below shows the total green investment needs of each sector between now and 2050, both in US dollars and as a share of the total, along with the total market capitalisation of each sector, total value of property plant and equipment (PPE) and the market capitalisation to PPE ratio.

Table 5: S&P 500 green investment required by sector, in net zero scenario

Sector name	Investment, needed USD bn[1]	Investment, % of total	Market cap, % of total	PPE, USD bn[2]	Market cap to PPE ratio
Energy	3,113	26.6	2.8	847	1.2
Utilities	2,408	20.6	2.5	1,161	0.8
Communication services	705	6.0	11.2	828	5.0
Capital goods	655	5.6	5.9	193	11.3
Materials	511	4.4	2.8	260	4.0
Automobiles & components	478	4.1	2.0	184	4.0
Health care	441	3.8	12.9	288	16.5
Information technology	418	3.6	25.6	354	26.7
Airlines	418	3.6	0.3	135	0.8
Retailing	390	3.3	7.4	367	7.5
Food & staples retailing	327	2.8	1.8	210	3.2
Air freight & logistics	302	2.6	0.7	90	3.0
Financials	247	2.1	11.6	378	11.3
Real estate	229	2.0	2.4	456	2.0
Road & rail	226	1.9	1.0	130	2.7
Hotels, resorts & cruise lines	212	1.8	0.7	88	2.9
Food products	172	1.5	1.1	58	6.9
Beverages	133	1.1	1.5	40	13.9
Household & personal products	123	1.1	1.5	42	13.4
Restaurants	64	0.5	1.1	67	6.2
Consumer durables & apparel	54	0.5	1.1	26	16.2
Commercial & professional services	47	0.4	0.9	35	9.6
Tobacco	24	0.2	0.7	8	29.7
Casinos & gaming	21	0.2	0.3	73	1.5
Total	11,719				

[1] Total green investment required by each S&P 500 sector by 2050, net zero scenario. Constant, 2021 prices. [2] Property, plant and equipment.
Note: unless otherwise stated all market data refer to end 2021. Source: Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

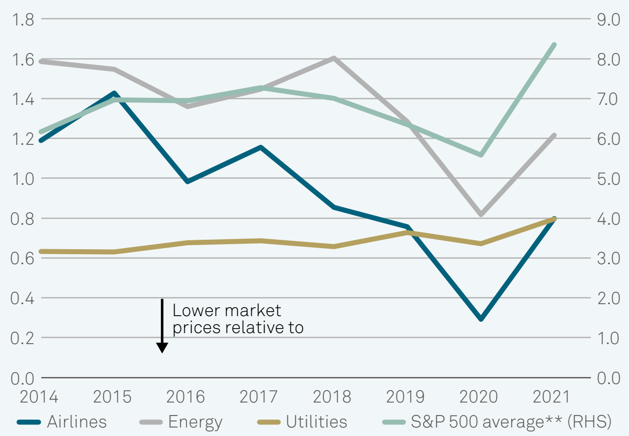
[10] We use the S&P 500 as a proxy for global corporate activity, given that many of the firms listed on this index are multinationals, which derive a significant proportion of their sales and hold a significant quantity of their fixed assets internationally. The share of investment accounted for in each country and market will be different, given variations in economic activity at the weightings in different indices. The 24 sectors are all classified using the Global Industry Classification System (GICS), using levels 1 to 4, and have been chosen in this way since Fathom Consulting have created transition pathways for each of these sectors, which have been used in the creation of a sector risk-scoring framework.

Several key takeaways emerge from this table. First, that just two sectors — energy and utilities — account for nearly half of the overall corporate green investment spending required. Second, that these sectors account for just 6% of the overall market capitalisation. Third, that these sectors have a much lower market capitalisation to PPE (fixed asset) ratio than any other sector except airlines.

There are a few possible explanations for points two and three. All three sectors tend to be asset-intensive, meaning that this ratio is typically lower in these sectors than the market average. Another interpretation is that this reflects a discount compared to other sectors for climate-related considerations. The chart below shows that since 2014 the market capitalisation to PPE ratio for the S&P 500 as a whole has risen significantly, while it has fallen in both the airlines and energy sectors. The ratio has increased slightly for the utilities sector.

MARKET CAP TO PPE*, SELECTED S&P 500 SECTORS

Ratio (both axes)



* Property, plant and equipment.

** Equally weighted average of all 24 sectors in this study.

Source: Refinitiv Datastream / BNYM / Fathom Consulting. Accessed as of September 2022.

The discount in the energy and airlines sectors may in part reflect the effect of the pandemic (and a lack of demand for airlines and energy in 2020), although the ratio had fallen even before COVID. This apparent discount may reflect climate-related considerations, of which there are three.

First, some investors may have decided to shun these sectors since they are responsible for a relatively high share of carbon emissions. Second, investors may already be conscious that these sectors must make a relatively large share of green investment and be unconvinced about their ability to do it; or they could be worried about the cost that this investment will have on their bottom lines. Third, as the analysis in section 3 of this paper shows, these three sectors are most exposed to transition risks. Investors may be worried about the effect of these risks materialising and not being managed properly, thus affecting their bottom line (although that doesn't explain why the ratio has risen in the case of utilities).

It would be fair to conclude that climate-related considerations have played a part. But herein lies the problem: the sectors that may need most of the investment to achieve net zero by 2050, are, it seems, at least in part, being shunned by some investors for the very same reasons. If the transition is to be achieved, these sectors will need capital and investors will play an important role in providing this capital; for maximum effectiveness in minimising transition risk and facilitating decarbonisation investors will need to identify those companies with the most credible decarbonisation and green investment plans.

The charts below highlight how the utilities and energy sectors are outliers in terms of the green investment share that they need, compared with both their market capitalisation and market capitalisation to PPE ratio. There doesn't appear to be any general trend or link between green investment needs and these two metrics, although the materials and automobiles sectors will probably need a relatively large share of overall investment relative to their weight in the overall index.

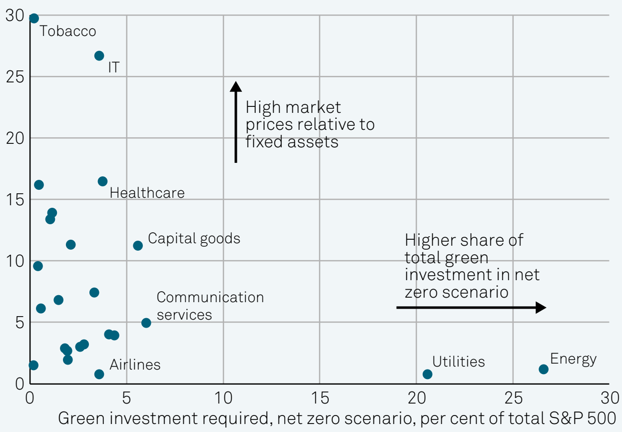
CORPORATE SECTOR INVESTMENT IN CONTEXT

Combined, S&P 500 firms will most likely need to spend nearly $12 trillion of 'green' capital expenditure by 2050. The market capitalisation of the S&P 500 is around $37 trillion; according to our calculations at the time of writing that was about 40% of the global listed equity market capitalisation. Scaling this figure up would give a total green investment of $30 trillion for all listed equities. By extension, unlisted equities, governments and households make up the remaining $70 trillion.

On the face of it this seems low, but it is plausible. A large share of the world's capital stock is held by households. And in a net-zero world, households will probably need to replace their conventional internal combustion engine (ICE) cars with EVs, make sure that their houses are insulated and that the heating systems are low carbon (installing heat pumps instead of boilers, for example). In a macro sense, these purchases are considered as investment in the global capital stock, and count towards our $100 trillion figure. It is also worth reiterating that we have used a different methodological approach to estimate sector-specific investment needs than the one we used to estimate the overall global green investment figure of $100 trillion, which may explain any possible discrepancy.

GREEN INVESTMENT REQUIRED AND MARKET CAP/PPE, S&P 500

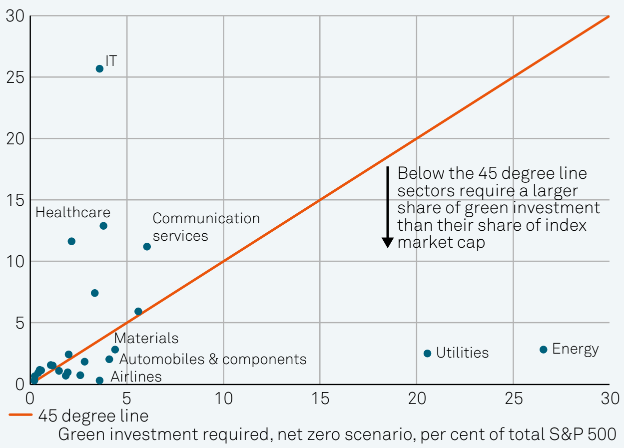
Market cap to PPE ratio, end-2021



Source: Refinitiv Datastream / BNYM / Fathom Consulting. Accessed as of September 2022.

GREEN INVESTMENT REQUIRED AND MARKET CAP, S&P 500

Market cap end-2021, % of total S&P 500



Source: Refinitiv Datastream / BNYM / Fathom Consulting. Accessed as of September 2022.

> **"S&P 500 firms will most likely need to spend nearly $12 trillion of 'green' capital expenditure by 2050."**

Section 3: transition risks by sector

KEY TAKEAWAYS

- We have established that the transition is feasible and should create huge investment opportunities, but there will also be risks and costs.
- We present a new, unique, methodology designed to help investors assess which sectors are most exposed to these risks and costs.
- This method distils exposure to three types of risk – carbon taxes, stranded assets and transition speed – into nine metrics, which are used to create sector-specific transition risk scores.
- According to this framework, three sectors – energy, utilities and airlines – are far more exposed to transition risks than any of the other sectors.
- The energy and utilities sectors also need far more transition capital than other sectors.
- Managing these risks, while providing these sectors with the capital they need, may be key to ensuring that the Paris climate goal is met.

The challenge of decarbonisation varies dramatically between sectors and investors need to be aware of these differences. To address this we have created a new and unique methodology, and used it to score 24 stock market sectors on their transition risks. The overall, sector-specific risk score considers three broad categories of risks: exposure to carbon taxes, stranded asset risks and the speed of the transition (more specifically, how quickly decarbonisation is likely to happen in each sector and how problematic, from an economic point of view, that is likely to be). We have created nine individual metrics of risk, which are presented in Table 6 below, alongside the overall risk score for each sector. A full explanation of each of these metrics is contained in Appendix V.

Table 6: S&P 500 transition risks by sector

Z scores

	Overall transition risk	Carbon tax 1	Carbon tax 2	Carbon tax + transition speed	Transition speed 1	Transition speed 2	Stranded assets 1	Stranded assets 2	Stranded assets 3	Disclosure
Utilities	2.0	3.6	2.3	4.2	3.4	3.2	0.5	1.9	0.0	-0.8
Energy	1.6	0.8	3.3	4.5	0.2	-0.3	2.2	1.0	2.0	0.6
Airlines	1.2	2.5	1.1	0.1	-0.8	-0.3	1.9	1.9	4.0	0.1
Road & rail	0.3	0.0	-0.4	-0.1	-0.2	-0.3	1.3	2.9	-0.2	-0.3
Real estate	0.2	-0.5	-0.6	-0.4	2.4	3.2	-1.1	-0.1	-0.3	-0.4
Hotels, resorts & cruise Lines	0.1	0.0	0.1	0.2	-0.6	-0.3	0.4	-0.1	0.7	0.6
Materials	0.0	0.2	0.1	0.4	-0.4	-0.3	0.2	0.0	-0.2	-0.4
Food products	0.0	-0.4	0.0	0.0	-0.3	-0.3	0.9	0.2	-0.2	-0.3
Automobiles & components	-0.1	-0.4	0.8	1.3	-0.5	-0.3	-0.3	-0.6	-0.2	-0.3
Capital goods	-0.1	-0.4	0.0	0.0	-0.8	-0.3	0.4	-0.2	-0.3	0.8
Casinos & gaming	-0.1	-0.4	-0.7	-0.5	0.8	-0.3	-1.2	-0.5	-0.3	2.1
Air freight & logistics	-0.1	0.1	0.2	-0.1	-0.8	-0.3	1.0	0.5	-0.3	-1.5
Consumer durables & apparel	-0.2	-0.5	-0.5	-0.3	-0.5	-0.3	-0.5	-0.7	-0.4	1.7
Food & staples retailing	-0.3	-0.3	-0.6	-0.4	-0.4	-0.3	0.1	-0.1	-0.3	-0.3
Restaurants	-0.3	-0.4	0.0	0.1	-0.7	-0.3	-0.5	-0.3	-0.4	-0.1
Beverages	-0.3	-0.4	-0.2	0.0	-0.5	-0.3	0.2	-0.2	-0.4	-1.1
Communication services	-0.3	-0.5	-0.7	-0.5	0.6	-0.3	-1.3	-1.0	-0.4	1.0
Retailing	-0.4	-0.4	-0.6	-0.4	-0.3	-0.3	-0.8	-0.6	-0.4	0.5
Health care	-0.4	-0.5	-0.7	-0.5	-0.2	-0.3	-0.7	-0.7	-0.4	0.6
Household & personal products	-0.4	-0.4	-0.5	-0.4	-0.2	-0.3	0.5	-0.1	-0.4	-1.7
Tobacco	-0.4	-0.4	-0.4	-0.2	-0.1	-0.3	0.3	-0.1	-0.4	-2.2
Commercial & professional Services	-0.4	-0.5	-0.7	-0.5	-0.3	-0.3	-0.8	-0.9	-0.4	0.6
Financials	-0.4	-0.5	-0.7	-0.5	0.3	-0.3	-1.2	-1.0	-0.4	0.4
Information technology	-0.6	-0.5	-0.7	-0.5	-0.4	-0.3	-1.3	-1.1	-0.4	0.2

Consistent with more transition risk / Consistent with less transition risk

Note: all variables and ratios have been calculated and adjusted so that higher scores reflect more exposure to transition risk. A Z score is the distance between a raw score and the mean of all scores in that series, expressed in standard deviations.

Source: BNYM / Fathom Consulting. Date as of September 2022.

This analysis clearly shows that utilities, energy and airlines face significantly higher transition risks than other sectors. This is due to their exposure to the three categories of risks outlined above. Below, we give examples which provide a flavour of how the scoring system works.

CARBON TAX RISK

The earnings of companies in all three of these sectors would be harder hit by any new carbon taxes than the earnings of companies in other sectors.[11]

TRANSITION SPEED RISK

One of the reasons that the utilities sector has such a high overall risk score (higher even than that of energy and airlines) is because this sector will be expected to fully decarbonise faster than other sectors. Fathom's transition pathways, which use a rigorous and data-driven method to generate sector-specific decarbonisation pathways, reflect this risk.[12] These risks are not just hypothetical: they are becoming real, for example, some countries are planning on decarbonising their electricity generation sectors by 2035 and are introducing legislation accordingly.[13] Decarbonising quickly creates risks and increases the chances of existing assets becoming stranded.

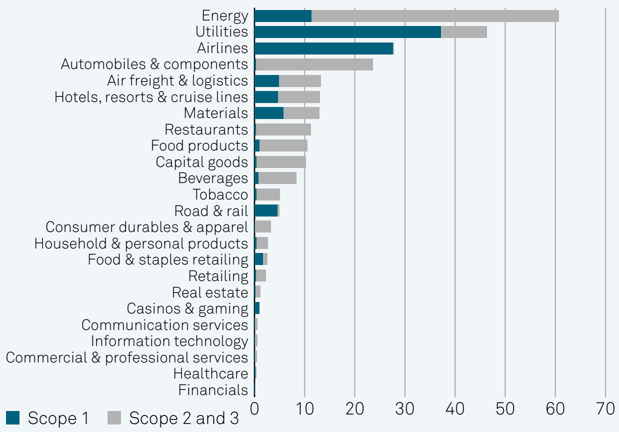
Taking this analysis further, we can compare the speed at which sectors need to decarbonise with their sensitivity to carbon taxes. This comparison is reflected in the chart below – where a green dot further to the right highlights where a sector ought to decarbonise quicker (as per Fathom's transition pathways). Being required to decarbonise quicker is likely to compound the risk of exposure to carbon taxes (and indeed, make the risk of carbon taxes materialising more likely). The chart also shows how different transition risks overlap.

STRANDED ASSET RISK

According to our estimates, in the utilities, energy and airlines sectors there is a relatively high share of fixed assets that are dirty and will probably need replacing to be consistent with net zero. Our stranded asset risk calculations consider these estimates, as well as how quickly assets typically depreciate and how asset-intensive these industries are. More asset-intensive industries, where those assets depreciate slowly and a high share of them need replacing to meet zero, will be most at risk. The airlines, utilities and energy industries fall into this category.

CARBON TAX EFFECT

% reduction in EBITDA due to $50/ton carbon tax*



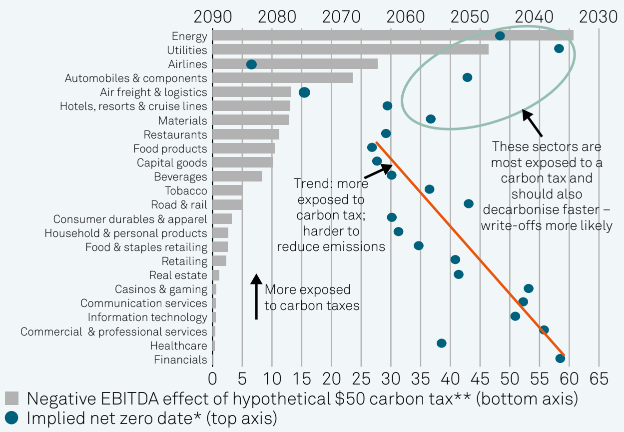
* Assuming tax is fully absorbed by company on its scope 1 emissions and 50% absorbed on its scope 2 and 3 emissions. Uses financial and emissions data between 2018 and 2020.

Note: carbon tax effect is calculated using publicly-available financial data and greenhouse gas emissions data accessed via Refinitiv Eikon.

Source: Refinitiv Eikon / BNYM / Fathom Consulting. Date as of September 2022.

CARBON TAX EFFECT AND IMPLIED NET ZERO DATE

Implied net zero date*



* As per Fathom's transition pathways, which allocate the global carbon budget in a manner consistent with achieving Paris climate goal.

** Assuming tax is fully absorbed by company on its scope 1 emissions and half absorbed on scope 2 and 3 emissions. See appendix for definitions of scope 2 and 3.

Note: carbon tax effect is calculated using publicly-available greenhouse gas emissions data accessed via Refinitiv Eikon.

Source: Refinitiv Eikon / BNYM / Fathom Consulting. Date as of September 2022.

[11] The blue bars indicate the estimated effect on EBITDA (earnings before interest, taxes, depreciation or amortisation) of a hypothetical carbon tax (over and above any carbon taxes already paid) of $50 per ton on scope 1 emissions, assuming that 100% of the cost of that tax was borne by the company. The green bar shows the additional effect on EBITDA if the company paid 50% of the cost of such a tax on its scope 2 and scope 3 emissions (i.e., those incurred by its suppliers and customers).

[12] Not all sectors are expected to decarbonise at the same speed. Organisations such as Fathom Consulting, the Science Based Targets Initiative and Transition Pathways Initiative create sector-specific decarbonisation pathways, which consider information such as technological availability and the price of decarbonising. Fathom's transition pathways are used in this analysis. For more information see Appendix VI.

[13] https://www.gov.uk/government/news/plans-unveiled-to-decarbonise-uk-power-system-by-2035.

We also include a metric which relates to the disclosure (or lack of it) of emissions data. Failure to fully report greenhouse gas emissions represents a risk for investors. Further explanation of these risks, and of all nine metrics, are contained in Appendix V.

TRANSITION RISKS AND INVESTMENT NEEDS

The chart below allows us to compare the sectoral risk metrics presented in this section with the green investment needs of each sector, and there is a clear takeaway: the utilities and energy sectors, which are the two most exposed to transition risks, are also the two sectors that have the greatest green investment requirements. (See chart and Table 7 below.)

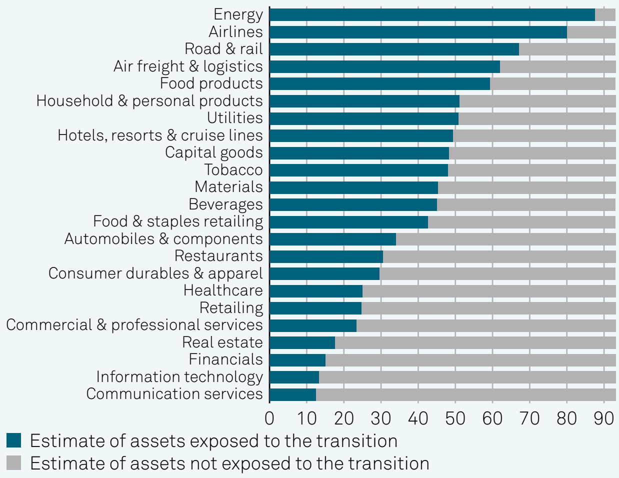
This finding has important implications for investors. While we explain these, and other takeaways for investors from our study, in more detail in section 4 of this paper, it is worth dwelling on this point: the sectors that are most exposed to risks are also the ones that need to make the most investment.

They will probably also need the finance to make this investment if the Paris climate goal is to be met. Some investors may choose to shun these sectors, due to the transition risks that they face. Others may shun these sectors since they are currently responsible for a large share of global greenhouse gas emissions. But the transition will not be achieved if firms in these sectors do not make the requisite green investments.

Impact investors, ESG investors and sustainability investors need to consider these issues carefully – as do regulators, incumbents in these sectors and other stakeholders. Divesting from these sectors will not solve climate change or ensure that the Paris goal is met. The utilities and energy sectors need capital, but they need to use that capital for green investment – and do much more of it than they have been doing thus far. (See section 4 for more details.)

S&P 500 PHYSICAL ASSET BREAKDOWN

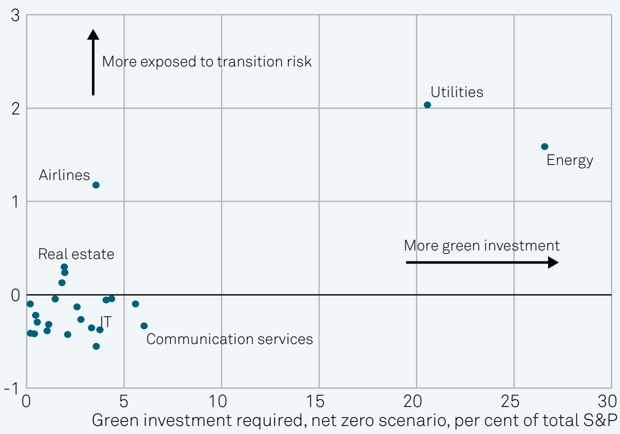
% of total



Source: Refinitiv Eikon / BNYM / Fathom Consulting. Accessed as of September 2022.

GREEN INVESTMENT REQUIRED AND TRANSITION RISK, S&P 500

Transition risk score



Source: Refinitiv Datastream / BNYM / Fathom Consulting. Date as of September 2022.

Table 7: S&P 500 green investment by sector, in net zero scenario, with transition risk scores

Sector name	Investment, 2020 prices, USD bn[1]	Investment, % of total	Market cap, % of total	PPE, USD bn[2]	Market cap to PPE ratio	Transition risk score[3]
Energy	3,113	26.6	2.8	847	1.2	1.6
Utilities	2,408	20.6	2.5	1,161	0.8	2.0
Communication services	705	6.0	11.2	828	5.0	-0.3
Capital goods	655	5.6	5.9	193	11.3	-0.1
Materials	511	4.4	2.8	260	4.0	0.0
Automobiles & components	478	4.1	2.0	184	4.0	-0.1
Health care	441	3.8	12.9	288	16.5	-0.4
Information technology	418	3.6	25.6	354	26.7	-0.6
Airlines	418	3.6	0.3	135	0.8	1.2
Retailing	390	3.3	7.4	367	7.5	-0.4
Food & staples retailing	327	2.8	1.8	210	3.2	-0.3
Air freight & logistics	302	2.6	0.7	90	3.0	-0.1
Financials	247	2.1	11.6	378	11.3	-0.4
Real estate	229	2.0	2.4	456	2.0	0.2
Road & rail	226	1.9	1.0	130	2.7	0.3
Hotels, resorts & cruise lines	212	1.8	0.7	88	2.9	0.1
Food products	172	1.5	1.1	58	6.9	0.0
Beverages	133	1.1	1.5	40	13.9	-0.3
Household & personal products	123	1.1	1.5	42	13.4	-0.4
Restaurants	64	0.5	1.1	67	6.2	-0.3
Consumer durables & apparel	54	0.5	1.1	26	16.2	-0.2
Commercial & professional services	47	0.4	0.9	35	9.6	-0.4
Tobacco	24	0.2	0.7	8	29.7	-0.4
Casinos & gaming	21	0.2	0.3	73	1.5	-0.1
Total	11,719					

1 Total green investment by each S&P 500 sector by 2050, net zero scenario.

2 Property, plant and equipment, 2021.

3 Higher score equals more transition risk.

Source: Refinitiv Datastream / BNYM / Fathom Consulting. Accessed as of September 2022.

Section 4: Implications for investors

KEY TAKEAWAYS

- The nature of around $100 trillion worth of investment will be very different in the net-zero scenario compared to business as usual – this creates opportunities and risks.
- To take advantage of the investment opportunities and manage the risks that the transition creates investors need to understand how the nature of investment is going to change.
- Investors should try to monitor how the price of buying and operating low carbon capital evolves, and how readily it can be deployed at scale.
- The firms which profit most from the transition will not necessarily be the ones making most of the green investment – sales of capital goods, intermediate goods, autos and semiconductors should rise.
- Mining activity is set to increase significantly as demand for metals and minerals used for transition-related technology (i.e., lithium) soars.
- A substantial share of global green investment will probably be in households; spending on new heating systems and EVs will create significant opportunities for corporates supplying such products.
- The sectors which may need the most investment are also those most exposed to transition risks.
- Climate change will not be addressed if investors shun the energy and utilities sectors; to support the net zero transition ESG and impact investors therefore should consider investing in these sectors, but in those companies that have credible decarbonisation plans.
- Incumbents from all sectors, but especially energy and utilities, should play a key role in making net zero a reality; but if they don't do the green investment, new players will.
- Green investment needs are greatest in EMs where resources are often limited – international investors can help meet these needs and potentially achieve more decarbonisation for their buck in the process.

KEY CONCEPTS AND TRENDS

What do the findings in this report mean from an investor's point of view? A huge sum of money needs to be invested to achieve net zero by 2050. This investment should not be seen as the cost of preventing climate change: it is an investment in capital that can help support economic growth in a decarbonised world. Most of this investment would have happened anyway in a counterfactual, business-as-usual scenario – but with a key difference: in the net-zero scenario, the investment is in clean capital, not "dirty" capital.

The nature of around $100 trillion worth of investment will be very different in the net-zero scenario compared to business as usual. EVs will be built instead of ICE vehicles. Wind turbines and solar panels will be installed instead of coal-fired power stations. Hydrogen-powered or electric battery-powered aircraft will be built, rather than kerosene-powered aeroplanes. And so on. Investors need to understand how the nature of investment is going to change, to take advantage of the investment opportunities and manage the risks that the transition creates.

The firms which profit most from the transition will not necessarily be the ones making most of the green investment. In fact, beneficiaries are more likely to be companies that provide the goods and services needed for the investment. The sectors that stand out in this regard include makers of capital goods, intermediate goods, autos, semiconductors, miners, and the owners of the mineral deposits used in the transition.

Mining activity will need to increase, given the raw-material intensity of renewable energy technology.[14] Capital goods manufacturers can benefit from sales to this sector, as well as from rising demand for EVs and other clean transportation equipment.

Meanwhile, green investment in the energy sector will probably benefit firms that produce battery storage, grid infrastructure and piping. Green hydrogen seems likely to play a big part in the transition (the German government, for example, has earmarked €9 billion for green hydrogen projects).[15] This would further boost demand for renewable electricity and the makers of electrolysers and of electrolyser parts.

Firms that supply green capital goods to households are also set to benefit. While corporates will do much of the heavy lifting to make net zero a reality, households and governments will probably make a large amount of this investment. In the case of the former, that is because they own a large share of the world's capital stock, in the form of automobiles and dwellings (and their heating systems) which need to be greened. Transition-related spending by households on things like electric cars and low-carbon heating systems, such as heat pumps, are set for a huge rise in the net zero 2050 scenario.

[14] For more see The Role of Critical Minerals in Clean Energy Transitions – Analysis – IEA.

[15] https://www.dw.com/en/germany-and-hydrogen-9-billion-to-spend-as-strategy-is-revealed/a-53719746.

MANAGING OPPORTUNITIES AND RISK

Investors, corporates and policymakers need to understand the costs and risks associated with the transition. We believe the framework presented in this paper is a key resource to help them to do this. The overall transition risk scores can help investors to orient themselves in this changing investment world. Identifying and comparing the different types of transition risks across sectors can provide important colour and context for risk management purposes. Much useful information can be gleaned from Table 6 in section 3 and by reading Appendix V.

In some cases, the cost of building and operating clean capital is cheaper than the status quo. But in other cases, clean capital is more expensive. Investors should try to monitor how the price of buying and operating low carbon capital evolves, and how readily it can be deployed at scale. Not only will these costs dictate the impact on the firms making the relevant investment and their willingness to invest, but they might also help to determine government policy.

The auto industry provides an example: countries such as the UK will ban the sale of new petrol and diesel vehicles from 2030 onwards, while some major auto manufacturers have voluntarily agreed to stop producing such vehicles entirely by the mid-2030s. These changes may affect the manufacturers, their supply chains and the entire ecosystem around the EV charging network.

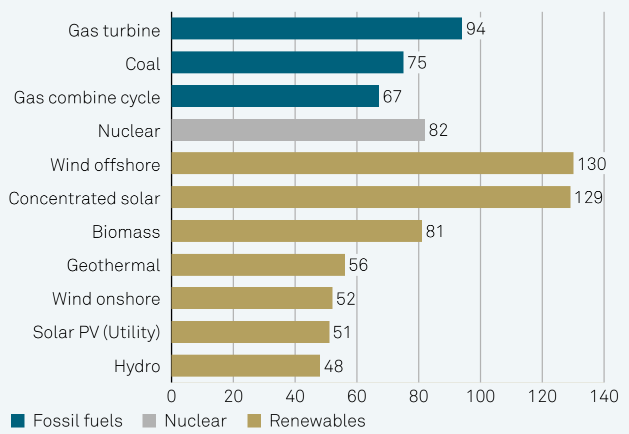
The charts below demonstrate how the price of low carbon ways of doing things has evolved. The first chart shows how the cost of renewable energy was already competitive with fossil fuels, if not cheaper, in 2020. It will be a lot cheaper now, since recent developments in the energy market. The second chart shows how the price of solar panels has fallen significantly, and much faster than expected, in recent decades.

The market seems to be pricing in transition risk for energy and airlines, more than for utilities. See the market cap to PPE chart on page 13. The market capitalisation to PPE ratios for energy and airlines have been declining since 2014, unlike the rest of the S&P 500; and unlike the utilities sector, where the same ratio has been increasing. Perhaps investors see the opportunity in utilities, which we think, for now, have a clearer path to net zero than energy or airlines (the technology is there at a competitive price). There could be an investment opportunity here if the market has not yet rewarded those airlines and energy firms with robust decarbonisation plans.

Incumbents from all sectors, but especially energy and utilities, will probably play a key role in making net zero a reality. But this will require many of them to make big changes to their business models and to the way they invest. The incumbents that are not up to the task of decarbonising and scaling up their green investment are quite likely to find that unicorns (and new Teslas, but in different sectors), or other incumbents from the same sector, will be waiting to take their place.

LEVELISED COST OF ENERGY

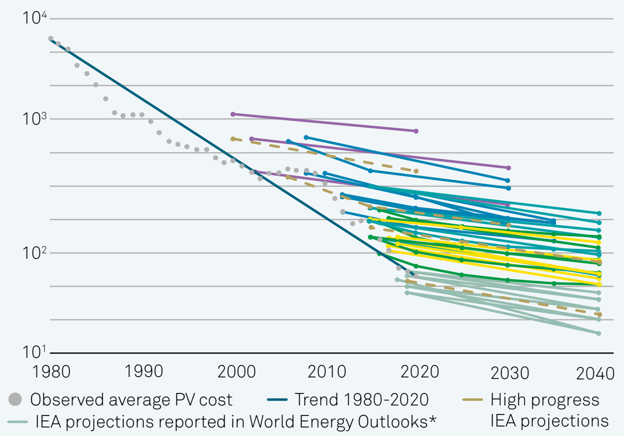
Median values, USD per megawatt hour, 2020



Source: World Bank / Fathom Consulting. Accessed as of September 2022.

HISTORICAL SOLAR PV COST FORECASTS

Levelised cost of electricity, USD (2020) per megawatt hour



* Colours from purple through gold denote the base year of projection.

Source: INET / Fathom Consulting. Accessed as of September 2022.

ESG AND IMPACT INVESTORS

The sectors that may need the most capital to turn the green investment needs of the net zero transition into reality – energy and utilities – are also responsible for a large share of global CO_2 emissions. Investors may feel legitimate concerns about the risks facing these sectors. But if investors shun the energy and utilities sectors completely this will not solve climate change.

The entire global economy depends on energy and the utilities, a fact highlighted even more by events since Russia's invasion of Ukraine. In particular, it needs clean energy and electricity, not energy and electricity made from fossil fuels. Policymakers thus have a very strong incentive to regulate, tax and support these sectors in a reasonable way, especially those firms that are decarbonising and making the requisite green investment.

The sectors that may need the most capital to turn the green investment needs of the net zero transition into reality – energy and utilities – are also responsible for a large share of global CO_2 emissions.

Investors can accelerate this process by directing capital towards firms in these sectors with credible decarbonisation plans. Similarly, investors could use their influence to encourage the management of companies to ramp up their green investment.

Another important consideration for ESG and impact investors is that for global net zero to happen, more than half of the $100 trillion worth of global green investment that is needed must take place in EMs. Many of these countries need finance to make this investment happen. Private sector investors in AEs can help. Not only are these funds badly needed, but they can achieve more decarbonisation for their buck relative to the same amount spent in an AE.

Some of the low-hanging fruit have not yet been picked. One example is the switch from coal-powered generation to renewables: financing this switch can have provide a wide-ranging impact, including cost savings for households on their electricity bills, leading to wider social benefits. Such investment doesn't just make sense for the climate, it makes business sense too, provided that the standard risks of investing in EMs can be successfully navigated.

Section 5: Final thoughts

Achieving net zero by 2050 will require huge, transformational investment. The numbers are subject to uncertainty for multiple reasons, but green, transition-specific investment of at around $100 trillion is likely to be needed. The scale of this investment is unprecedented, and while such investment needs to be scaled up significantly from current levels, according to our analysis it will represent less than a fifth of total economy-wide global capital expenditure that is likely to take place over the next thirty years.

There is some uncertainty about the overall effect of the transition on GDP growth (see Appendix VII for more details). What is clear, however, is that there will be bumps along the way, highlighted by the recent spike in gas prices. And there will be costs too. Even if the transition is net positive for growth, large, up-front costs will be required. Financing this expenditure in emerging markets and for lower-income households will be a key challenge.

Assets worth around $20 trillion may need replacing and retrofitting before the end of their useful lives. Transition risks vary significantly by sector. Those asset-intensive industries that will need to decarbonise relatively quickly to meet the Paris climate goals face larger risks. The risks are even higher for those industries whose assets tend to depreciate more slowly and where a relatively high share of those assets will need replacing in a net-zero scenario, such as utilities. The more disorderly or delayed a transition becomes, the higher these risks will become.

There are lessons here for investors. Most notably, the sectors which need capital most to make the investments that the world needs to achieve limit global warming are also those that are currently responsible for emitting most greenhouse gas emissions and most at risk from the net zero transition. Engaging with those companies most serious about decarbonising and managing their transition risks may be a more effective strategy to have an impact than shunning these sectors completely. Green investment in these sectors needs to be scaled up significantly from current levels. If incumbents won't do this, then new players will need to.

The upshot is that the composition of investment and capital stock can also change significantly in the transition, creating risks, but a series of business opportunities too. Investors should also be cognisant of the difference between 'investment by' and 'sales of'. The corporates that will benefit most from the transition will not necessarily be the ones that need to do most of the greening of their own capital stock. The companies supplying the goods used to do this investment, such as capital goods manufacturers or miners, stand potentially to benefit significantly.

Companies such as Tesla highlight the potential upside for businesses with a first mover advantage in net zero solutions. But a new entrant isn't necessarily needed to unlock these opportunities: incumbents will play a key role in the net zero transition too, including in autos and energy. Businesses in all sectors, and at all stages of their lifecycle, will need to consider these issues and adapt. Investors need to too. Those that don't risk missing unprecedented business opportunities, as well as failing to spot and manage significant financial risks.

Achieving net zero by 2050 will require huge, transformational investment. The numbers are subject to uncertainty for multiple reasons, but green, transition-specific investment of at around $100 trillion is likely to be needed.

Appendices and methodologies

Appendix I:
Global green investment modelling methodology

OVERVIEW

In this section we explain how we have estimated the investment required to 'green' the world's capital stock by 2050. The methodology follows six steps:

1. Estimate the current world capital stock ($360 trillion).
2. Estimate global carbon emissions, GDP and capital stock in 2050 under two scenarios: business as usual and net zero.
3. Subtract the depreciated value of current capital stock in 2050 from the current capital stock to estimate the total replacement investment between now and 2050 in both scenarios.
4. Calculate the change in total capital stock between now and 2050 under both scenarios. Add this number to the replacement investment (step 3) to calculate the total global gross investment ($540 trillion) over the next 28 years.
5. Estimate the clean (80%) and dirty (20%) shares of global capital or gross investment. Under the net-zero scenario, we assume that dirty investment is replaced by clean, giving the truly 'green' investment required. ($90-125 trillion).
6. Estimate the dirty share (20%) of non-depreciated capital in 2050 ($18 trillion) in the net zero 2050 scenario. This is our estimate of 'stranded' capital that must be scrapped before the end of its useful economic life.

The key assumptions we use are as follows:

1. The global capital/output ratio (4.1).
2. The clean share of the existing capital stock (80%).
3. The annual depreciation rate of capital (4.5%).
4. Trend real global GDP growth under business as usual (2%).
5. The abatement cost of implementing 'greening' measures (2.8% of 2050 Business as Usual GDP).

STEP ONE

Estimating the current world capital stock

There are no official data on the aggregate capital stock (machinery, equipment and structures) on a global scale. Instead, the value is often estimated by multiplying a 'sensible' capital/output estimate by world GDP.

This is not as straightforward as it sounds as there are various views of what a 'sensible' capital/output ratio might be. Small changes in that assumption imply large changes in the dollar value of the current world capital stock.

One of the most widely cited sources of data for the global fixed capital stock is the Penn World Table,[16] produced by the University of Groningen. Its data are in current prices and adjusted for purchasing power parity (PPP). We convert these into nominal US dollars using PPP multipliers from the International Monetary Fund (IMF). This equates to a combined global capital stock ratio of around 4.1 times world GDP. We call this the K/Y ratio.

The K/Y ratio using the Penn World Table is significantly higher than estimates of the same ratio from other sources. For example, the K/Y ratio in Fathom's global macroeconomic model is 2.7, while data from the UK's national accounts suggest that the UK's K/Y ratio is 2.1.

Most economists would argue the equilibrium capital-output ratio is 'around three'. Theory suggests the equilibrium capital-output ratio is given by the capital share of national income divided by the cost of capital.[17] Given a capital share of around a third and an average cost of capital around 10%, that generates an equilibrium capital-output ratio of 3.33. On top of this, empirical observation of individual country or sector estimates of capital-output ratios tend to cluster around 3, though there is significant variation. It is also worth remarking that capital income (profit) shares have tended to rise in recent years while the cost of capital has fallen, arguing for higher capital-output ratios more recently.

We have chosen to work with the Penn estimate of 4.1 but recognise that this may overestimate both the value of the current capital stock and the amount of investment required to green it over the next 30 years. We therefore do some sensitivity analysis, based on different values of the equilibrium capital-output ratio.

[16] https://www.rug.nl/ggdc/productivity/pwt/?lang=en.

[17] This assumes a so-called Cobb-Douglas production technology, with capital and labour as inputs, and that the marginal cost of capital is equated to its marginal product.

STEP TWO

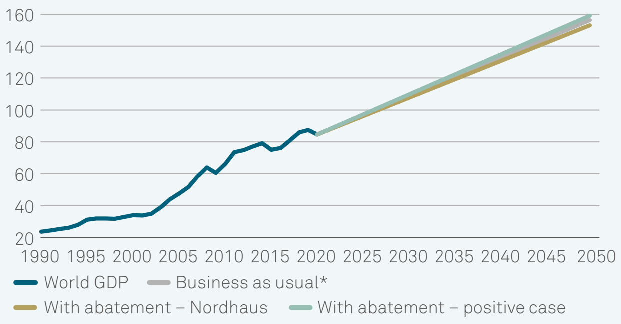
Estimating global carbon emissions, GDP and capital stock in 2050 under both business-as-usual and net-zero scenarios

We assume trend global growth of 2% in business as usual. Accordingly, we grow both global output and the global capital stock at that rate to 2050, implying that the capital-output ratio remains constant throughout this period.

Under business as usual we also assume that carbon emissions (billions of tons CO_2 equivalent, or CO_2E) continue to grow at the same speed as they have done over the last decade. This equates to a 55% increase from the current 40 billion tonnes CO_2E to 62 billion tonnes CO_2E in 2050. For our net-zero scenario, we assume that the quantity of global carbon emissions falls to zero, although a different approach might let carbon emissions sit at a small positive, offset by carbon capture or storage.

There are various estimates of the so-called 'transition costs' – the GDP cost of reducing carbon emissions to zero (also known as abatement costs). We use estimates produced by William Nordhaus,[18] who suggests that a good central estimate might be 2.8% of global GDP over 30 years. This estimate suggests that the 'transition costs' would knock around 0.1% off the trend growth rate.

GLOBAL GDP SCENARIOS
USD, trillions, real 2020 prices



* no physical damage assumed.

Source: BNYM / Fathom Consulting. Accessed as of September 2022.

Using these figures, both GDP and the world capital stock are 2.8% lower in 2050 in our net-zero scenario than in our business-as-usual scenario. These estimates are somewhat controversial, although there is no consensus on what they should be.

Business as usual would incur greater physical economic costs than the net-zero scenario due to a failure to stem global warming. However, since the cumulative stock of greenhouse gas emissions causes global warming, rather than the flow, the cost of additional emissions in this half of the century will predominantly be felt in the second half. For simplicity, we assume that all physical costs are borne in the second half of the century and all transition costs in the first half – in line with our assumption that this is at heart an intertemporal question. In reality, as the climate changes, significant physical costs could become apparent earlier than 2050, and transition costs may last longer.

STEP THREE

Estimating the total replacement investment in depreciated assets between now and 2050 in both scenarios

We assume an annual depreciation rate on aggregate capital of 4.5%, based on the figures from Penn, using a weighted average of the depreciation rates of the different forms of capital and the shares of that capital in the overall capital stock. The charts below describe how.

It is impossible to say which is the right figure to use, but it is important to recognise that depreciation rates and the share of capital that is clean and dirty will vary depending on the source.

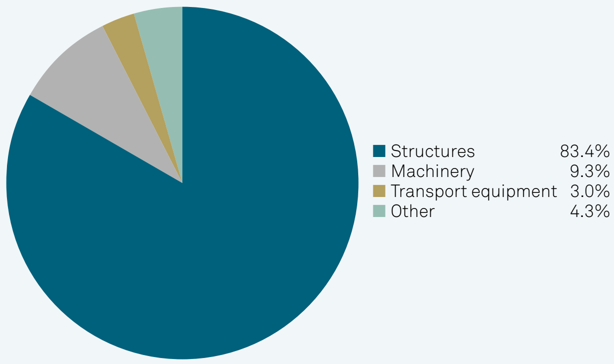
For example, structures account for a larger share of the total in the Penn figures. Compared to other forms of fixed assets, structures have a lower depreciation rate. While these figures appear high to us, we nevertheless use data from Penn due to the detailed breakdown by country and by type, with depreciation rates.

[18] Nordhaus, W. (2015).

To calculate total replacement investment between now and 2050, we work out how much of the current capital stock will remain in place in 2050. We do this by dividing the current capital stock estimate by 3.43=(1+0.045) . We then subtract the estimate of the remaining capital stock from the current capital stock to generate our estimate of total replacement investment between now and 2050.

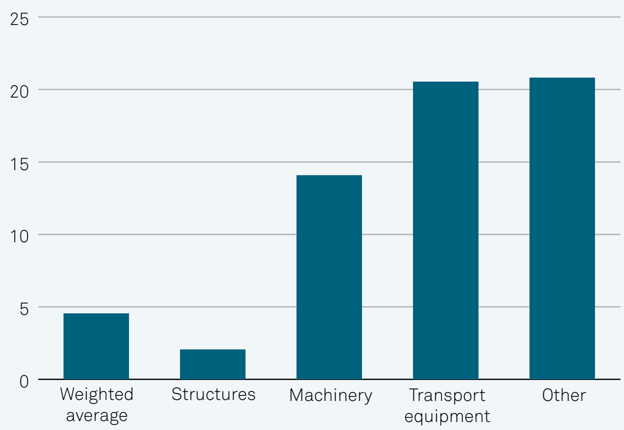
The calculated replacement investment is large – around three-quarters of the existing stock will probably have turned over by 2050. This shows that, so long as we replace dirty with clean, we can achieve a lot of the necessary 'greening' gradually.

BREAKDOWN OF CURRENT GLOBAL CAPITAL STOCK



Source: Penn World Table v10.0 / BNYM / Fathom Consulting. Accessed as of September 2022.

DEPRECIATION RATE BY TYPE OF CAPITAL STOCK
%, per annum



Source: Penn World Table v10.0 / BNYM / Fathom Consulting. Date as of September 2022.

STEP FOUR

Calculating total global gross investment ($540 trillion) over the next 28 years

Importantly, it won't only be necessary to replace capital that wears out over the next 30 years; we will also be considering investing in new things. The change in the capital stock over any period is equal to gross investment minus replacement investment. We can calculate gross investment out to 2050 by adding the change in the capital stock between now and 2050 (step 2 minus step 1) to replacement investment (step 3). The resulting figure is immense; around $540 trillion dollars in 2020 prices.

STEP FIVE

Assuming that dirty investment is replaced by clean, calculate the truly 'green' investment required ($100 trillion) under the net-zero scenario

As we know, much of the $540 trillion is investment that would occur anyway, regardless of whether it is replacement or new. In order to estimate how much 'green' investment is required, we have to work out how much of the $540 trillion would be invested into dirty assets under business as usual.

We define clean capital (KC) as capital that does not directly generate greenhouse gas emissions. This includes clean energy infrastructure or EVs, but also things like IT equipment. While IT equipment requires electricity to run, much of its carbon footprint results from the emissions generated in the production of the electricity required to power the equipment, rather than in making the equipment itself. The net zero transition does not require IT equipment to be scrapped, but it does require the power to come from green sources. Net zero also requires the equipment and processes that are used to create IT products (such as semiconductors, which require the mining of silicon) to be green. The same is true for most structures – the structures themselves do not generate emissions, and therefore would not need to be replaced in a net zero world; however, the systems used to heat them would, as would the capital used to make the steel, cement and other building materials.

At the economy-wide level, most capital is therefore KC. "Dirty" capital (KD) is that which is directly responsible for generating emissions, such as coal-fired power plants, internal combustion engine vehicles and jet aircraft. This also includes the infrastructure used to extract the fossil fuels used to power them, such as oil rigs and coal mines. After considering a range of factors (such as size and makeup of existing global capital stock, and assumptions about compatibility of existing capital stock with likely future tech) we estimate that around 80% of the world's current capital stock is KC.

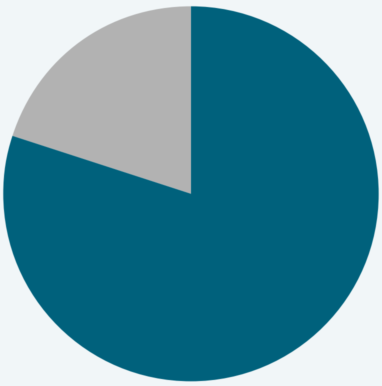
We calculated both 2050 scenarios, business as usual and net zero, using a Cobb-Douglas production framework. The KD/KC ratio remains constant in the business-as-usual scenario, while KD drops to zero in the net-zero scenario. Practically, it is highly likely that some greenhouse-gas-emitting capital will remain in a net-zero world. In order to accommodate this and still achieve net zero by 2050, it is essential to offset the ongoing emissions with emission-extracting technology such as carbon capture and storage. For simplicity, we include any emission-generating KD from which emissions are offset as KC.

Using this modelling framework, there are two ways of estimating the total green investment required between now and 2050.

FIRST METHOD

Our model indicates that $540 trillion of total investment (new and replacement) will be needed between now and 2050 in the net zero scenario. If we assume that the current 80-20 split holds, but that the 20 is invested in clean assets instead of "dirty" assets, this part of the investment amounts to $108 trillion. We can call this new type of investment 'truly green' investment and we essentially create a new variable: KG (green capital). This is the capital (renewable power plants, electric cars, etc.) that replaces the current KD capital stock in the net-zero world.

ESTIMATED BREAKDOWN OF GLOBAL CAPITAL STOCK 2020



Source: BNYM / Fathom Consulting. Accessed as of September 2022.

We also calculate that $18 trillion of assets will be 'stranded' (see step 6 below). Adding this to our estimate generates a total of around $125 trillion of green investment required between now and 2050.

SECOND METHOD

We focus on capital stocks rather than on investment flows. We apply the 80-20 split to the current capital stock and assume all emissions are generated by the KD ("dirty" capital) stock. We then calculate the carbon intensity of KD by dividing total current emissions by the estimate of the KD stock today (yielding emissions per dollar of KD). We assume that carbon intensity remains unchanged out to 2050 and calculate the KD stock in 2050 under business as usual by simply reversing the calculation – dividing 2050 projected emissions by carbon intensity. The clean capital stock under business as usual in 2050 is given by the total capital stock minus the "dirty" capital stock.

In the business-as-usual projection, the "dirty" capital stock increases from around $71 trillion today to $111 trillion in 2050, but to meet climate targets it must fall to zero. Therefore, a rise of $40 trillion under business as usual becomes a fall of $71 trillion in the net-zero scenario. Once again, the majority of that fall can be achieved through replacement; we estimate the replacement investment to be around $53 trillion. Since gross investment in dirty assets between now and 2050 under business as usual is $93 trillion ($40 trillion net new plus $53 trillion replacement), this is also our second estimate for the gross 'truly green' investment required to reduce the "dirty" capital stock to zero by 2050, without materially affecting the size of the overall capital stock. When we subtract the $53 trillion of depreciated dirty assets from the $71 trillion of dirty 'disinvestment' required, we get an estimate of $18 trillion of stranded assets that will need to be scrapped. This is identical to the estimate in the first approach (see step 6 for further detail).

The merits of the first approach are that it distinguishes between things like IT equipment and structures as KC, although they are different to the truly 'green' investment required for decarbonisation. Green investment, by contrast, makes a distinction between these two types of capital. The drawback, however, is that the model outputs implicitly assume that the 80:20 split will hold, and this is arbitrary.

The merit of the second approach is that it assesses the outcomes directly under the two scenarios, without imposing the 80-20 investment split and without implicitly assuming KG and KD are perfect substitutes. The drawback is that the estimates are very sensitive to small changes in assumptions about carbon intensity amongst other things, occasionally leading to nonsensical results (such as negative scrapping).

Fathom prefers the first approach, while BNYM favours the second. We explore how the different modelling approaches play out in Appendix II. Ultimately their findings are quite similar in range, despite the different methodology.

The reality is that there is no right approach; nobody can predict the total investment numbers with certainty. This is for the reasons outlined – namely, the uncertainties relating to today's capital stock, the future K/Y ratio, depreciation rates, economic growth, the KC/KD ratio, the pathway taken by technological change and the compatibility of future green technologies with the existing capital stock. The two interpretations offered here are helpful indicators of the range of uncertainty implicit in any estimates of this kind.

One thing is certain, however: to incentivise the switch from KD to green capital (KG) capital the price of KD will have to rise relative to KG. This could occur naturally through technological means (the price of key renewable technology has already been falling for some time), or through government interventions that mandate it (for instance, a carbon tax or regulatory intervention that raises the shadow price of KD). The most likely scenario is a combination of the two. In extremis, in a world in which "dirty" capital has been banned, its relative price will end up being infinite.

If KD becomes much more expensive, this can have implications for the relative stock prices of the two types of capital. In many economic models, new capital is costly to install. Firms must balance the benefits of new investment against those installation costs. This calculation is summarised in a variable known as 'Tobin's q', which is the ratio of the economic benefit of an additional unit of investment to the benefit of an additional unit of capital.

In a world where the relative q of KG to KD is falling, but that rate of decline is fixed by technology and financial factors, many models predict that relative q should 'jump' immediately before starting to fall again as the clean share of capital starts to rise. In other words, we should see a relatively short-lived 'boom' in clean capital stock prices, followed by a much longer period of relative decline.

STEP SIX

Estimating the dirty share (20%) of non-depreciated capital in 2050 ($18 trillion)

This is our estimate of 'stranded' capital that must be scrapped before the end of its useful economic life, one of the big costs of tackling climate change. In an orderly transition, most existing capital would have fully depreciated by 2050, including "dirty" capital. The "dirty" capital could be replaced by clean (or green) capital once it has depreciated. This is starting to happen as clean/green investment spending is being ramped up (although, as mentioned, this is still lower than the levels required, according to analysis by the IEA and Bloomberg NEF). In a best-case scenario, a capital stock of $18 trillion will need to be scrapped and/or retrofitted at a cost.

The estimate for stranded capital is the same in both approaches. In the first approach, it is simply 20% of the non-depreciated total capital stock in 2050. In the second, it is the section of the initial "dirty" capital stock that has not fully depreciated by 2050. These turn out to be the same value.

The final value of the stranded capital stock that may need to be scrapped may, however, be higher. It will be difficult, or even impractical in some circumstances, to ensure that "dirty" capital is replaced by clean or green capital in a smooth and orderly manner. Another consideration is that simultaneously operating two types of capital, clean/green and dirty (e.g., a fleet of vehicles where some run on diesel and others are electric), will incur extra costs relative to managing a single, homogeneous set. A third concern is that if the capital of companies operating in easy-to-abate sectors depreciates more slowly than they need to decarbonise, then different sectors will need to decarbonise at different speeds. This means that additional write-offs are likely. Utilities are a prime example, and this has already happened in some places, for example in California, where in 2019, General Electric decided to demolish a large power plant after only one-third of its useful life – stating that it was no longer economically viable to run.[19]

Finally, coal-fired power plants and internal combustion engine vehicles and other "dirty" capital stock are still being built, meaning that KD is still growing – or at least it is not gradually declining, as it ought if the Paris goal is to be met. While much of the heavy lifting needs to be done by the private sector, governments have a role to play to help redirect more capital and investment away from "dirty" capital to clean capital – they can do this through a combination of carrot (subsidies, tax breaks and supportive regulation) and stick (taxes and punitive regulations).

[19] https://www.reuters.com/article/us-ge-power-idUSKCN1TM2MV.

Appendix II: Sensitivity analysis

Given the inherent uncertainties of many of the inputs into our model, we have run a sensitivity analysis to see how the value of green investment and stranded assets vary under differing scenarios. Specifically, we run the estimates using different economic growth rates, K/Y ratio and depreciation rates, and varying the estimate of the share of the overall current capital stock that is clean (KC share of total K in the charts below). And we present the results using each of the two methods for interpreting the model outputs described in step 5 of Appendix I.

The depreciation rate and KC share of total K will vary depending on the source used to estimate capital stock. In our central case, where we obtain capital stock estimates from the Penn World Table, the K/Y ratio is 4.1 with a depreciation rate of 4.5% and a KC to total K ratio of 80%. The capital stock estimate implied by Fathom's global macro model is lower, resulting in a K/Y ratio of 2.7. The depreciation rate is 5.5% and we estimate that KC share of total K is 75%. The difference in the two sources can be explained by structures, which are larger in the Penn World Table.

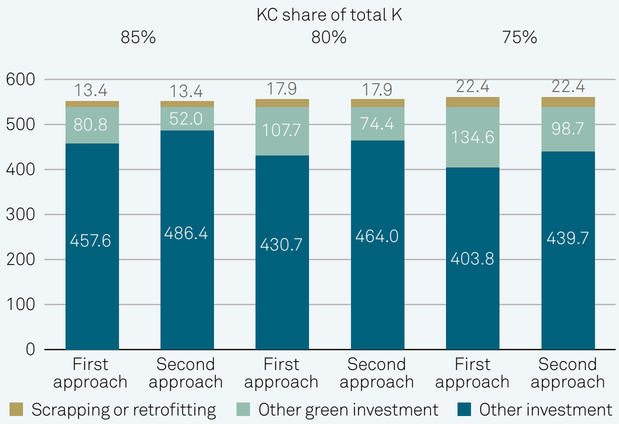
In the charts below, each bar represents cumulative investment between now and 2050 in the net-zero scenario. The type of investment is broken down by colour: the dark blue area indicates clean investment (but not truly green); the light blue area is investment that replaces stranded assets (this value is also the value of stranded assets in this scenario); the green area is green investment that replaces dirty assets once they have reached the end of their useful life or green investment that supports future economic growth. Total green investment is the sum of the values in the green and light blue areas.

The figures in the first three charts all use a K/Y ratio of 4.1 and a depreciation rate of 4.5% (consistent with the Penn World Table as a data source for capital stock). The next three charts use a K/Y ratio of 2.7 and a depreciation rate of 5.5% (Fathom's macro model as capital stock source). Each chart contains six bars. Three of the bars show the model implied outputs using the first interpretation, and the other three show the outputs using the second interpretation (see above and step 5 of Appendix I).

The other difference in the charts relates to the GDP growth rate assumed in the net-zero scenario. As discussed in Appendix I our central scenario assumes that global GDP is 2.8% lower in the net-zero scenario by 2050 relative to the business-as-usual scenario. This growth differential affects the global green investment and stranded asset estimates. The second chart assumes no growth differential between business as usual and net zero 2050, while the third chart assumes faster GDP growth between now and 2050 in the net-zero scenario than in business as usual.

INVESTMENT BREAKDOWN NET ZERO SCENARIO, GDP HEADWIND*

USD trillions, using K/Y ratio of 4.1 and 4.5% depreciation rate

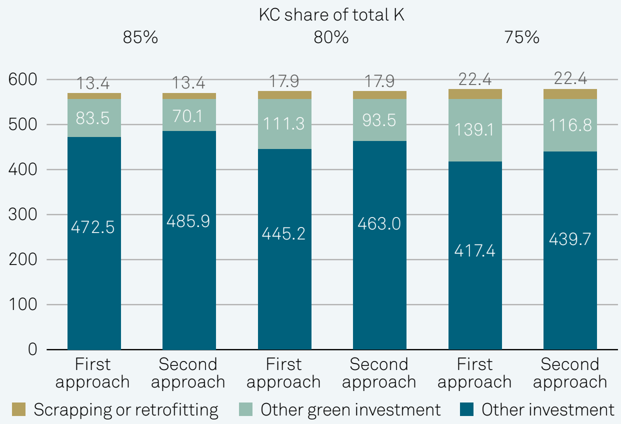


* 2050 global GDP is 2.8% smaller in the net zero scenario compared to the business-as-usual scenario.

Source: BNYM / Fathom Consulting. Date as of September 2022.

INVESTMENT BREAKDOWN NET ZERO SCENARIO, GDP NEUTRAL*

USD trillions, using K/Y ratio of 4.1 and 4.5% depreciation rate

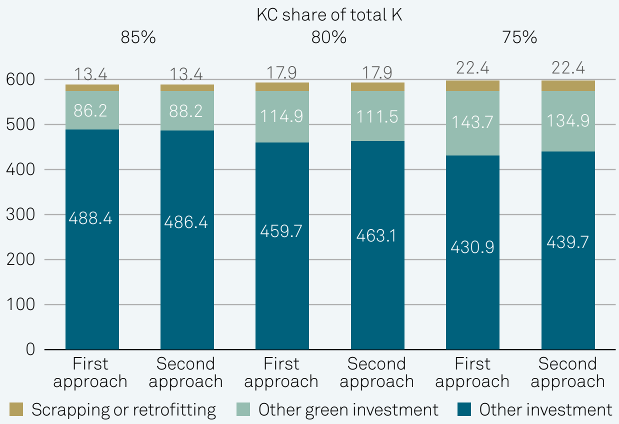


* 2050 global GDP is the same in the net zero and business-as-usual scenario scenarios.

Source: BNYM / Fathom Consulting. Date as of September 2022.

INVESTMENT BREAKDOWN NET ZERO SCENARIO, GDP BOOST*

USD trillions, using K/Y ratio of 4.1 and 4.5% depreciation rate

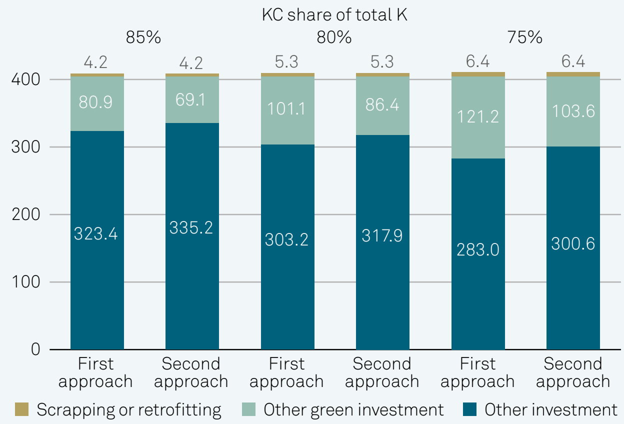


* 2050 global GDP is 2.8% smaller in the net zero scenario compared to the business-as-usual scenario.

Source: BNYM / Fathom Consulting. Date as of September 2022.

INVESTMENT BREAKDOWN NET ZERO SCENARIO, GDP NEUTRAL*

USD trillions, using K/Y ratio of 2.7 and 5.5% depreciation rate

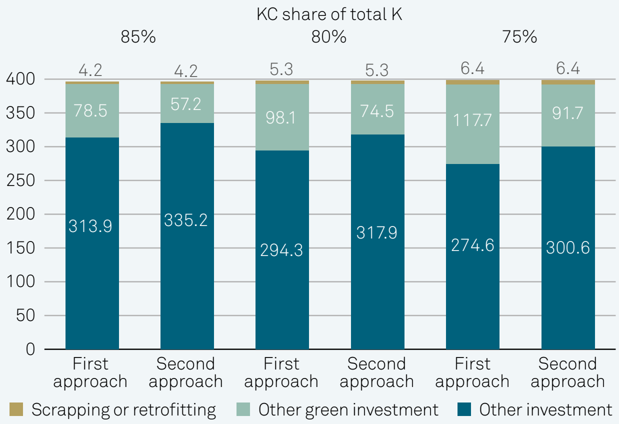


* 2050 global GDP is the same in the net zero and business-as-usual scenario scenarios.

Source: BNYM / Fathom Consulting. Date as of September 2022.

INVESTMENT BREAKDOWN NET ZERO SCENARIO, GDP HEADWIND*

USD trillions, using K/Y ratio of 2.7 and 5.5% depreciation rate

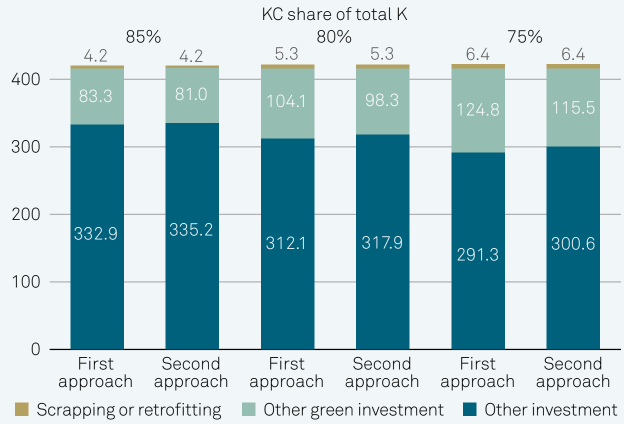


* 2050 global GDP is 2.8% smaller in the net zero scenario compared to the business-as-usual scenario.

Source: BNYM / Fathom Consulting. Date as of September 2022.

INVESTMENT BREAKDOWN NET ZERO SCENARIO, GDP BOOST*

USD trillions, using K/Y ratio of 2.7 and 5.5% depreciation rate



* 2050 global GDP is 2.8% smaller in the net zero scenario compared to the business-as-usual scenario.

Source: BNYM / Fathom Consulting. Date as of September 2022.

Some key takeaways from this sensitivity analysis:

- Assumptions about the KC to total K ratio have a big impact on green investment, but little impact on economy-wide investment.
- The choice of capital stock (and consequently the K/Y ratio, depreciation rates and KC to total K ratios) have a big impact on the value of stranded assets.
- All investment figures (economy-wide, green and stranded assets) are lower when Fathom's global macro model is used to infer global capital stock, compared with figures published in the Penn World Table.
- The value of stranded assets is not sensitive to GDP growth rates or to the different methods of model interpretation (see step 5 from Appendix I).
- Investment, both economy-wide and green, is however more sensitive to GDP forecasts in the second approach than in the first (see step 5 of Appendix I for more on both approaches).
- Green investment is much more sensitive to GDP growth rates in the second approach than the first.

With many model parameters to adjust, a wide range of estimates are plausible:

- Stranded assets: $4.2 trillion to $22.4 trillion.
- Green investment: $61.4 trillion to $166.1 trillion.
- Economy-wide investment: $396.6 trillion to $597.0 trillion.

These are all cumulative figures between now and 2050 in the net-zero scenario.

Appendix III:
Data and methodology for estimating country-specific investment requirements

OVERVIEW

We use a range of country-specific data — including capital stock and economic growth forecasts and more — to estimate the investment needs by country. The data have then been modelled using the same approach taken to estimate overall global green investment needs, once again considering both interpretation methods (see step 5 of Appendix I and method 1 and 2 below). The results vary between the two approaches, but the share of total global investment attributable to each country is similar. Unless otherwise stated, in the results that follow we take the average of both approaches.

We create country-specific KC to total K ratios by considering each country's share of fossil fuel used in electricity generation and the CO_2 intensity of its GDP (more fossil fuels and higher CO_2 intensity of GDP suggest that country has above-average KD, hence a lower KC to total K ratio). This method will not yield precise estimates by country, but it will better reflect the composition of an economy and its capital stock than using the global average. We use this ratio to estimate the amount of green investment required to replace existing capital stock in the net-zero scenario in each country.

DATA

We use the Penn World Tables for country-specific capital stock estimates. These data are in local currency, current prices and adjusted for purchasing power differentials – we convert them into nominal US dollars using PPP multipliers from the IMF. We create K/Y ratios using figures from the IMF for GDP in current US dollars. We also use the country-specific depreciation rates provided by the Penn World Tables. The $100 trillion investment figure is in today's prices and assumes annual real GDP growth of 1.9%. For country-specific growth figures we use IMF forecasts for the next five years. We assume that growth continues at that rate until 2050 but adjust so that countries that have higher GDP forecasts than the US and a lower GDP per capita converge to US rates of growth by 2050.

The IMF projects US real GDP growth of 1.7% in 2027, which seems like a reasonable estimate of trend growth. We take Fathom's forecast for growth in China of 4.2%, 3.4% and 2.9% in 2023, 2024 and 2025 respectively and assume that it drops to 2.0% by 2028 and continues at that rate each year until 2050 (we assume no further convergence to the US over this period).

Of course, these numbers are subject to a lot of uncertainty and there are many ways in which long-term growth rates can be forecast, which is itself a huge study with a detailed literature. A full assessment, or one based on more detailed country forecasts, is beyond the scope of this note. Finally, we obtain country-specific CO_2 emission and electricity generation data from the World Bank.

METHOD 1

Step 1: estimate growth using the method described above (and subtracting a small amount each year to reflect the 2.8% overall transition cost).[20]

Step 2: calculate a 2050 estimate of total K, assuming it grows by the same amount as GDP (i.e., the K/Y remains constant).

Step 3: calculate the change in total K between 2020 and 2050.

Step 4: calculate the value of 2020's capital stock that is undepreciated in 2050 (using country-specific depreciation rates).

Step 5: calculate the value of green investment to replace 2020 capital stock as it depreciates.

Step 6: calculate the value of green investment to replace undepreciated "dirty" capital stock in 2050.

Step 7: calculate the value of green investment to support new economic growth between now and 2050.

Step 8: sum up values from steps 5-8, and calculate each country's investment as a share of the total.

METHOD 2

Step 1-4: same as above.

Step 5: create a business-as-usual scenario and run steps 1-4 on this scenario.

Step 6: calculate KC in 2050 in the business-as-usual and net-zero scenarios.

Step 7: calculate the difference between KC in the net-zero scenario and the business-as-usual scenario in 2050, to infer the total green investment in the net-zero scenario.

Step 8: calculate each country's investment as a share of the total.

[20] For simplicity we use the figures from William Nordhaus 'The Climate casino' and assume business-as-usual costs from physical climate change are all borne in the second half of the 21st century.

Appendix IV:
Data and methodology for estimating sector-specific investment requirements

We use a different method to estimate the share of required investment by sector to the way we estimate global green investment needs or green investment needs by country. This is because of major differences in the type and availability of corporate financial data compared with country-aggregated economic and capital stock data.

There is a long history of corporate financial data, and we think the simplest method is to project capital expenditure growth for each sector, taking the average capital expenditure figures between 2018 and 2020 and applying 2% real growth each year until 2050, the same rate of growth we assume for global GDP elsewhere.[21] To estimate the share of this investment that should be green we multiply the this figure by the current share of fixed assets that dirty. This is because those assets will need replacing with green assets in a net zero scenario and is consistent with our earlier assumption, detailed in Appendix I, that "dirty" capital is replaced with green capital once the "dirty" capital has reached the end of its useful life and fully depreciated, provided that happens before the net zero target date for that sector.

Admittedly, this could underestimate growth in some sectors, such as basic materials, which may grow faster than global GDP due to the demand that the transition is likely to create for raw materials, and the associated increase in mining activity. Of course, some sectors are likely to expand more quickly than others but estimating sector-specific growth rates would subject this analysis to more layers of complexity and uncertainty. We decided against making such sector-specific judgements.

Since we have sector-specific estimates of clean capital and "dirty" capital, and our net-zero scenario assumes that all new investment is green (as explained in Appendix I), by extension the share of new, green investment should mirror the ratio of KC to total K.

We also recognise that some of the existing capital stock won't have naturally depreciated by the time that the sector ought to have decarbonised (as per Fathom's transition pathways);[22] in these cases, additional spending, over and above the natural course of business, will be required to replace capital stock that needs scrapping or retrofitting. We therefore estimate residual assets using depreciation rates for property, plant and equipment in each sector, and add the spending on these assets that will need to take place over and above the spending in the regular course of business described above.

[21] In reality the transition will cause varying sales and investment growth by sector, but it is beyond the scope of this project to quantify these variations. For example, sales and investment by the materials sector may increase by more than other sectors, due to the mineral intensity of the transition. All else equal, that may imply a higher share of green investment spending in this sector than our modelled numbers suggest.

[22] We could also assume that each sector needs to decarbonise at the same speed and by 2050 (a less plausible outcome), but the results do not vary greatly by sector.

Appendix V:
Measuring sector transition risk

The net-zero transition will create a variety of risks for companies, some in the form of economic costs. We have created a unique methodology to quantify transition risk, which is comparable across sectors (and could be comparable over time, going forward). We have identified three broad categories of transition risk that we are able to quantify using publicly available data. Those risks are: carbon taxes; stranded assets and transition speed. The data we use includes financial metrics and greenhouse gas emissions. We create nine risk metrics using these data. The results are contained in Table 6 on page 15.

For this analysis we have sorted all companies listed on the S&P 500 into 24 sectors using the Global Industry Classification System (GICS). The GICS system has four levels of classification (level one being the broadest, four being the most granular). Weuse level one sector names when we consider the constituents of this sector to have similar emission profiles. Level two, three and four are used when the emission profiles of their constituents are significantly different from each other making more granular groupings helpful.

For example, the GICS 'Industrial' sector includes 'Capital Goods', 'Commercial & Professional Services' and 'Transportation'. Clearly, the emissions profile of companies in the Transportation sector are very different to those in Commercial & Professional Services. And even within Transportation, Airlines will have a very different emissions profile to firms in the Road & Rail sector. Hence, in these cases we use more granular sector classifications. Fathom has also produced decarbonisation pathways for these 24 sectors, which have been used in this risk analysis. (Appendix VI).

We have produced sector-specific data and metrics using the median value of companies in each sector, using publicly reported financial and greenhouse gas emissions data for 2018, 2019 and 2020. Admittedly, there are significant within-sector differences in these variables and some of the estimates are subject to uncertainty, meaning that the scores should be seen as a guide to identify risks at a high level – company-specific analysis is needed to identify risks at a more granular level.[23]

CARBON TAX RISK 1

This metric assesses the potential impact that a hypothetical $50 per tonne of CO_2 or CO_2 equivalent tax would have on a company's earnings over and above any taxes currently levied. We simulate the hypothetical impact on each company's earnings before interest, tax, depreciation and amortisation (EBITDA) assuming that such a tax were fully paid by the company on its scope 1 emissions.

CARBON TAX RISK 2

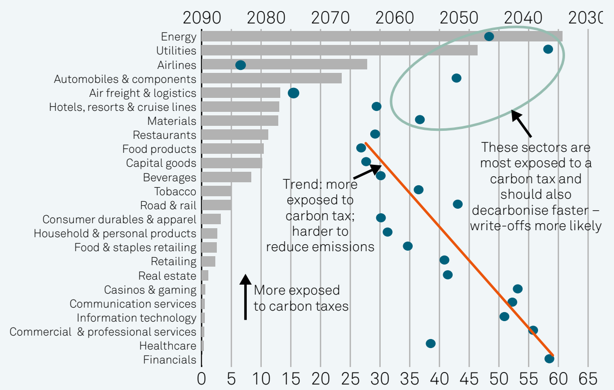
This metric assesses the same thing as the metric above, but on a wider range of emissions (i.e. assuming that the company pays 100% of the tax on its scope 1 emissions and half of the tax on its scope 2 and 3 emissions).[24] In reality, these figures will probably be affected by availability of substitues and the price elasticity of demand, which will vary by industry. Therefore, the results should not be seen as a literal guide as to what the effect on EBITDA would be. However, applying the same simulation to the earnings in each industry provides a useful guide for ranking industries based on this risk.

CARBON TAX AND TRANSITION SPEED RISK

This metric considers carbon tax risks 1 & 2 as well as the date at which the sector ought to decarbonise, based on Fathom's transition pathways (for more on the pathways, their use and the methodology underpinning their construction, see Appendix VI). Companies that need to decarbonise quicker face more risks. Companies that are more exposed to taxes face more risks. These is reflected in the chart below. There is a trend in the case of most sectors (reflected by the light blue line): those more exposed to carbon taxes will have longer to decarbonise. But some sectors, like energy and utilities, face a double whammy: they need to decarbonise relatively quickly and are more exposed to carbon taxes.

CARBON TAX EFFECT AND IMPLIED NET ZERO DATE

Implied net zero date*



Negative EBITDA effect of hypothetical $50 carbon tax** (bottom axis)
Implied net zero date* (top axis)

* As per Fathom's transition pathways, which allocate the global carbon budget in a manner consistent with achieving Paris climate goal.

** Assuming tax is fully absorbed by company on its scope 1 emissions and half absorbed on scope 2 and 3 emissions.

Source: Refinitiv Eikon / BNYM / Fathom Consulting. Date as of September 2022.

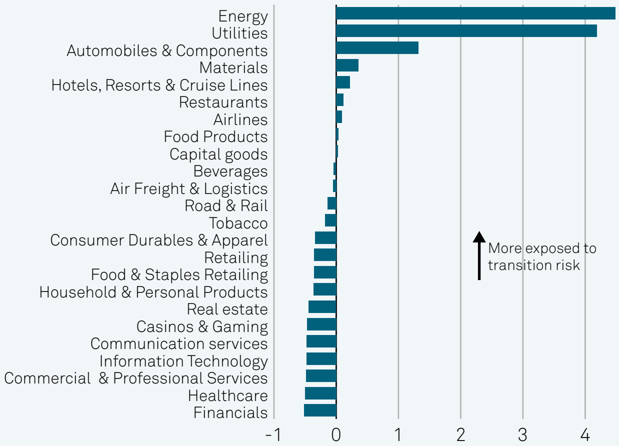
[23] We have estimated the ratio of KC to total K of a typical company in each of sector using a combination of sources: the published annual accounts of firms from these sectors, industry reports and other sources. We also use this information to estimate the weighted average depreciation rate of assets on the balance sheet. (We have cross-referenced our depreciation rate estimates using this method with reported depreciation rates and the results are similar, which gives us confidence in our approach for estimating the KC to total K ratio.) These figures can be re-estimated in due course. While we use subjective judgment in some cases, this is sector-specific subjective judgement and does not substitute for company-specific assessments. Company-specific risk may be very different to average sector-specific risk. And while this may be true for the KC to total K estimates, it is also true for many other financial metrics.

[24] i.e., those emissions that a company is directly and indirectly responsible for creating, which includes those created upstream, by suppliers, and downstream, by the end users

Multiplying the carbon tax sensitivity by the date by which that sector ought to decarbonise gives a number which can be used to rank sectors based on these two risk factors. This is reflected in the chart below, in z-score terms, where a higher number indicates higher transition risk.

CARBON TAX TO POTENTIAL EMISSION REDUCTION RATIO

Z score*



* Created using the product of PER scores and earnings sensitivity to hypothetical carbon taxes.

Note: A Z score is the distance between a raw score and the mean of all scores in that series, expressed in standard deviations.

Source: Refinitiv Eikon / Fathom Consulting. Date as of September 2022.

TRANSITION SPEED RISK 1

The second of the transition speed-related metrics is created by comparing the date at which sectors ought to have reached net zero to the date at which the assets they currently own are likely to have depreciated fully. All else equal, companies and sectors with lower depreciation rates face a greater risk of assets becoming stranded. These risks are largest in the sectors that need to decarbonise quickly, such as utilities. The ratio between these two variables is one of the nine risk metrics.

TRANSITION SPEED RISK 2

The risk described in the metric above will be amplified when a sector's net-zero date is sooner than the date at which all current assets will have depreciated to zero. In other words, transition risks will be higher when a sector needs to decarbonise quicker than its assets depreciate. This metric measures this risk using a binary 'yes/no' score. Only two sectors fall into this category: real estate and utilities. These sectors have long-lived assets and need to decarbonise relatively quickly. These risks are already materialising in the utilities sector.[25]

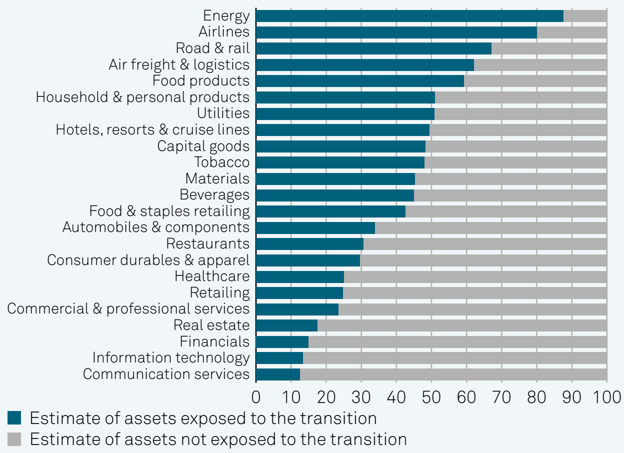
The next three metrics incorporate the share of assets that are 'dirty' and likely to have a limited useful life in the net zero transition.

STRANDED ASSET RISK 1

This metric is a score that is directly proportional to the share of assets we estimate to be 'dirty' and have no use in a net zero world of a typical firm in a sector (see first chart below). A relatively high share of the assets of companies in the energy and transportation sectors fall into this category.[26]

S&P 500 PHYSICAL ASSET BREAKDOWN

% of total



Source: Refinitiv Eikon / BNYM / Fathom Consulting. Date as of September 2022.

[25] https://www.reuters.com/article/us-ge-power-idUSKCN1TM2MV

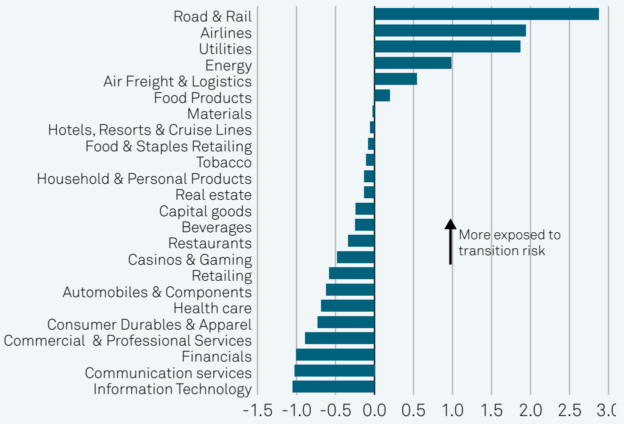
[26] Note: these estimates are best guesses based on available information and current technologies; they are inherently subject to uncertainty since we do not know for sure how technology will evolve and whether existing infrastructure will be compatible with the future technologies that are adopted – whether, for example, hydrogen gets widely adopted, giving a new purpose to existing gas power generation plants and pipelines, or how much it will cost to retrofit them. The framework we use for this estimation is detailed earlier in the paper.

STRANDED ASSET RISK 2

The second of these metrics is created by dividing the share of dirty assets by the depreciation rate. Z-scores of this ratio are presented below. The road and rail sector is riskiest on this metric, since their assets tend to be long-lived, and a relatively high share are estimated to be dirty and will need replacing as the sector decarbonises.

STRANDED ASSET RISK 2

Z score*



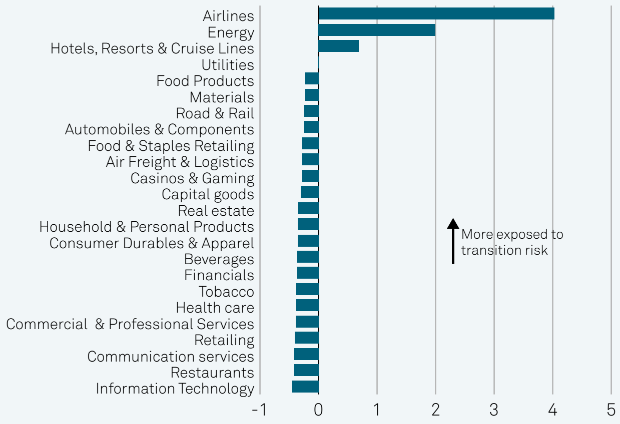
* Created by dividing share of assets exposed to the transition by average asset depreciation rate.

Note: A Z score is the distance between a raw score and the mean of all scores in that series, expressed in standard deviations.

Source: Refinitiv Eikon / Fathom Consulting. Date as of September 2022.

STRANDED ASSET RISK 3

Z score*



* Created by dividing share of assets exposed to the transition by average asset efficiency.

Note: A Z score is the distance between a raw score and the mean of all scores in that series, expressed in standard deviations.

Source: Refinitiv Eikon / Fathom Consulting. Date as of September 2022.

STRANDED ASSET RISK 3

This metric is derived by dividing the share of 'dirty' assets by two measures of asset efficiency.[27] Different firms and industries have different levels of asset efficiency – some are asset-intensive and require a large amount of assets to generate returns (they have a low marginal product of capital). Firms that are more reliant on assets to generate profits and where a higher share of those assets will need replacing or retrofitting in a net-zero world are more at risk. Airlines, energy and the hotels, resorts & cruise lines sectors are all asset-intensive industries, where a relatively high share of those assets are exposed to the transition and therefore score top on this metric. Service-based sectors such as communications, restaurants and information technology are least risky on this basis.

DISCLOSURE RISK

The final metric relates to the share of companies in each sector that disclose emissions data (we consider scopes 1, 2 and 3). Investors may be unable to properly assess climate transition exposure risk if this information is not made available, and being unable to assess this risk is itself a source of risk. In addition, it is possible that companies that do not report this information could either be hiding some 'bad' news, unprepared to deal with transition-related issues, or both.

[27] The average of the reported return on assets ratio and our calculation of the EBITDA to PPE ratio (i.e., earnings before interest, tax, depreciation and amortisation divided by property plant and equipment) are taken. The former is a more conventional and well-known financial metric. We incorporated the second since EBITDA is arguably a better measure of underlying earnings and PPE a more accurate reflection of those assets that are long-lived and more vulnerable to becoming stranded.

Appendix VI:
Fathom's transition pathways

TRANSITION PATHWAYS – WHAT ARE THEY?

For the world to achieve the Paris climate goal it needs a plan. That plan is often simplified as getting annual global greenhouse gas emissions to net zero by mid-century.[28] But not all forms of economic activity, or industrial sectors, can decarbonise at the same speed and at the same cost. It is easier for some to do so where the technology exists and is cheap (such as utilities), than for others where this isn't the case (such as airlines).

Requiring all sectors to decarbonise at the same speed would cause economic damage and be inefficient. Because of this, and recognising sectoral differences, some organisations have started creating sector-specific decarbonisation pathways. These are guides which state the speed at which companies in any given sector should decarbonise. Often, the pathways are created in a way that is claimed to be 'Paris-consistent'.

THE PATHWAYS MARKET

The most well-known of these pathways are those of the Science-Based Targets Initiative (SBTi) and Transition Pathways Initiative (TPI), but other private sector actors have also started creating sector-specific pathways. Currently, there is no agreed-on or right way of creating these pathways, and the specifics and methodologies vary from organisation to organisation. Many of the principles underpinning them are the same and relate to the difficulty and economic cost of decarbonising each sector (typically a function of the technology and cost).

There are some drawbacks with many of these pathways, however. First, they do not cover all sectors of the economy. And second, they tend to focus on sector-specific emission intensity metrics (for example, emissions per passenger kilometre flown) rather than on gross or net emissions. This is a problem because it means that comparability across sectors is not possible, and users cannot be confident that the global carbon budget will be met even if all companies in all sectors follow them. Moreover, for completeness and confidence in the Paris alignment, pathways should be economy wide.

FATHOM'S PATHWAYS

Fathom Consulting's transition pathways have been created using a top-down macro approach, which aims to overcome any problems with completeness and comparability. They cover 24 sectors into which all companies from all sectors can be classified using the GICS sector classification system. The global carbon budget is allocated among these 24 sectors based on a quantitative scoring methodology, which considers the difficulty for each sector of decarbonising, coupled with its emissions. This top-down approach is different to those of other providers. As well as addressing the completeness issue and comparability across sectors (by avoiding sector-specific metrics), they are also economically efficient from a macro perspective, and they consider the entire global carbon budget. As an additional feature, the shape of the pathways can change based on certain assumptions, including different temperature targets (and the respective carbon budgets consistent with those). More information about Fathom's pathways and their construction can be obtained by contacting Fathom directly.

WHY INVESTORS CARE ABOUT PATHWAYS

Transition pathways have several uses for investors. With ESG, climate and impact investing all gaining more prominence in recent years, it can be very useful to have a pathway against which to compare corporate decarbonisation plans and historical trends in emissions. Investors can use this reference to engage with and question the companies to which they seek to provide capital.

One of the key findings in this report is that the sectors that pollute most and are most exposed to transition risks are also the ones that have the biggest role to play in the solutions to rising emissions, and need most capital to invest. Rather than shun these sectors, many ESG and impact investors will prefer to pick the companies that have the most credible decarbonisation plans. Pathways are a very important tool against which to measure those plans, and whether those plans are Paris-aligned.

There are other uses too: various metrics of greenness or transition risk can be created using the pathways; assessing the degree to which investments, from individual companies to portfolios as a whole, are aligned (or not) with the Paris climate target. They can be used by corporates themselves to set strategies or policymakers and regulators. The pathways have been used in this project to create three of the nine metrics used to assess sector transition risk. For more details see section 3 and Appendix V.

[28] The shape of the pathway to zero is important since its trajectory will determine the overall amount of emissions that go into the atmosphere and the amount of warming that is likely as a result. While achieving net zero greenhouse gas emissions by 2050 is generally considered to be the way to do so, in actual fact, the way in which the emissions get reduced, and the path of reduction, is more important than the final date. That is because it is the overall stock of greenhouse gas emissions in the atmosphere that causes global warming, not the flow (or lack of) in any one year. In its latest benchmark assessment, the IPCC has told us by how much the stock of emissions can increase at different levels of warming. This is called the carbon budget. It is a complex area; suffice it to say, allocating this carbon budget in the most efficient way possible is a hugely important exercise. This question sits at the heart of Fathom's sector transition pathways.

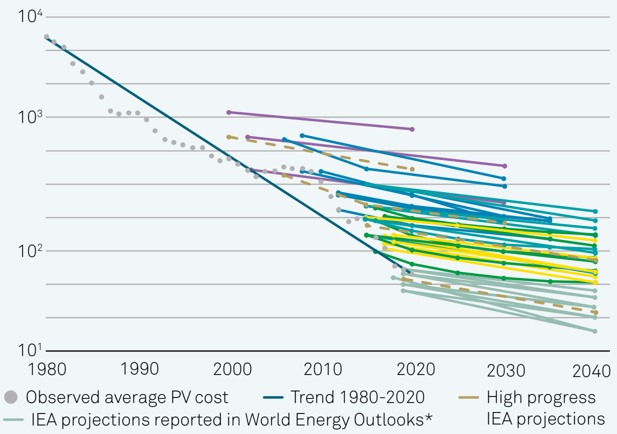
Appendix VII:
The cost of preventing climate change – modelling difficulties

Forecasting the economic consequences of climate change – the so-called physical risks – is extremely challenging. Integrated assessment models (IAMs) are a well-known models used to do this. These models incorporate aspects from different fields of study, including economics and climate science. They are, typically, computable general equilibrium models built using a neoclassical Ramsey-style framework. Although they face criticisms (including the underestimation of tipping points and catastrophic outcomes), IAMs are considered by some to be the best of a bad bunch for what is a terribly complex modelling problem. There is no consensus on a better approach.

Econometric climate models fail too. Indeed, any model training GDP on historical temperature data is likely to fail as a predictor of the economic outcomes under more extreme climate scenarios. That is due to the complexities, non-linearities and tipping points present in the climate system, on which historic data can cast little light since the global temperature has never in recorded economic history increased to anything like the degree anticipated in a business-as-usual scenario. A new class of models which use geolocated data and detailed climate projections to quantify economic risks under different climate scenarios offers promise but are still largely unproven.

HISTORICAL SOLAR PV COST FORECASTS

Levelised cost of electricity, USD (2020) per megawatt hour



* Colours from purple through gold denote the base year of projection.

Source: INET / Fathom Consulting. Accessed as of September 2022.

Another issue with most mainstream climate economic models is their failure to accurately predict the costs of preventing climate change (the so-called transition risks). Typically, carbon taxes are the mechanism by which greenhouse gas emissions are reduced in these models, and the way in which transition costs are calculated. But for decarbonisation to happen in these models, taxes often need rise above thousands of dollars per tonne.

Not only is this implausible politically, but it seemingly overstates transition costs, especially if green technologies continue to fall in price faster than expected — as they have done in the case of solar panels (see chart below). By extension, the estimates of transition costs keep declining as the costs of replacing high-emission activities fall faster than expected. With more resources being dedicated to climate solutions, including to research and development (R&D) and to scaling up green technologies, transition costs are likely to be lower still.

Of course, there is no guarantee that costs will keep falling. And it has not yet been proven whether some new green technologies (such as direct air carbon capture and storage) can be deployed at scale, meaning that costly carbon taxes may be the only way to reduce emissions to zero.

But some of the literature on marginal abatement cost curves (MACCs) suggests that the hardest-to-abate emissions could in fact be abated at a much lower cost than many mainstream climate models suggest. They also show that some emissions could be decarbonised at a net negative cost (i.e., decarbonising would save money).[29] The IEA, for example, estimates that more than a third of emission reductions in emerging market and developing economies over the next decade would fall into this category.[30]

All this considered, there are huge uncertainties related to both the physical costs of climate change and the transition costs. To calculate the net cost of solving climate change, the costs of not solving the problem (physical costs) should be subtracted from the cost of solving it (transition costs). Because of the difficulties associated with modelling these costs, outlined above, we have not attempted to answer this question in this report.

[29] See page 3 Kesicki. Pg 55 of this report: https://www.mckinsey.com/business-functions/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost;

[30] https://www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies.

We have conducted a literature review on the figures that various well-known organisations have attributed to solving climate change. Below is a short summary:

The UK CCC estimates that the costs for the UK to reach net zero (i.e. the transition costs) would be less than 1% of GDP, down from 1-2% in 2015.[31] Meanwhile, a growing literature points to net economic benefits from a mid-century net zero transition, due to the investment boom that would be necessary to achieve it, and the savings that would be made from the declining cost of renewables and other green technologies and negative externalities avoided.

For example, the Institute for New Economic Thinking argue that net present savings would be positive at 'all reasonable' discount rates, and equal to $26 trillion at the median.[32] In other words, the transition would have net economic benefits. The IMF think that 'annual average global GDP' could be boosted by 0.7% between now and 2035 in a net-zero-by-2050 scenario, compared to current trends.[33]

The IEA expects the impact of the increase in clean energy investment alone would boost annual global GDP growth by 0.4% between now and 2030,[34] while the OECD expects GDP to be 2.8% higher on average across the G20 by 2050, and nearly 5% higher once the positive effects of avoiding climate damage are considered.[35]

While the potential transition benefits are becoming increasingly well recognised, even in optimistic scenarios they require large upfront outlays — making access to finance and cost of capital key considerations. For this study, we therefore use the figures of William Nordhaus in our central scenario (which show that GDP would be 2.8% smaller in 2050 in the net-zero scenario compared to business as usual). This may be considered somewhat conservative compared to the estimates of these other organisations; accordingly, in the sensitivity analysis in Appendix II we have simulated the results of our model under two different scenarios: no difference between size of the economy in 2050 and BAU and net zero; and a larger economy in net zero relative to BAU in 2050.

Glossary

Marshall Plan: An American initiative enacted in 1948 to provide foreign aid to Western Europe.

Net Zero: The balance between the amount of greenhouse gases produced and the amount removed from the atmosphere.

Green investment: Investing activities aligned with environmentally friendly business practices and the conservation of natural resources.

Green assets: Assets that have social, environmental and or economic values.

Stranded capital: Assets that have been subject to unanticipated or premature devaluations, write-downs or conversion to liabilities.

Stranded asset: Assets that have been subject to unanticipated or premature devaluations, write-downs or conversion to liabilities.

Green bonds: Green bonds or climate bonds are fixed income financial instruments that can generate positive climate or environmental benefits.

Dirty Capital: Capital, when operated, that is directly responsible for generating greenhouse gas emissions.

Clean Capital: Capital, when operated, that is not directly responsible for generating greenhouse gas emissions.

[31] 5th and 6th UK carbon budget.

[32] https://www.inet.ox.ac.uk/files/energy_transition_paper-INET-working-paper.pdf.

[33] G20 Note On Environmentally Sustainable Investment For The Recovery https://www.elibrary.imf.org/view/journals/007/2021/025/article-A001-en.xml.

[34] Net zero by 2050 https://www.iea.org/reports/net-zero-by-2050.

[35] G20 contribution to the 2020 agenda https://www.oecd.org/dev/OECD-UNDP-G20-SDG-Contribution-Report.pdf

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Since 2019, Fathom Consulting has provided bespoke macroeconomic modelling and scenario analysis for BNY Mellon IM's quarterly economic and investment outlook publication, Vantage Point.

Quarterly meetings are held to decide the key questions that will inform developments over the forecast horizon so that Fathom can conduct detailed scenario analysis that is theoretically founded, empirically driven and consistent with BNY Mellon IM's house views. This helps to inform stakeholders of the outlook for the economy and markets, as well as the risks.

Fathom also engages in other bespoke projects for BNY Mellon IM, such as the work and analysis involved in the production of this research. BNY Mellon IM hired Fathom Consulting to provide expertise on the economics of climate change and undertake certain elements of this project. The final output, presented in this report, reflects the efforts of both parties.
The modelling framework and report conclusions were developed in collaboration, while Fathom's proprietary climate data and tools were used to develop the sectoral risk framework presented in this report. Fathom Consulting is not affiliated with BNY Mellon.

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