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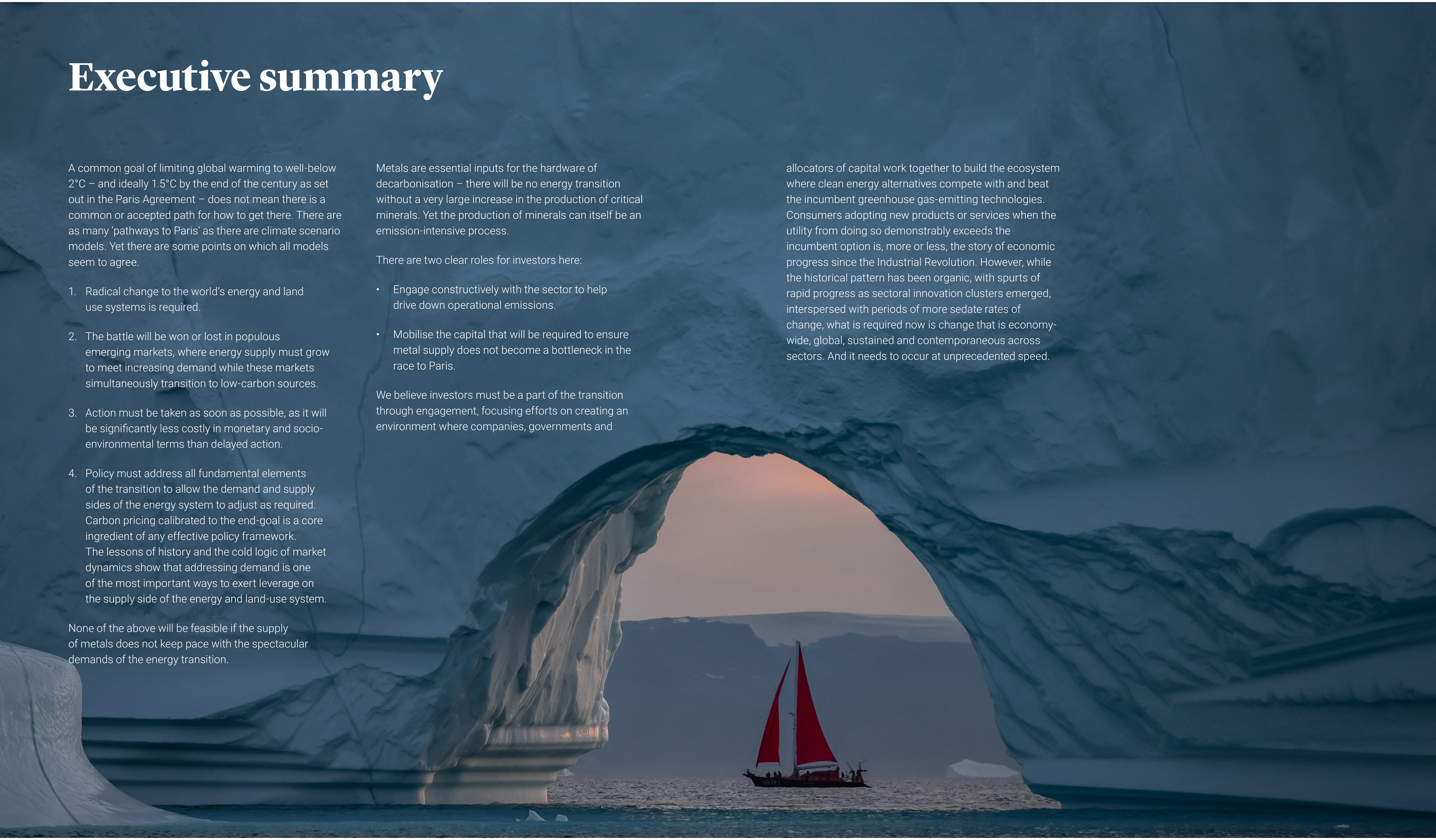
The energy transition dilemma

A joint research paper by LGIM and BHP

BHP LGIM

2022 | The energy transition dilemma



Executive summary

A common goal of limiting global warming to well-below 2°C – and ideally 1.5°C by the end of the century as set out in the Paris Agreement – does not mean there is a common or accepted path for how to get there. There are as many 'pathways to Paris' as there are climate scenario models. Yet there are some points on which all models seem to agree.

1. Radical change to the world's energy and land use systems is required.

2. The battle will be won or lost in populous emerging markets, where energy supply must grow to meet increasing demand while these markets simultaneously transition to low-carbon sources.

3. Action must be taken as soon as possible, as it will be significantly less costly in monetary and socio-environmental terms than delayed action.

4. Policy must address all fundamental elements of the transition to allow the demand and supply sides of the energy system to adjust as required. Carbon pricing calibrated to the end-goal is a core ingredient of any effective policy framework. The lessons of history and the cold logic of market dynamics show that addressing demand is one of the most important ways to exert leverage on the supply side of the energy and land-use system.

None of the above will be feasible if the supply of metals does not keep pace with the spectacular demands of the energy transition.

Metals are essential inputs for the hardware of decarbonisation – there will be no energy transition without a very large increase in the production of critical minerals. Yet the production of minerals can itself be an emission-intensive process.

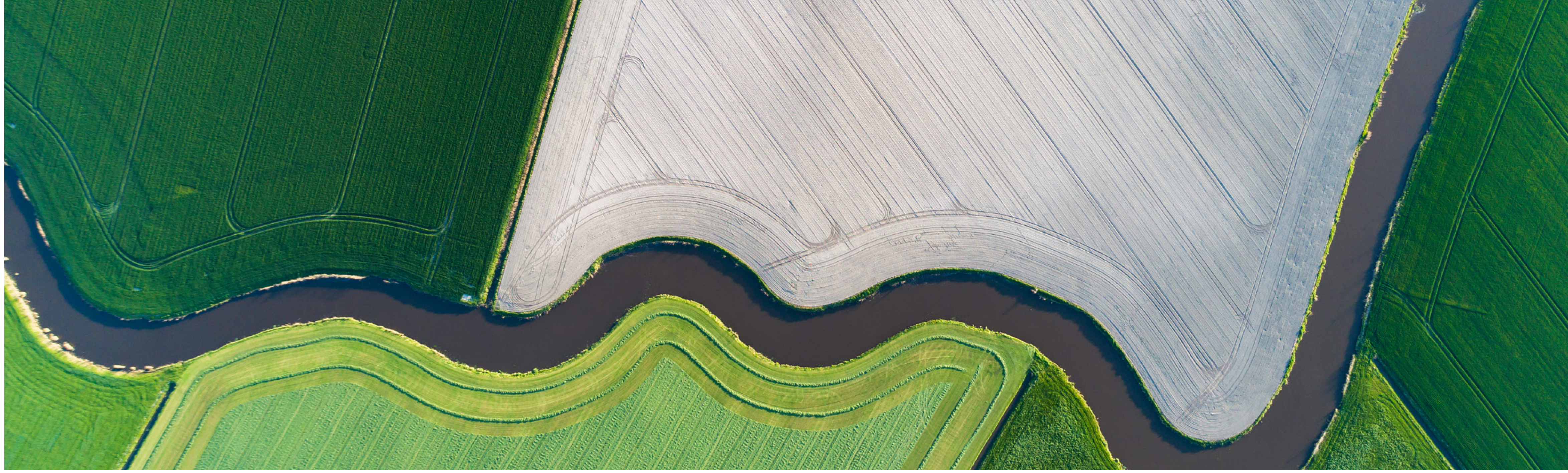
There are two clear roles for investors here:

- Engage constructively with the sector to help drive down operational emissions.

- Mobilise the capital that will be required to ensure metal supply does not become a bottleneck in the race to Paris.

We believe investors must be a part of the transition through engagement, focusing efforts on creating an environment where companies, governments and allocators of capital work together to build the ecosystem where clean energy alternatives compete with and beat the incumbent greenhouse gas-emitting technologies. Consumers adopting new products or services when the utility from doing so demonstrably exceeds the incumbent option is, more or less, the story of economic progress since the Industrial Revolution. However, while the historical pattern has been organic, with spurts of rapid progress as sectoral innovation clusters emerged, interspersed with periods of more sedate rates of change, what is required now is change that is economy-wide, global, sustained and contemporaneous across sectors. And it needs to occur at unprecedented speed.

Introduction – many roads to Paris



The Paris Agreement aims to hold "… the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change". This means global emissions must reach net zero by 2050, requiring the world's energy and land use systems – the economy's 'engine room' and society's 'bread basket' – to undergo the fastest, most coordinated transition in human history.

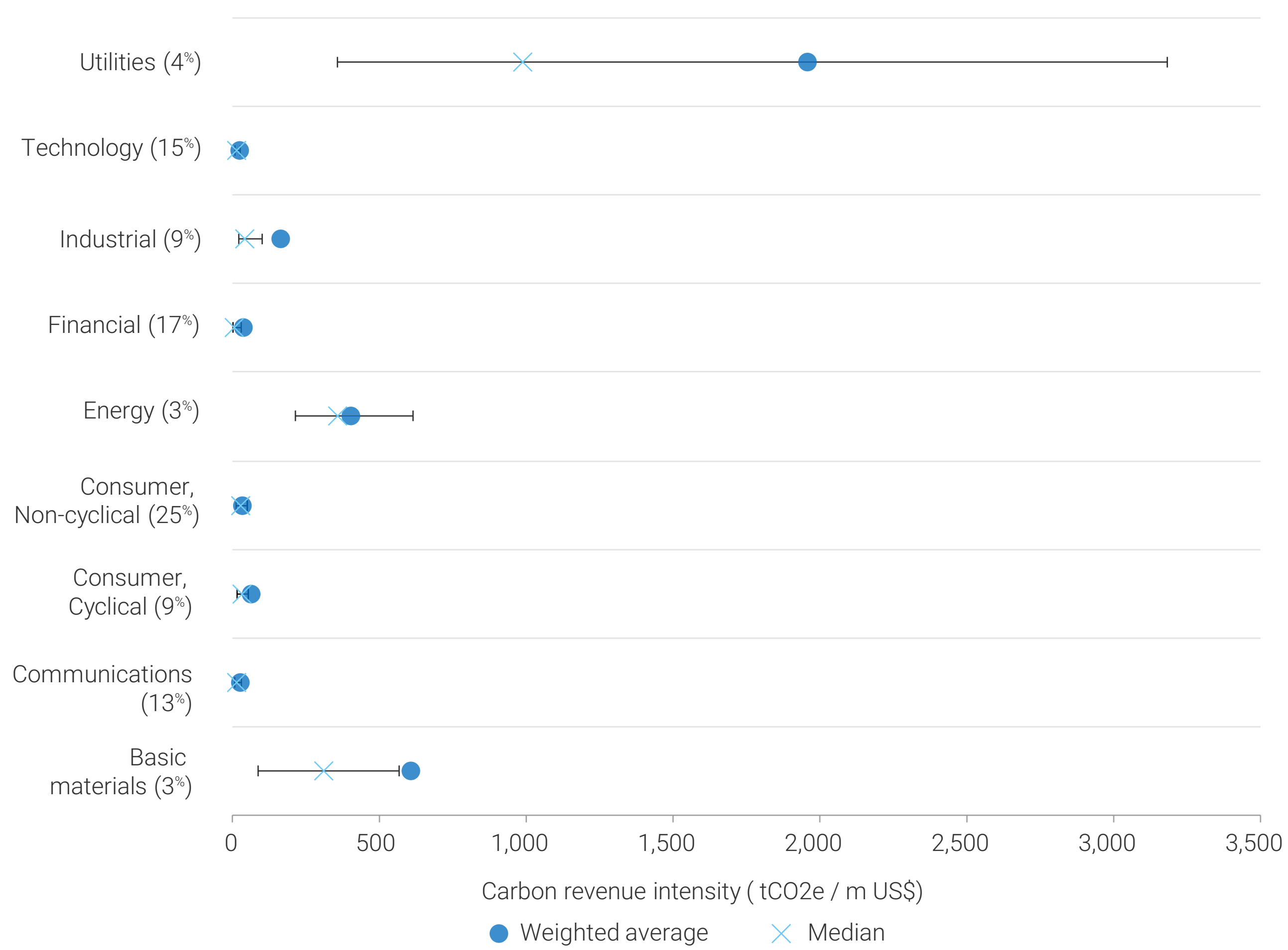
Successful transition will require a vast capital reallocation and will likely generate material risks and opportunities, placing investors and global capital markets at the very centre of the challenge. Building out electricity transmission; distribution infrastructure; and renewable generation capacity is highly capital intensive (offset somewhat by lower operating expenses). Annual average energy capital investments would rise from around US$2tn today (2.5% of GDP) to around US$5tn for the period from 2021-50 (4.5% of GDP in 2030, falling to 2.5% of GDP by 2050) in the International Energy Agency's (IEA) Net Zero 2050 scenario.[1] Total investment requirements in energy supply and infrastructure over the next 30 years could range from US$92-173tn, according to Bloomberg New Energy Finance.[2] Governments world-wide will need to play their part, directly contributing finance and using public policy to encourage private sector involvement.

Against this backdrop many investor portfolios, as they are presently composed, face considerable risks under Paris-aligned pathways, in our view. LGIM's analysis of asset valuations under its Paris-aligned scenarios shows that a representative global equity index could be worth 6% less today in net present value terms in an immediate action well-below 2°C scenario, or 15% less in a net zero 1.5°C scenario, considering impacts to 2050. If action is delayed by 10 years, but still achieves a well-below 2°C (around 1.75°C) outcome, the loss rises to 20%. That is compared to asset value to 2050 in the absence of physical and transitional climate risk.[3] Investors have an important role to play in supporting companies in future-proofing their business models and significantly reducing their carbon footprint to reduce their exposure to climate transition risk and contribute to the mitigation of physical climate risk.

Equally central to meeting the challenge is the global resources sector, which sits at the intersection of this change and will be pivotal on both sides of the decarbonisation coin. The total value chain for natural resources, from discovery, to extraction, through processing, distribution and use is highly energy intensive, which in today's world, also means carbon intensive. As shown in the following chart, companies in the energy and basic materials sectors are among the most carbon-intensive equity issuers.

1. Sources: https://www.iea.org/reports/net-zero-by-2050
2. Source: https://about.bnef.com/new-energy-outlook/
3. Further information on LGIM's climate risk metric is provided in Appendix 1.

Figure 1: Carbon revenue intensity of global equities



Source: LGIM Analysis, as at 31 December 2021.
The value of an investment and any income taken from it is not guaranteed and can go down as well as up, you may not get back the amount you originally invested.
Notes to chart:
(1) Results shown are for a representative global equities portfolio and include Scope 1 and 2 emissions
(2) Average is weighted by market capitalisation.
(3) Numbers in brackets indicate the Index's PV in each sector
(4) Black error bars show the interquartile range of carbon revenue intensity within the sector

On a business-as-usual basis, rising standards of living and population growth point to increasing resource consumption. Modern life is fundamentally dependent on the metals, energy and chemicals that the natural resources sector provides, affordably and at scale. And as the difficulty of finding and developing new mineral deposits increases, even as existing assets see their grades inevitably decline, the industry's energy footprint is likely to continue to grow for both demand and supply reasons. The resources industry must provide the material building blocks of the hardware required to radically reconstitute how we produce energy and use land. Whether the nickel used in electric batteries; the uranium needed to power zero operational[4] carbon emissions nuclear reactors; the steel used in wind turbines; the potash required to boost agricultural yield for biofuels and conserve land for afforestation; the silver and silicon used in solar panels; or the copper that will enable the electrification megatrend at large, the products produced by this industry will only grow in importance to the world. Ergo, the size of the prize for reducing and ultimately eliminating the sector's operational carbon footprint is large. That is why a number of major resources companies, like BHP, have established ambitious and transparent objectives for operational emissions reduction.

In the six years or so since the Paris Agreement was adopted, thousands of scientists and economists have set out to model how the world might go about meeting its objectives. LGIM first published "orderly" and "disorderly" pathways to well-below 2°C (around 1.75°C) – referred to as 'Destinations' – in 2019. In 2022, LGIM added a 1.5°C scenario that achieves net zero CO_2 emissions around 2050. BHP had done similarly in 2015, in its Portfolio Analysis, and updated this in its Climate Change Report 2020 (available at bhp.com/climate), which included a Paris-aligned technical pathway to 1.5°C and a non-linear "Climate Crisis" scenario. This 1.5°C pathway has since been incorporated in corporate planning processes, as described in BHP's Climate Transition Action Plan 2021 (CTAP – also available at bhp.com/climate).

The respective suite of LGIM and BHP scenarios, and of more than 100 Paris-aligned scenarios that we have looked at (see Appendix 2) virtually all, explicitly or implicitly, converge on the following important conclusions:

1. the need to radically transform the way the world produces and consumes energy and uses land;
2. the need for massive investments in clean energy to meet this transformative challenge;
3. the utility of universal pricing of carbon emissions to tackle the demand side of carbon intensive energy use and to stimulate the supply of clean alternatives is unmatched by other potential levers;
4. the fact that this battle is global: it can't be won in the developed world alone, but it can be lost in the developing world, where the majority of future emissions are likely to come from under a business-as-usual scenario;
5. the need for unprecedented levels of international cooperation to accommodate all of the above, including the containment of carbon leakage and swift diffusion of clean technology;
6. and the need for a step-wise increase in the supply of the future-facing metals that are the building blocks of the hardware of decarbonisation.

That's often where the similarities end. The complexities of the energy system, the array of commercial and emergent decarbonisation options and the behavioural and policy choices and levers available to modellers – which can, at least theoretically, be deployed in almost infinite combination – mean that a very wide variety of pathways can be generated that target alignment with the goals of Paris.

Given this fundamental reality, substantial differences between independently modelled pathways to the Paris-aligned end-state can and do arise, depending on the assumptions chosen with respect to: efficiency; international cooperation and coordination; domestic policy frameworks; the rate of technological development and adoption; and behavioural change. While global emissions curves in these scenarios all trend downwards towards a green end-state, the shape of these curves vary considerably. Some cut emissions more steeply in the early years before easing towards the objective further out, others produce almost constant linear progress, while more still are relatively less ambitious in the early years, allowing technology to mature, policy ambition to rise steadily and certain segments of the capital stocks to reach end-of-life before seeing emissions plunge towards net zero on a just-in-time basis.

4. Here we distinguish between "operational" emissions from the generation process itself and "cradle to grave" emissions, which draws the boundary more widely, and are more correctly assessed as "low" rather than "zero" carbon.

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While it is important to note that different time-paths to the end-state carry different physical climate risks (just-in-time being potentially riskier than early action on multiple fronts, all else being equal, as we will argue below), some of the Intergovernmental Panel on Climate Change's past work has shown that scenarios that technically meet the goals of the Paris Agreement can reach net zero from as early as 2045 to as late as 2080.

This variety is not helpful to those who advocate for a simple "consensus" path to Paris that can be used in, for instance, financial reporting for listed companies or climate investment risk analysis. The scientists and economists who comprise the climate modelling community are a long way from landing on an uncontentious "one size fits all" scenario that can serve this purpose. This is partly due to the reality that settling on a single pathway based on the information we have today is inappropriate (and arguably impossible) given the complexity of the systems under consideration, the long time frames involved and the inherent uncertainty pertaining to most of the major assumptions. Critically, even the area that could be the simplest – national and international policy frameworks – at this stage leaves much to speculation: even post COP26.

Prior to the 2021 summit in Glasgow and the weeks leading in, the world's governments fell into two basic camps on this score. Either they were still mapping out a bottom-up plan to effectively deliver on top-down ambitions that are aligned with the aggregate goals of Paris.

Or they were lacking a top-level ambition that is proportionate to the global challenge to begin with. Post Glasgow, there are, thankfully, fewer countries in the second camp. New pledges on methane, and a net zero goal for India, if delivered, certainly constitute positive progress. We hope that as the many announcements from COP26 are translated into official policy, this greater clarity will reduce the variations in assumptions across the research community, as well as help to bend the global emissions curve closer to "a" (not yet "the") Paris-aligned road. We revisit this issue below when we discuss the pricing of carbon.

To reiterate the point, at our current collective state of knowledge, we firmly believe that no single scenario should become the unquestioned benchmark. Accordingly, we advise interested parties to study the growing suite of pathways consistent with Paris, seek to learn from them all, and embrace the complexity – from which will spring opportunity. The closer to the analytical work you sit, the less likely you are to elevate any single pathway as the unique or superordinate road to Paris, that is too heavy a burden for any one scenario to carry – including those we have created ourselves (See Appendix 2).

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Pathways to Paris: common elements

Radical change to energy and land use

To get to a Paris-aligned outcome and avoid the unthinkable, the pace and scale of change needs to be monumental. New global value chains must be built from scratch and scaled at breakneck speed and trillions of dollars of long-life capital stock must be either retrofitted or retired. The proportion of the stock of buildings retrofitted for energy efficiency annually must spike upwards. Millions of hectares of land must be turned over to afforestation, solar arrays and onshore wind, and crops/plantations for bioenergy production. Nascent and emergent technologies need to sprint from the laboratory to global commercial deployment at a fraction of historical timelines. Consumer behaviour in both the developed and developing world needs to lean in powerfully to amplify the direction of travel.

Starting with the stationary power sector, today this accounts for roughly two-fifths of global CO_2 emissions and fossil fuels generate about two-thirds of the power used. This sector needs to reach a net zero balance in the next three decades if the world is to stay within a 1.5°C budget, yet in the populous developing world, the capital stock is still young, with the average age of coal power plants (weighted by capacity) in China, India, Indonesia and Vietnam being 12, 13, 11 and seven years respectively.

There are certainly positive portents. Solar costs have fallen by over 90% since 2008 and utility-scale batteries are being installed across the US, Australia and Europe. President Xi Jinping has announced an aim for China to reach net zero emissions before 2060, the manufacturing powerhouses of Japan and South Korea are now aiming for net zero by 2050, Prime Minister Narendra Modi's India has signalled a 2070 net zero objective, and the Biden administration in the US has signalled a clear intent to make up for lost time. And yet, in big picture terms, much is still the same, and that is not enough when "radical" is required. In its World Energy Investment 2021 report (released in June of that year), the IEA estimated that fossil fuel supply and power generation combined would attract US$813bn of new investment, with US$119bn of that going to new power generation. Renewables attracted US$382bn by comparison, and electricity networks, demands on which will increase considerably as more and more intermittent power sources are discharged, attracted US$286bn. On the glass-half-full front, recognising that great can sometimes be the enemy of good, the pipeline of new coal power projects has fallen considerably since Paris, utilisation of existing facilities has come down and the pool of potential financiers of greenfield projects has narrowed considerably.

Nurturing these green shoots and expediting the reallocation of capital within the energy system will initially require the massive deployment of known technologies – onshore and offshore wind, industrial scale solar and the swift multiplication carbon capture and storage (CCS) for existing heavy industry and power generation and an expansion of the nuclear fleet in jurisdictions where that is both affordable and socially palatable. Beyond current technologies there needs to be a heightened focus on the further development and testing of emergent technologies such as bio-energy facilities incorporating carbon capture and storage (BECCS). However, there will also be collateral challenges to be solved, for example land competition and network resilience. Where land is concerned, note that every megawatt of solar power capacity on average currently requires about six acres of land, and onshore wind increases land requirements approximately seven-fold.[5]

So while the above is daunting, the availability of plausible options that can be adopted today puts power into the easier-to-abate category.

The other major emissions sector with a clear road towards zero emissions is light duty transport. In the BHP 1.5°C scenario[6] (see figure 2 below), net zero for light duty transport means turning over most of the global auto value chain, one of the world's most disaggregated and complex, from internal combustion engine (ICE) production to electric vehicle (EV) production by the early 2030s for developed countries and achieving the full global takeover during the 2040s. To put this in context, 6.7 million EV sales in 2021 need to become two billion EVs on the road in 2050. Here policy is turning very supportive in many key auto production and consumption regions, with supporting infrastructure, most notably reliable and pervasive fast charging, being the final piece of the puzzle.

Beyond power generation and light duty transport, the path to net zero emissions is less clear. Emissions from land-use are between one-fifth and one-quarter of total emissions and radical change will require major shifts in behaviour (e.g. dietary choices) and economic incentives in the developing world to break the insidious warming feedback loop between land clearing for cultivation, stored carbon release, loss of biodiversity, inefficient use of nitrogen and phosphate fertilisers, and the emissions generated directly by livestock. The Global Methane Pledge that emerged from Glasgow is a positive signal of intent in this regard, albeit with some major methane emitters not yet choosing to participate.[7]

5. See estimates of MW per unit land by technology, documented at https://www.nrel.gov/analysis/tech-size.html , accessed 16/02/2022. The 7-fold figure compares a 1-10 MW photovoltaic facility (6.1 acres) to a 1-10 MW wind facility (44.7 acres).
6. There are inherent limitations with scenario analysis and it is difficult to predict which, if any, of the scenarios might eventuate. Scenarios do not constitute definitive outcomes for BHP. Scenario analysis relies on assumptions that may or may not be, or prove to be, correct and may or may not eventuate, and scenarios may be impacted by additional factors to the assumptions disclosed.
7. See https://www.unep.org/news-and-stories/story/new-global-methane-pledge-aims-tackle-climate-change?__cf_chl_managed_tk__=tso1wGVF4Pw78CECoGjy1iegnQ7Z7__l4WeRBbSHHwM-1636434916-0-gaNycGzNCOU

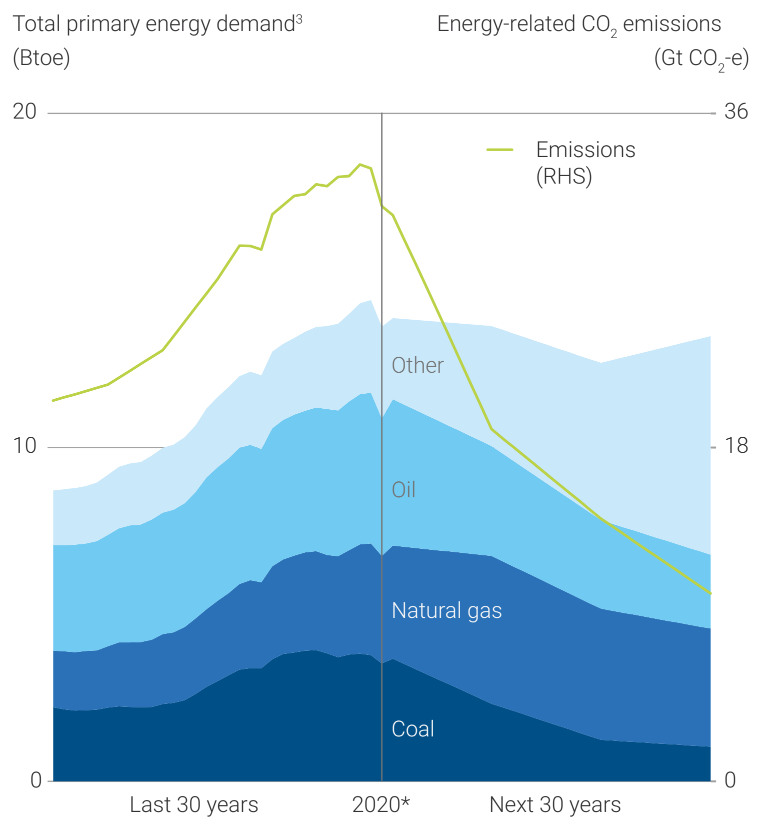
Significant technological progression will be required to feasibly and affordably address the emissions from industrial activity, notably steelmaking, cement and chemicals and other forms of transport such as heavy road, rail, shipping and aviation. While every one of these sectors has begun experimenting with alternatives, and ambition is increasing, very little has been done at scale.[8] If rapid technological progress does not occur, then these harder-to-abate sectors would have to explore the viability of decarbonising at considerable cost and potential delay, both at the individual plant level and via broader infrastructure requirements, by deploying known but very expensive technology options, such as the deployment of green hydrogen direct reduced iron steelmaking. These industries will also lean heavily on developments in the easier-to-abate sectors, where costs for backbone technologies like wind and solar generation and battery super-charging networks, will be driven down by manufacturing economies of scale as well as by pure technological progress.

Over and above the shifts described above, there will still likely be a need for "last-mile" decarbonisation produced somewhere along the spectrum from affordable and more straightforward approaches (e.g. afforestation) to the more technologically nascent and relatively expensive, such as direct air capture. BHP's analysis below summarises just one scenario for how a few key parameters could move to achieve a 1.5°C outcome.

The task the world faces is truly monumental but we believe it is mission *possible*. However, to improve the outlook from "possible" to "plausible" and then to "probable" a great many things still need to happen, they need to happen fast, they need to endure and they need to happen everywhere – especially in the populous emerging and developing world.

Figure 2: What does BHP's 1.5 degree transition look like?

Paris Agreement goals met through radical changes to the global energy, industrial and land-use systems



	2019	2050
Fossil fuels in the primary energy mix	80%	Approximately half
Electric light vehicles	5 million	>2 billion
Homes heated by solar and wind	1 in 50	1 in 3
CCUS facilities	<20	~10,000
Land used for afforestation	14,200 km^2	+4,000,000 km^2

Source: Historical data from IEA. Forward looking analysis from BHP as at 10 September 2020, the date of publication of published in its Climate Change Report 2020 (available from bhp.com/climate).

Assumptions, opinions and estimates are provided for illustrative purposes only. There is no guarantee that any forecasts made will come to pass.

8. For example, a number of heavy vehicle OEM have announced zero-emissions vehicle production or sales targets, including Daimler, Volvo, Scania, Hino, FAW and Hyundai, along with major fleet operators DHL, FedEx and Walmart. Container giant Maersk has brought forward its target for zero-emission shipping.

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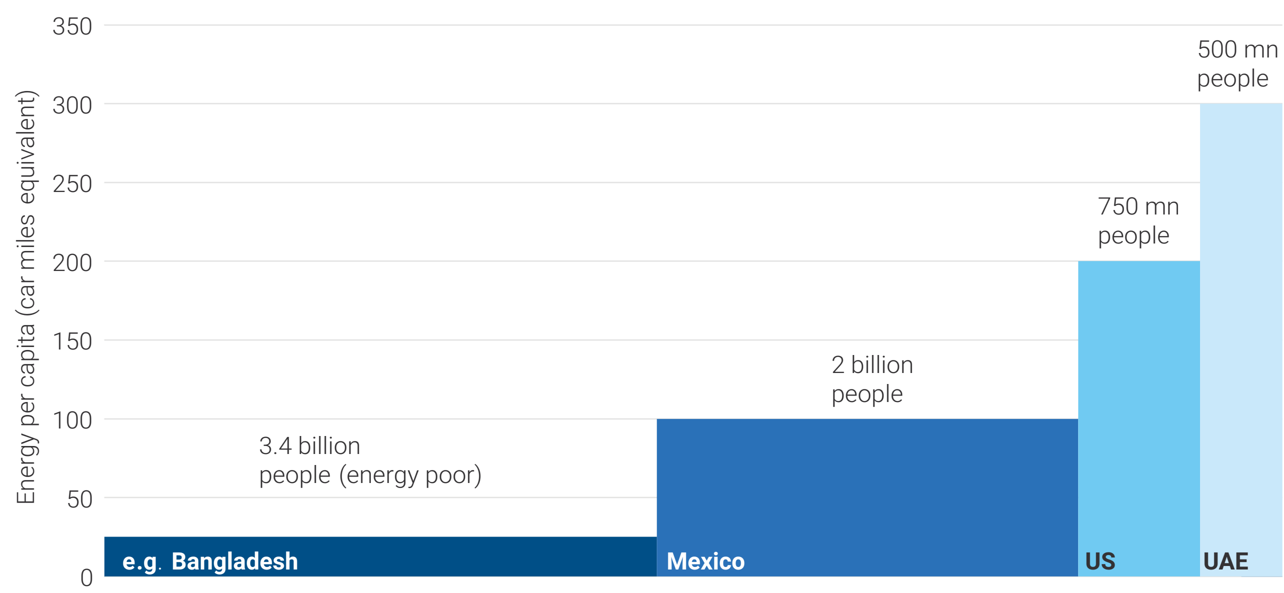
Focus on emerging and developing economies

A successful transition to a Paris-aligned climate outcome must not only transform the energy system, but also alleviate energy poverty and account for the growth in demand for energy services this will entail. In Bangladesh, for example, a country of approximately 165 million people today (and projected to approach 250 million in 2050), primary energy consumption per person is around 6 kWh per day, around 3% that of the US, where each person consumes an average of 220 kWh per day. More generally, the developed world uses anywhere from 10-20 times more energy per person per year than the developing world. This means around half of the world's population currently live in 'energy poverty', with a daily energy budget of less than what is needed to drive a typical European car for 25 miles. A further two billion people live in middle-energy countries, using the equivalent of 25-100 miles of energy. A little over one billion enjoy abundant energy access.

A successful energy transition depends on the alleviation of the striking inequality of energy access. The vast amount of energy demand growth is expected to come from emerging economies and must be accompanied by a transition to lower carbon energy sources if the Paris Agreement's goals are to be achieved. The developed world cannot decarbonise in isolation and expect the developing world to continue consuming significantly less energy per person. Today, around 750 million people globally do not have access to electricity. Increasing energy access while ensuring it is not detrimental to global climate targets will be one of the defining challenges of the transition. Here the modular nature of renewables, working through a micro-grid or fully decentralised, can come into their own where local conditions are conducive. Where they are not, or if sheer scale of population inhibits this strategy, affordability constraints still steer policymakers towards traditional forms of energy supply, especially where the indigenous geological endowment features abundant reserves of coal (e.g. India, China, Indonesia, Colombia, South Africa) or petroleum (e.g. Middle East, Russia, Nigeria, Venezuela). This also highlights that delivery on high level climate ambition in Europe, the global leader, guarantees nothing if the developing world does not move at an equally urgent pace.

Figure 3: Inequality in energy use per capita



Source: LGIM analysis as at 31 December 2021. Note: countries inside bars are examples of those included in a category

The data are stark (figure 4). In 2019, the split of emissions between the developed and developing world was approximately 33%/67%.[9] In terms of projected share of cumulative emissions from 2019 to 2050 in the Stated Policies Scenario (STEPS) and Sustainable Development Scenario (SDS) of the IEA, those ratios move to either 21%/79% or 9%/91%. Europe declines from 8% in 2019 to 4% of cumulative emissions in the outlook. Under STEPS, China alone emits more than the developed world combined, while India will emit roughly two and half times more than all of Europe.

The simple conclusion here is that while this battle cannot be won in the developed world alone, it can certainly be lost in the developing world.

In this regard, it is extremely heartening that both China and India have now committed to a net zero future. The task for the rest of us is to provide the right conditions in terms of technological diffusion, green financing and policy coordination for these two giants to feel confident advancing the timing of their national targets from 2060 and 2070 respectively.

Figure 4: The developing world is the key decarbonisation battleground

Energy-related CO2 emissions

Country/region	**Shares of CO_2 emissions**		
		2050	
	2019	STEPS	SDS
US	13%	9%	1%
EU	8%	4%	2%
Other advanced	12%	9%	6%
Total advanced	***33%***	***21%***	***9%***
China	31%	25%	16%
India	7%	11%	12%
Other developing	26%	38%	53%
International bunkers*	4%	6%	10%
Total developing	***67%***	***79%***	***91%***
World	100%	100%	100%

Source: IEA, BHP analysis as of 16 February 2022. Notes to chart: *High level regional splits in text include international bunkers in "developing".
Assumptions, opinions and estimates are provided for illustrative purposes only. There is no guarantee that any forecasts made will come to pass.

Timing is of the essence

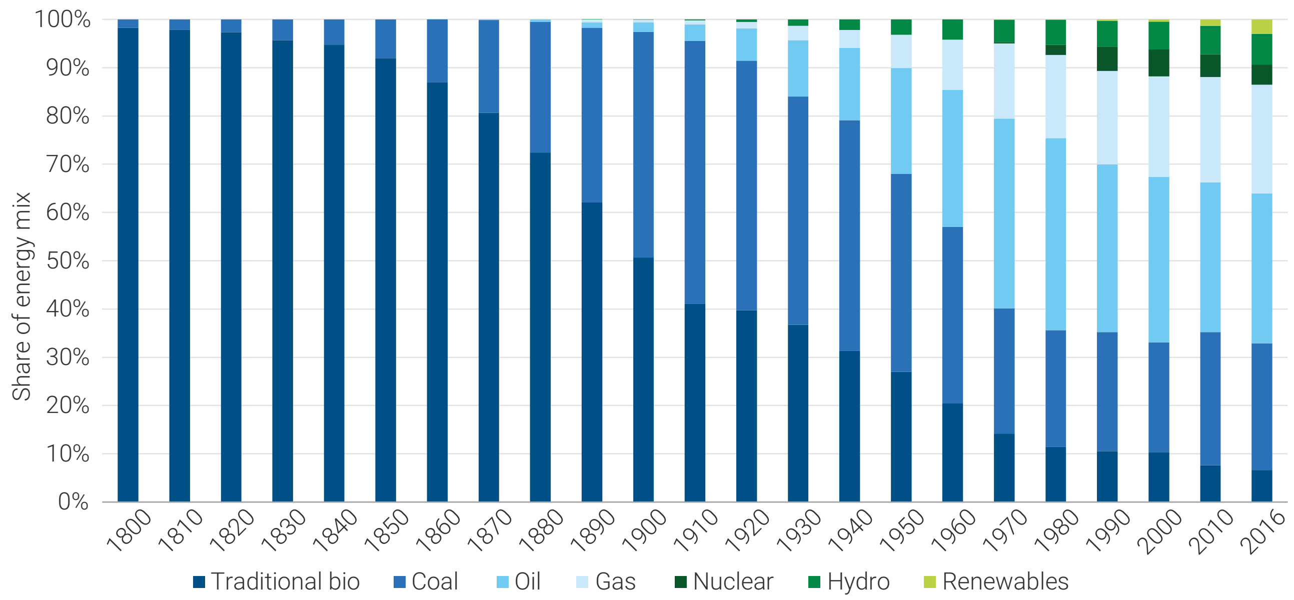
The world doesn't have very long to begin adopting the changes outlined at a high level above. Best estimates are that we have about a decade left before we have fully exhausted our remaining 1.5°C carbon budget. To paraphrase IEA head, Fatih Birol, the race to Paris is not a race among nations, it is a race against time. A speedy transition is not something that will be easy to achieve, when considered through the lens of history. LGIM's study of the history of industrialised energy – over 200 years of it – tells us that the world of energy moves slowly at the national level and even more slowly at the global level. The past two "transitions", the first from wood to coal, and the second from coal to oil and gas, took between 70 and 100 years for the new source of energy to reach 50% market share.

BHP's technological diffusion database tracks the rate of transition at a granular level. Beneath the surface of the major parameters of primary energy demand sit the enabling technologies that drive change in everyday life. Here too we find that multi-decade timespans are the historic norm for material change. Examples of protracted periods of technological takeover include the transition from open-hearth to blast furnace steel-making (around 60 years), the time it took for complete electrification of the US housing stock (around 80 years), the time it took for sea ports to convert crane infrastructure to standardised containers (around 30 years), and the time it took for computer-aided design software to displace manual techniques (around 40 years). In some instances, these time lags reflect the long life of the incumbent capital stock, such as in steelmaking. In computer-aided design, it reflected generational turnover in terms of skill and knowledge, as well as uptake of an enabling technology – the personal computer. In others, it is the immensity of the infrastructure task required to reach universality across a continent sized land mass, and the spreading financing costs over longer periods of time, given other competing demands on public and private balance sheets. The message is clear: major transitions at the economy or sectoral level naturally take time and enormous mobilisations of financial and physical capital, and taking time is a luxury the world no longer has.

9. For simplicity, "international bunkers" are included in the developing category. They range from 4% to 7% of the total.

Today, low carbon energy – here defined as nuclear and renewables including bioenergy – accounts for around 15% of global primary energy demand (although higher as a share of final energy demand). That share has been growing consistently over time, accelerating since the financial crisis in 2008. Yet so far, there is no evidence of the start of any "energy transition". Low carbon energy is yet to supply at a global level more than 100% of the incremental demand for energy. Only when these low carbon energy sources are growing faster than (or at least at the same rate as) overall energy demand will action start to match the rhetoric. To date, renewables meet around 30% of incremental energy demand, with the broader low carbon contribution slightly higher. Market share continues to grow but not nearly fast enough to halt the level of global emissions and decouple growth in the economy from growth in emissions, let alone start to structurally lower emissions.

Figure 5: Global primary energy mix since 1800



Source: LGIM analysis, as at 31 December 2021.

Figure 6: Low carbon primary energy consumption share

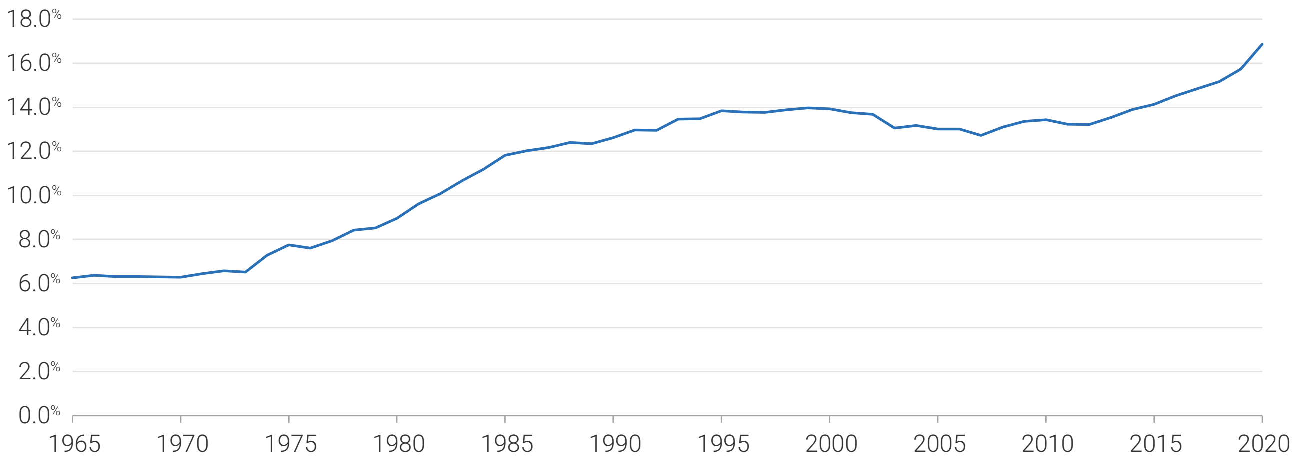
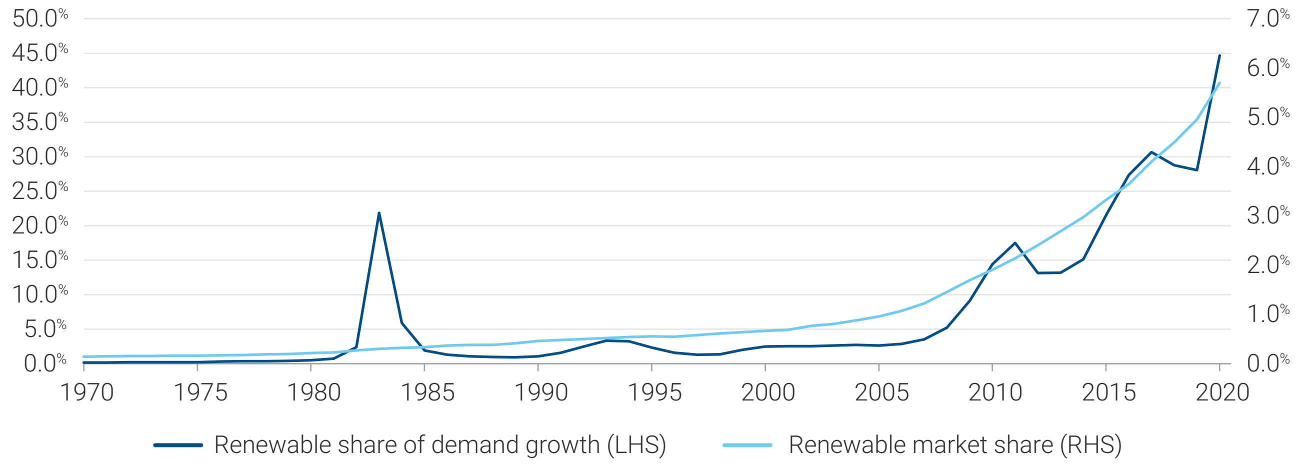


Figure 7: Renewable share of incremental demand



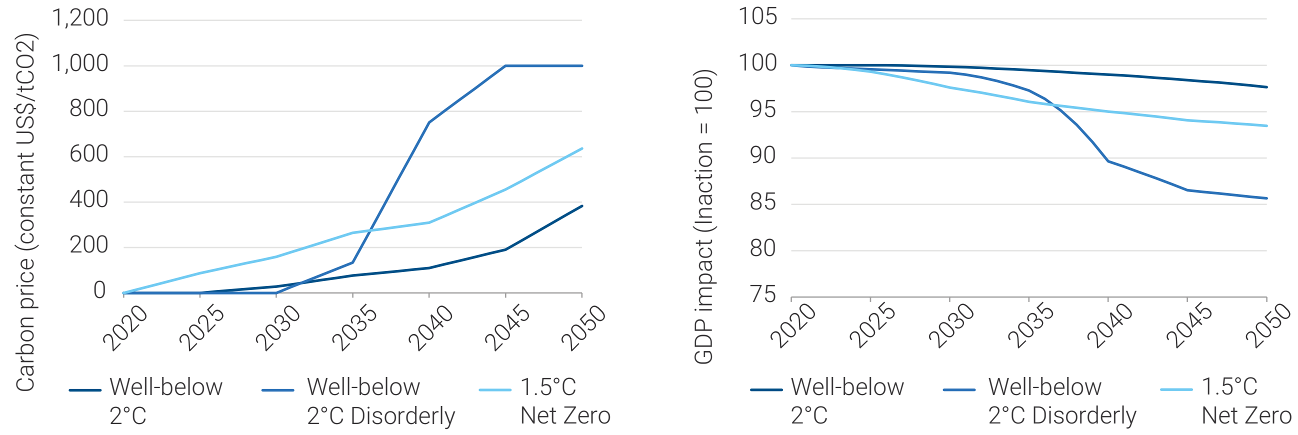
Source: BP Statistical Review of World Energy, July 2021, LGIM analysis as at 31 December 2021. Notes to chart:
(1) Low carbon here includes nuclear, hydro and other renewable energy sources, including bioenergy.
(2) Incremental demand is here defined as the change in average primary energy consumption in the past 3 years compared to the average in the 3 years prior.

Action is needed, and quickly. LGIM's scenarios show that a delay of 10 years causes a shock to the economy that is more than five times that of an immediate and orderly transition to well-below 2°C (around 1.75°C), and double the impact of an immediate transition all the way down to 1.5°C with net zero CO_2 emissions around 2050. This is because to achieve a Paris-aligned outcome in two-thirds of the time entails ramping up carbon prices quicker and further, up to US$1,000/t$CO_2$ by 2050, the impact of which is much more disruptive for the economy than a steady but inexorable approach.
It means paying for the 'reversal' (through sequestration) of another 10 years' worth of carbon emissions, which is much more expensive than preventing them from happening in the first place, in an orderly transition.

LGIM estimates put the additional cost of a disorderly transition to well-below 2°C at roughly US$5.1 trillion per year by 2050 in today's dollars, compared to around US$700 billion per year in an orderly transition. A 1.5°C net zero outcome would cost around US$2.2 trillion per year by 2050 in comparison, despite achieving a lower temperature outcome (1.5°C rather than the around 1.75°C targeted by our well-below 2°C scenarios).

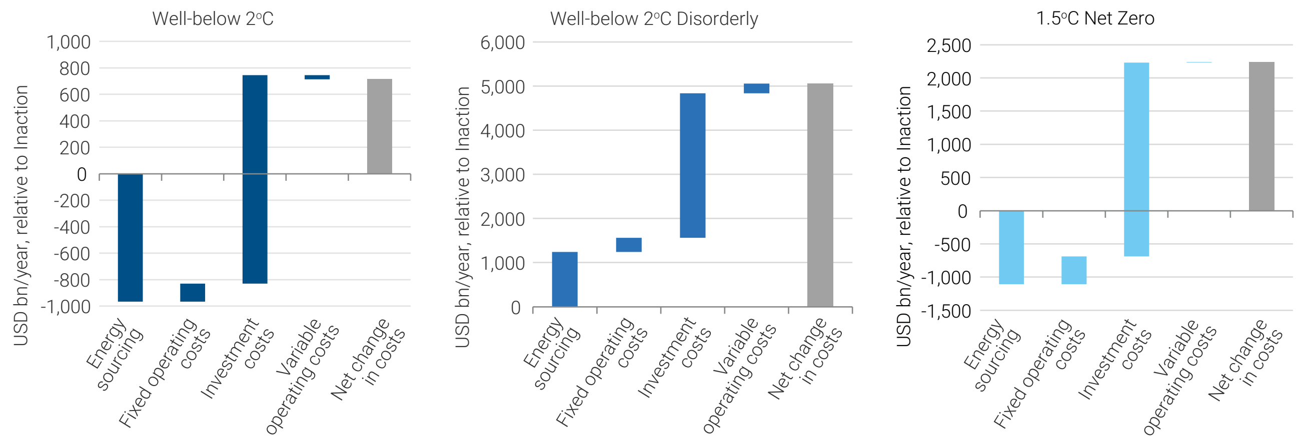
BHP modelling of impacts to its own portfolio of assets under orderly versus disruptive scenarios highlights that many of its commodities perform best under its orderly 1.5°C transition scenario among all the formal scenarios that they have examined. By contrast, a disorderly scenario (what BHP calls its "Climate Crisis" scenario) is its least favoured path.

Figure 8: Scenario impacts



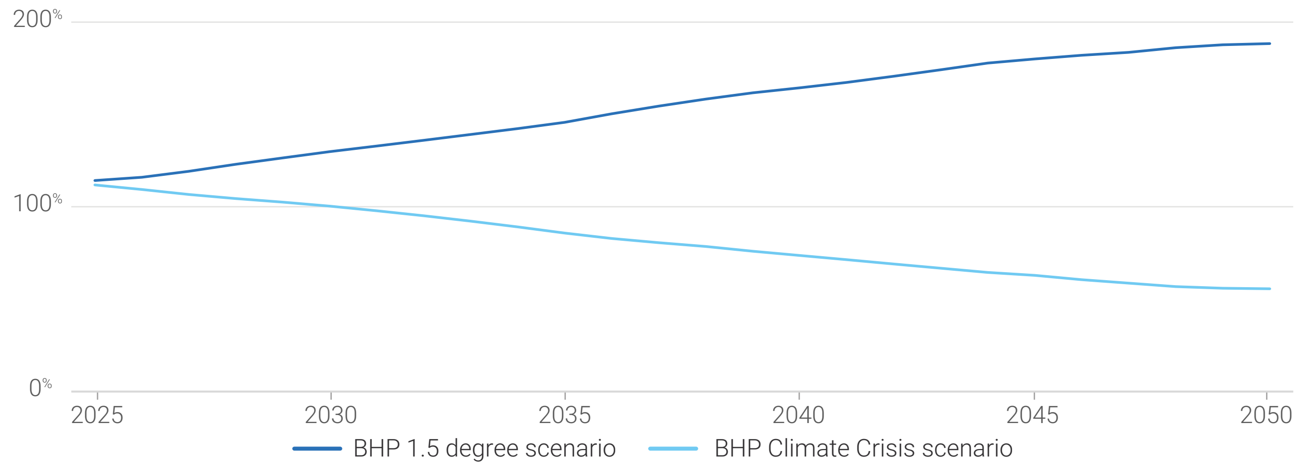
Source: LGIM Analysis as at 31 December 2021. **Assumptions, opinions and estimates are provided for illustrative purposes only. There is no guarantee that any forecasts made will come to pass.**

Figure 9: Scenario costs



Source: LGIM analysis, as at 31 December 2021. **Assumptions, opinions and estimates are provided for illustrative purposes only. There is no guarantee that any forecasts made will come to pass.**

Figure 10: Rolling NPV of BHP enterprise value versus reference case



Source: BHP analysis as at 10 September 2020, the date of of the publication of its Climate Change Report 2020, available from www.bhp.com/climate. Refer to the BHP Climate Report 2020 for information about the assumptions, outputs and limitations of BHP's 1.5°C scenario. Present value of unlevered free cash flows relative to reference case, estimated from financial year 2020 forward. Data in this chart is based on BHP's portfolio as at the date of its Climate Change Report 2020 (10 September 2020) and does not include any potential future divestments. **There is no guarantee that any forecasts made will come to pass. The value of an investment and any income taken from it is not guaranteed and can go down as well as up, you may not get back the amount you originally invested.**

Pricing carbon effectively

Uncertainty over future policy, demand and investment returns is currently contributing to under-investment in both traditional and zero carbon energy supply.

On the green side of the energy investment coin, the IEA warns that the US$750bn expected to be spent on energy efficiency and clean energy technologies this year would need to triple in the 2020s to ensure a 1.5°C outcome remains possible.[10] Put another way, the world is currently under-investing by two-thirds on the hardware requirements of decarbonisation.

In the traditional energy system, consider this remarkable statistic: according to IEA data, total upstream petroleum spending in calendar 2021 will be 44% below the level of 2015, but oil demand and prices are both higher today.[11] While petroleum demand will certainly have to decrease substantially in the fullness of time, right now global mobility and a range of everyday household products are almost completely dependent on the petroleum value-chain. Meeting that demand requires considerable upstream investment.

Uncertainty over future policy is impacting both of these trends, in diametrically opposing ways. These twin capex gaps could lead to mismatches between energy supply and demand for some time, risking two elements of the energy trilemma simultaneously: security of supply and affordability. It also has ambiguous near-term consequences for the third element, emission minimisation, given that system resilience is reduced by these trends which can drive short-termism in decision making.

Decisive policy can make an enormous difference. Policy must drive the shift of demand from high carbon technologies and fuels to lower carbon alternatives, while letting the market "pick the winners" with respect to specific technologies. It must establish the business case for ending the current under-investment in clean energy, thereby bringing about the acceleration of run-rates that a swift transition requires. Key to achieving this shift will be the pricing of carbon, be it through a direct carbon tax or through a cap-and-trade mechanism. Carbon pricing forces the market to internalise the negative impact that carbon has on the climate as a cost and increases incentives to reduce emissions in response. As shown in the previous section, the earlier policymakers act, the sooner investors will price in and mitigate associated risks and pursue relevant opportunities. And the sooner the non-financial sector can begin to allocate capital to carbon abatement and carbon displacement with greater assurance.

The current average price of emissions globally is US$3 per tonne of CO_2, with 80% of global emissions remaining unpriced.[12] In OECD and G20 countries, the share of unpriced emissions is around 60%. Where emissions are priced, fuel excise taxes are the most-used policy instrument. These may or may not have been set up with an explicit climate objective.[13] Globally, inconsistent carbon pricing initiatives are leading countries or trading blocs to consider levelling the playing field through so-called carbon border taxes. These would adjust the price of any imported goods by the cost of the embodied carbon under the local carbon pricing scheme, net of carbon charges already paid.

The administrative complexity here is immense, with very high information requirements to succeed. Early proposals in Europe have illustrated this complexity very well at the sectoral level.[14] It remains to be seen how the EU-US agreement to devise a carbon-based steel and aluminium trade deal, announced on 31 October 2021, is operationalised.

Carbon pricing instruments urgently need to be more widely applied both within and across countries. Estimates of the required level vary, as shown in our comparison across scenarios. However, it is not unusual to see projected prices exceeding US$200 per tonne of CO_2 by 2050 to get anywhere near a climate outcome that is consistent with the Paris Agreement. Ideally, a global minimum carbon price would be introduced sooner rather than later, led by the largest emitters, and cover potent greenhouse gases beyond carbonCO_2 to capture the extent of anthropogenic emissions more holistically. A minimum carbon price level could allow tiering of carbon prices for countries at different stages of development, with differing ability to mobilise financial resources and with different social attitudes to the trade-offs involved.

Governments also need to ensure carbon is priced long term and provide companies with appropriate foresight on the pricing trajectory over a multi-decade horizon, to encourage the development of lower carbon alternatives and clearly demonstrate the value of near-term abatement decisions. Such a long-term approach also needs to provide confidence that changes in political administration will not alter the path, thereby encouraging companies to spend more on innovation today to avoid facing the consequences tomorrow. This in turn would maximise the likelihood that lower carbon alternatives are available when very high carbon prices do come around.

Consideration will also need to be given to the use of carbon pricing revenues. The significance of these should not be overstated, since a carbon tax may render obsolete the income from other sources such as fossil fuel duties as the economy transitions. However, they can still play a part in helping companies transition, through subsidies for green technology investment, or be applied to alleviate the pressure on very low income consumers through income tax breaks or similar.

10. Source: https://iea.blob.core.windows.net/assets/5e6b3821-bb8f-4df4-a88b-e891cd8251e3/WorldEnergyInvestment2021.pdf
11. https://www.iea.org/reports/world-energy-investment-2021
12. Source: https://blogs.imf.org/2021/06/18/a-proposal-to-scale-up-global-carbon-pricing/ . Excluding land use change and forestry (LUCF), the proportion priced/unpriced is closer to 25%/75% and the average price of emissions that are priced is around $17. (BHP calculations from World Bank data).
13. Source: https://www.oecd-ilibrary.org/sites/0e8e24f5-en/index.html?itemId=/content/publication/0e8e24f5-en
14. See ERCST (2021) "Border Carbon Adjustments in the EU: sectoral deep dive".

The role of critical minerals

Natural resources are integral to modern everyday life. They are just as important to the life we want to lead tomorrow, as the critical building blocks of the energy transition. Metals, in particular, are ubiquitous in the built environment. Our houses, cars, smart phones, televisions, refrigerators, washing machines, computers, shopping malls and mass transit systems all rely on metals: not to mention the delivery of electricity and water into our homes. The array of clean energy technologies that will drive Paris-aligned outcomes, are also highly dependent on metals. Given the essential role that metals play in furnishing the hardware of decarbonisation – it is no exaggeration to say that there will be no energy transition without a very large increase in the production of critical minerals.

In the coming 30 years, cumulative demand for metals is expected to grow substantially compared with the prior 30 years. In the 1.5°C scenario that BHP described in its **Climate Change Report 2020** (available at bhp.com/climate), cumulative demand for primary copper may double in the coming 30 years, and for primary nickel it may almost quadruple. Steelmaking raw materials do a little better than one might think in the scenario – with an uplift over traditional crude steel ranges due to additional demand from extra wind turbines and carbon distribution pipelines, which should be more than enough to offset a loss of steel demand from the fossil fuel industries as their output falls in the long run.[15]

The vital role for natural resources implied by this research is supported by striking projections of the world's critical minerals needs under the energy transition from The International Energy Agency,[16] Bloomberg New Energy Finance, the US Department of Energy,[17] the World Bank[18] and Wood Mackenzie, among others. The debate is not about whether metals are essential or not, but whether the resources industry is investing fast enough to keep pace with the demand projections derived from incontrovertible themes such as the EV 'S-curve', and the double-digit trillions of dollars to be deployed on renewable energy capacity and the future proofing of the energy grid.

Figure 11: Resources are essential to daily life

The industry must grow if the world is to decarbonise while continuing to improve living standards

Cumulative demand to 2050
(Compared to prior 30 years, 1.5°C scenario[1])

Future facing commodities:		Traditional use	plus	Emerging use
Nickel	3.7x	Stainless steel, refrigerators, cookware, homeware, medical equipment		Electrification mega-trends Electric vehicle batteries, grid storage solutions
Potash	2.3x	Feeding the world		Improved diets and optimised land use Replenishing depleted soils, crop quality, biofuels
Copper	2.1x	Home wiring, power cables, cars, smart phones, televisions, laptops, air conditioners		Electrification mega-trends Wind turbines, electric vehicles, solar panels, battery charging
Steelmaking commodities:				
Iron ore	1.8x	Cities, hospitals, schools, houses, bridges, trains, cars		Supporting development and clean energy transition Wind turbines, carbon capture infrastructure, climate adaptation, rising material intensity
Met coal	1.5x			

Source: BHP analysis as at 10 September 2020, the date of publication of its Climate Change Report 2020, available at bhp.com/climate. Note to chart (1) refer to the BHP Climate Change Report 2020 for information about the assumptions, outputs and limitations of BHP's 1.5°C scenario.

15. Potash, a future facing portfolio commodity for BHP, receives an additional demand fillip on top of its already compelling demand fundamentals under deep decarbonisation due to biofuel crops and the need for even greater intensification of agriculture as competition for land from afforestation and renewables ramps up. BHP's 1.5 degree scenario did not simulate an abrupt change in diet. A standalone scenario on what a global move towards veganism would do to potash demand has however been conducted. The answer is that there are many moving parts, and potash demand finishes roughly square. The dynamics are that livestock feed demand declines, reducing crop demand, but this is offset by two forces. (1) Plant based calories replace meat calories, partially offsetting the loss of feed demand. (2) The manure provided by livestock, which is a competing source of nutrients for crops (20% of potassium supply), is lost and is replaced by higher potash intensity of use. For more details see BHP's potash briefing at https://www.bhp.com/investors/presentations-events

2022 | The energy transition dilemma

Figure 12: Mineral intensity of electric and conventional cars

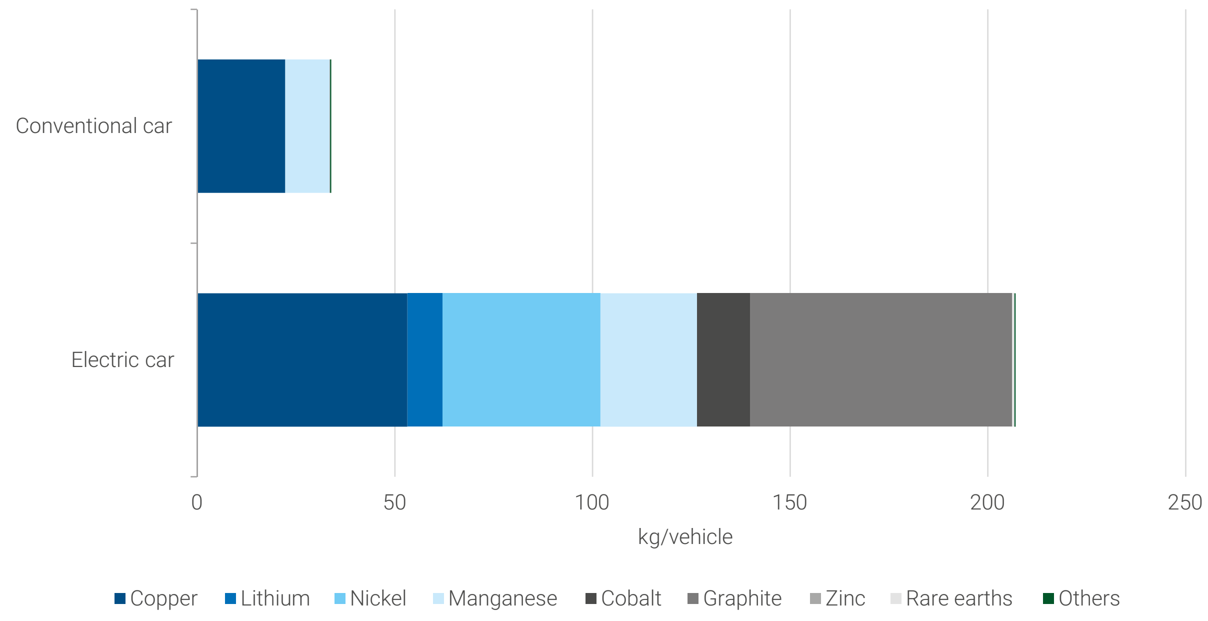
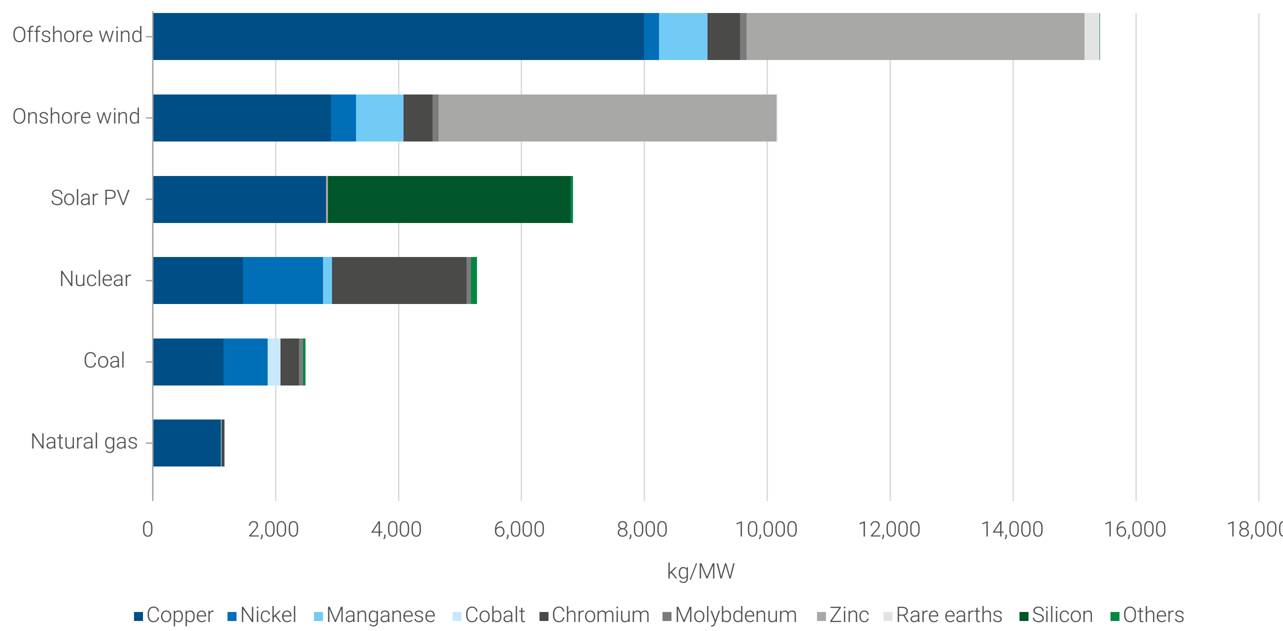


Figure 13: Mineral intensity of clean and conventional power generation technologies



Source: IEA. https://www.iea.org/data-and-statistics/charts/minerals-used-in-clean-energy-technologies-compared-to-other-power-generation-sources, https://www.iea.org/data-and-statistics/charts/minerals-used-in-electric-cars-compared-to-conventional-cars

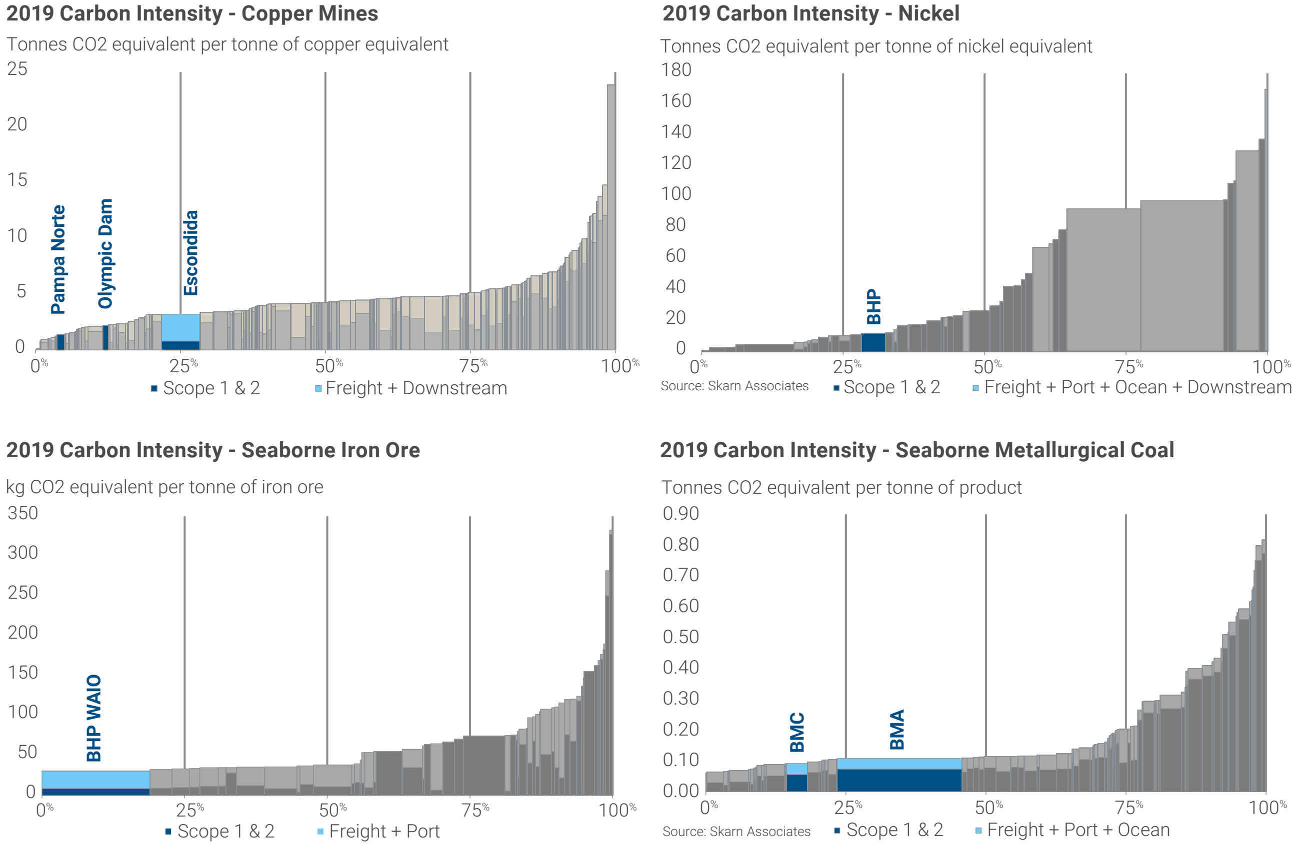
16. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
17. https://www.nrel.gov/transportation/assets/pdfs/battery-critical-materials-presentation.pdf
18. Hund, Kirsten, Daniele La Porta, Thao P. Fabregas, Tim Laing, John Drexhage (2020) 'Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition', World Bank: Washington DC, available from https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

The IEA's sustainable development scenario (SDS) has copper demand increasing by 2.7 times between 2020 and 2040, nickel increasing 19 times, cobalt 21 times, graphite 25 times and lithium 42 times.[19] The IEA's net zero emissions (NZE) vision, which models even more radical change than the SDS, would put even greater pressure on the supply side of the minerals industry. As for the current decade, Wood Mackenzie argues that even putting the world on a 2.0°C pathway will require triple digit percentage gains in cobalt and lithium production, around a 70% lift in copper and around a 50% lift in nickel. It puts the base metals capex bill to achieve a 1.5°C outcome at US$2tn – noting the market size of copper, the bellwether for the complex, is currently about US$140bn at 2019 prices. That US$2tn investment is additive to the spending requirements cited elsewhere in this report.

It is also important to recognise that the operational emissions of mining assets can vary considerably, and an industry average may tell you little about any particular producer. Differences in emissions intensity from assets producing the same commodity are due to a number of factors, only some of which are controllable. Some of the most important are the power source for the project; the geological characteristics of the deposit; the distance to port; and the economies of scale at play, for instance the size of the mobile equipment and non-production infrastructure in place. Additionally one needs to consider the different technological routes to the chosen saleable product, for example the wide variety of nickel products ranging from ~8% Ni content nickel pig iron, 40-50% Ni content ferro-nickels, 70-75% Ni content mattes, up to 99.8% London Metal Exchange (LME) grade and nickel sulphate, the battery precursor feedstock that trades at a premium to LME. Management actions can impact upon many of these items and we would expect the best in class to take action to reduce the emissions from production.

Consider the example of nickel, which is the key metal in the battery cathode chemistry that will help to enable the decarbonisation of transport. The industry-wide emissions intensity curve is the top right panel of Figure 14. There is an enormous gap between the emissions intensity of an integrated nickel sulphide operation utilising renewable power and an Indonesian nickel laterite operation fed with power from a plant burning lower calorific value coal, producing an intermediate product through high pressure acid leaching. And that is before questions of land clearing, tailings disposal and broader biodiversity impact are considered. The energy transition requires a lot more nickel to be produced, promptly, but the world should not be indifferent to where it comes from. Auto original equipment manufacturers (OEMs) are increasingly conscious of the differentiation within the industry and are acting to secure the sustainable supply that their customers demand. BHP's recent agreements with Tesla and the Toyota-Panasonic battery joint venture (Prime Planet Energy & Solutions and Toyota Tsusho Corporation) are indicative of this. Other OEMs, like Renault and Rivian, have indicated they will back a moratorium on sea-bed mining, which is a controversial new supply frontier.[20]

Figure 14: Operational emissions vary widely across assets and across commodities



Source: Skarn Associates, Wood MacKenzie and BHP internal analysis as at 10 September 2020, the date of the publication at its Climate Change Report 2020, available from bhp.com/climate. BHP assets updated for renewable power agreements concluded since that date. **The value of an investment and any income taken from it is not guaranteed and can go down as well as up, you may not get back the amount you originally invested.**

A final consideration is that capital needs to be mobilised today to ensure metals remain the affordable backbone of the energy transition. The discovery, appraisal and development of new metal deposits is a time and capital-intensive process, where a decade from start to finish would be regarded as incredibly swift. Exploration success has been only modest over the last decade, and in the case of copper, the bellwether for both the base metal complex and the electrification mega-trend, grade decline is expected to become a material headwind for primary supply over the course of this decade. The industry does not currently have an abundance of high-quality development opportunities ready to go, and scrap supply is insufficient to fill the gap.[21] Further, investment uncertainty has increased, with a range of copper-rich regions moving to alter royalty and taxation regimes. Against this challenging backdrop, it is far from inevitable that low-cost supply will be induced continuously to neatly match demand period-by-period as the energy transition unfolds at pace. Indeed, periods where demand considerably outpaces supply are extremely likely, given the long lead times on the latter and the possibly exponential performance of the former as radical change in the energy system proceeds. It is telling that copper prices achieved a record high just short of US$11,000/t in May 2021, despite energy transition investment today being only one-third of the levels that the IEA estimates are required to ensure their net zero pathway.

Summing up the key message on minerals demand and supply:

1. The energy transition will not happen without a massive increase in the supply of metals.

2. Yet the extraction of minerals can itself be an emission-intensive process in general, albeit there is considerable diversity across commodities and across operators as to emissions intensities.

We believe there are two clear roles for investors here: (i) engage constructively with the sector to help drive down operational emissions; and (ii) help mobilise the capital that will be required to ensure affordable metal supply does not become a bottleneck in the race to Paris.

19. The IEA estimates of metal intensity assumptions depicted in the charts are, in BHP's view, somewhat conservative vis-à-vis copper and EVs in terms of the average for the full fleet.
20. https://www.reuters.com/business/autos-transportation/exclusive-frances-renault-says-it-backs-moratorium-deep-sea-mining-2022-02-09/
21. BHP analysis indicates that scrap currently provides around 31% of copper units globally, 33% of steel and 30% of nickel, with end-of-life collection rates of around 55-60%, 80-90% and 65-75% respectively. These proportions are expected to rise, but in BHP's view are unlikely to pass 50% of total metal units in any of the three before mid-century.

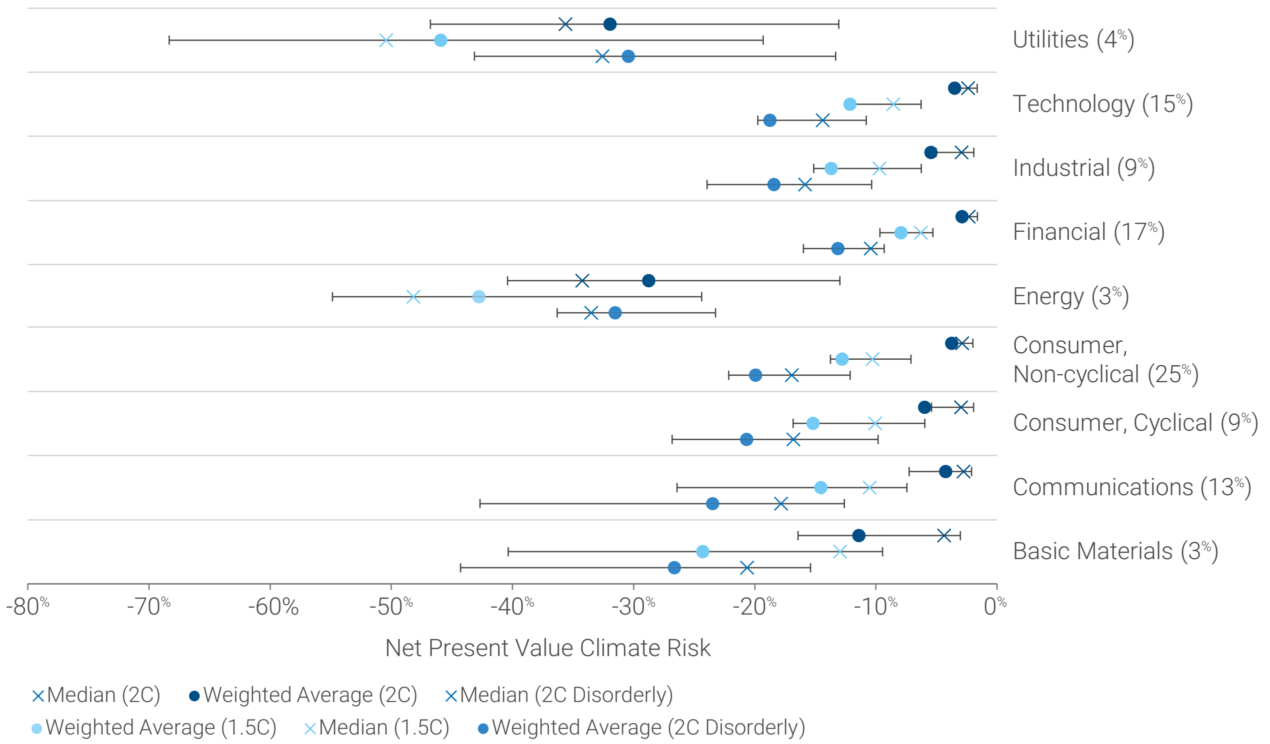
The role of investors

There is increasing pressure on asset owners to reduce their investments' carbon footprint by divesting entirely or partially from high-carbon sectors, particularly the resource extraction industry. However, the world needs some of the products produced by these industries. Some even become more important as the energy system decarbonises, as shown in the previous section. Instead of achieving a reduction in supply, divestment could have the adverse effect that resource extraction assets are moved entirely onto private (or sovereign-related) balance sheets, where there is potentially much less visibility and accountability around environmental impact and long-term extraction plans. For as long as demand for fossil fuels continues to grow and risk-adjusted returns are available, even if one group of investors stops supplying capital, another group will fill the gap – even if the capital is not provided to the same companies. This is especially likely given the structure of many fossil fuel industries, with large numbers of government-backed entities supplying large parts of the market.

While it may be easier for investors to lower the carbon intensity of their investments by divesting entirely from carbon-intensive sectors, it does not necessarily increase the probability of a successful low carbon transition, or reduce an investor's climate risk. Not all companies in carbon intensive sectors are equal. LGIM's analysis of climate risk to companies in its energy transition scenarios shows that the energy and basic materials sectors in fact exhibit some of the largest diversity in risk exposure, as illustrated for a representative global equity index below – and that is without taking into account the possible opportunity of producing the minerals needed for critical transition technologies. The same is true in the utilities sector, which is the most carbon-intensive sector per dollar of revenue in the global equity universe. Yet they provide essential services, and companies within the sector range from pure coal-fired power producers to 100% renewable players. This explains the significant range in impacts within the sector seen below, most pronounced in our 1.5°C net zero scenario.

More generally, companies which have started to lower their carbon intensity or transition their business models towards a proactive role in the low carbon transition are likely to outperform late-mover peers – this will be true across all sectors. These companies are in the minority, as the activities of most companies effectively track to a temperature outcome of more than 3°C, according to LGIM's temperature alignment analysis. Temperature alignment (sometimes called 'implied temperature rise', or ITR) is a forward-looking metric mapping the expected future trajectory of a company's emissions footprint to an estimate of the expected global warming that would occur if all companies acted in its image. The metric considers the company's historical emissions intensity improvements, as well as its future targets, adjusted for their credibility. It is important to note that there is no one generally accepted forward-looking metric for climate decision making, [22] and ITR sits alongside other metrics such as climate value at risk, discussed above.

Figure 15: Climate risk to global equities



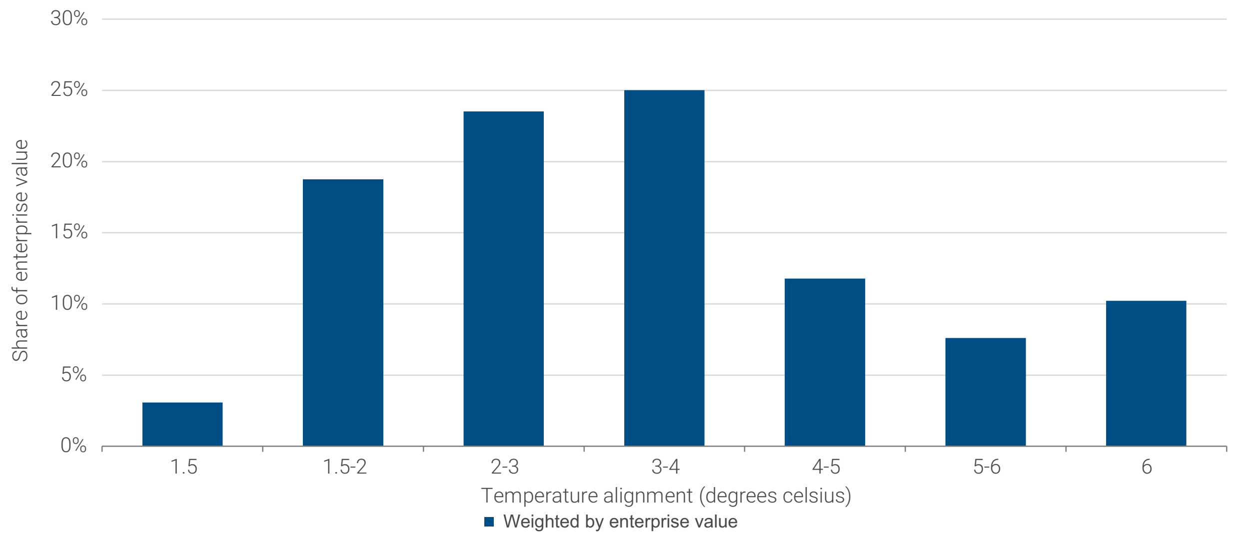
Source: LGIM analysis, as at 31 December 2021. **The value of an investment and any income taken from it is not guaranteed and can go down as well as up, you may not get back the amount you originally invested.** Notes to chart:
(1) Results shown are for a representative global equities portfolio
(2) Climate risk in forward NPV terms, compared to a counterfactual 'inaction' scenario without climate risk. Does not consider opportunity.
(3) Average is weighted by market capitalisation
(4) Numbers in brackets indicate the Index's PV in each sector
(5) Black error bars show the interquartile range of risk within the sector

Less than 5% of global equities by enterprise value are currently aligned to 1.5°C, with a further 19% or so in the 1.5-2.0°C range. Merely shifting available capital into these companies is not a solution, for many reasons. (1) Listed companies do not cover the full universe of technology solutions required to meet the global decarbonisation challenge; (2) portfolios consisting entirely of 1.5°C aligned companies are unlikely to be sufficiently diversified, compromising investors' other objectives such as risk and return targets and/or inflation hedging; and (3) removing capital from existing companies abruptly could leave many assets stranded, increasing the adverse impact on the economy.

Against this backdrop, there is a clear case for engagement with companies in carbon-intensive sectors. Investors with voting rights maintain a degree of influence over companies, which can be used to encourage them to set targets and pivot business models and bond investors providing primary capital to these companies can also express their expectations through engagement. In the fossil fuel industry, this influence can also be used to encourage the effective and safe decommissioning of relevant assets on a climate-consistent timeline – as opposed to selling them to private investors and losing influence on their management.

Engagements are most effective when they are based on evidence, so investors and their advisers must ensure they are integrating climate analysis into their strategic investment frameworks. Independent evaluation of company performance is one of the key pieces of evidence LGIM uses to engage with companies. This includes the climate risk and alignment metrics mentioned above. Both measures are helpful in starting conversations around both the impact of the climate on companies, and the impact of companies on the climate. We cannot rely purely on carbon intensity to understand companies' complex relationships with the climate. That said, where engagement is ineffective and companies continue to ignore the need for decarbonisation and refuse to engage on their environmental performance, there may of course still be a case for divestment.

Figure 16: Temperature alignment of global equities



Source: LGIM analysis, as at 31 December 2021. Notes to chart:
(1) Results shown are for a representative global equities portfolio
(2) Considers historical emissions reductions per unit of revenue, as well as credible forward targets
(3) Refer to Appendix for further detail on LGIM's temperature alignment metric
There is no guarantee that any forecasts made will come to pass.
22. A summary of the current state of play regarding forward-looking climate metrics can be found at: Task Force on Climate-related Financial Disclosures (TCFD) March 2021, available at https://assets.bbhub.io/company/sites/60/2021/10/Summary-of-Forward-Looking-Financial-Metrics-Consultation.pdf"

Conclusions

Today there is no certainty over the world's climate pathway, and markets struggle to understand the associated risks and opportunities. But the current level of uncertainty can't persist forever: as time goes on, pathways start to get closed off, and the range of possible outcomes will continue to narrow. What we can say with certainty is that:

- Radical change to the world's energy and land use systems is required: time is short and current rates of investment are insufficient to bring about the required change.
- The battle will be won or lost in populous emerging markets, where energy supply must grow to meet increasing demand while simultaneously transitioning to low-carbon sources.
- Action must be taken as soon as possible, as it will be significantly less costly in monetary and socio-environmental terms than delayed action.
- Policy must address all fundamental elements of the transition to allow the demand and supply sides of the energy system to adjust as required.
- Carbon pricing calibrated to the end-goal is a core ingredient of any effective policy framework.

And finally, the hardware of decarbonisation will be highly metals intensive, and meeting this stepwise uplift in demand will require very substantial capital to be allocated to the discovery, extraction, processing and recycling of these metals. Yet the extraction of minerals can itself be an emission intensive process.

There are two clear roles for investors here:

- Engage constructively with the sector to help drive down operational emissions.
- Mobilise the capital that will be required to ensure metal supply does not become a bottleneck in the race to Paris.

Appendix 1

LGIM's climate risk metric

LGIM's climate risk metric allows investors to evaluate the transition risks from climate change for their portfolios, across multiple scenarios. Risks are based on forward-looking valuations of individual companies across the capital structure, recognising the stock-specific nature of climate risk. Given the uncertainty around future climate outcomes, it is unlikely that climate risk is properly priced into markets today. The climate risk metric offers a view on the extent of this mispricing for various climate scenarios. It is primarily a statement on the exposure of companies as they are today and hence allows only for minimal mitigation on the companies' part.

Climate risk translates macroeconomic variables from climate scenarios into company and country financial impacts, which in turn can be used to infer security impacts across listed equities and bonds. The analytical approach varies by sector, in recognition of the differences in the way companies are likely to experience climate risk. For example, in the financial sector, exposure to climate risk is primarily through the balance sheet rather than the income statement. The metric does not currently cover acute physical risk or chronic physical risk beyond labour productivity impacts. It does cover both micro- and macroeconomic transition risk.

The metric is usually expressed as the change in asset valuation relative to a counterfactual scenario without climate risk. This means that a company with X% climate risk by 2050 would see its valuation be X% lower in a climate scenario compared to a counterfactual scenario without climate risk by 2050. We express risk in this way to abstract from idiosyncratic growth – a large driver of asset value for companies in some sectors. The X% difference between a climate scenario and no climate risk hence only captures climate related risk.

As a result, we view as critical the consideration of climate risk alongside all other investment risks and its integration into the full investment process.

LGIM's temperature alignment metric

The purpose of LGIM's temperature alignment metric is the measurement and management of investment impact. Temperature alignment asks of companies: What climate outcome would the world head towards if all companies' emissions evolved in line with yours? This approach reflects the direct linkage between global carbon emissions and the likely severity of global warming. It allows investors to measure their impact on climate change and evaluate their performance relative to science-based targets, such as well-below 2°C or net-zero 2050.

The temperature alignment calculation considers both backward- and forward-looking data. Using 10 years of data on companies' historical emissions intensity, it extrapolates the next 10 years of emissions performance. We add a probability-adjusted projection of company emissions given current reduction targets, if any. The combination of these two pathways (historical and target) brings us to an understanding of companies' direction of travel. We compare this to the implied pathway by sector from our climate scenarios to assess the companies' implied temperature alignment. Again, the approach differs slightly by sector – for example, assessing financials' based on the emissions intensity of their balance sheets rather than their operational emissions.

Appendix 2

The many, many paths to Paris

	Energy requirement (demand)				Electrification of end use				Harder-to-abates		
	Energy efficiency (EJ per unit of GDP vs. 2019)	**Primary fossil fuel demand (EJ)**	**TFC (EJ)**	**TPED (EJ)**	**Electricity share of TFC**	**Electricity share of transport**	**Wind and solar capacity (TW)**	**Wind & solar share of power**	**CCUS**	**Hydrogen share of TFC**	**Biomass share of TPED**
BHP 1.5C	**42%**	**284**	**407**	**558**	**41%**	**35%**	**12.2**	**45%**	**5.6**	**2%**	**16%**
LGIM 1.5C	**42%**	**225**	**402**	**583**	**43%**	**29%**	**19.5**	**69%**	**7.3**	**10%**	**19%**
IEA NZE	38%	119	344	543	49%	44%	23.2	70%	7.6	13%	19%
Shell Sky	63%	375	549	828	43%	18%	na	62%	5.3	2%	13%
BP NZ	46%	136	321	625	52%	42%	13.4	64%	5.5	9%	11%
Equinor Rebalance	45%	221	366	513	45%	39%	12.7	52%	2.0	na	11%
IHS CCS	41%	249	383	551	44%	44%	15.3	61%	7.3	8%	15%
IHS Multitech	37%	143	347	509	46%	47%	20.9	70%	1.3	9%	15%
Wood Mackenzie 1.5C	44%	172	374	481	na	48%	17.3	67%	7.6	13%	na
BNEF Green	na	51	391	577	49%	48%	21.6	70%	zero	22%	11%
BNEF Red	na	51	391	761	49%	48%	21.7	61%	zero	22%	11%
BNEF Grey	na	281	395	536	49%	49%	17.4	62%	7.4	2%	15%
TOTAL Rupture	na	150	336	674	39%	20%	13.3	63%	7.5	9%	17%
IPCC Q1 average	34%	133	324	440	34%	9%	5.2	30%	6.2	1%	16%
IPCC Q2 average	41%	200	403	552	40%	17%	11.5	46%	9.3	2%	22%
IPCC Q3 average	50%	250	475	648	46%	22%	20.3	63%	12.7	3%	29%
IPCC Q4 average	55%	339	555	728	56%	32%	42.2	78%	16.3	6%	42%
IPCC Min	23%	57	245	289	30%	2%	2.9	17%	3.8	1%	10%
IPCC Max	65%	608	695	1,013	71%	59%	51.9	92%	18.6	17%	54%
NGFS GCAM	47%	239	396	572	57%	25%	17.3	69%	10.6	1%	18%
NGFS MESSAGE	39%	133	388	475	48%	33%	20.8	64%	4.0	2%	17%
NGFS REMIND	39%	121	342	449	53%	26%	23.2	74%	8.5	5%	25%
Average total sample	44%	211	402	586	47%	33%	18.7	60%	7.7	7%	19%
Median total sample	42%	186	390	555	46%	34%	17.3	63%	7.4	6%	16%

EJ = exajoules, TFC = Total Final Consumption, TPED = Total Primary Energy Demand, TW = Terrawatt, CCUS = Carbon Capture, Utilisation and Storage

Source: BHP and LGIM analysis, as at 31 December 2021. Note to table: Refer to the BHP Climate Change Report 2020 available at bhp.com/climate for information about the assumptions, outputs and limitations of BHP's 1.5°C scenario.
Important notice: There are inherent limitations with scenario analysis, and it is difficult to predict which, if any, of the scenarios might eventuate. Scenarios do not constitute definitive outcomes for us. Scenario analysis relies on assumptions that may or may not be, or prove to be, correct and may or may not eventuate, and scenarios may be impacted by additional factors to the assumptions disclosed.
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