Climate risks to nine key commodities

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Executive summary

'Climate change is already fracturing the stability of the natural world, and it will increasingly fracture the stability of global supply chains unless adaptive measures are taken.'

Will Jackson-Moore, Global Sustainability Leader, PwC UK

Climate change poses a serious and growing threat to the world's ability to produce essential commodities. Even in a best-case scenario in which the world manages to slow the rate of greenhouse gas emissions, climate change will cause extreme weather conditions to occur with far greater frequency and severity. These conditions, in turn, cause hardship for the miners and farmers who supply the commodities on which industries and communities depend. Unless commodity producers and buyers take preventive action now, they are likely to find their operations increasingly disrupted.

> ‘This research grounds the climate risks that businesses have to contend with. Businesses need to prepare for a climate reality where production and supply chains, including that of critical commodities, will be increasingly at risk of significant disruption.’
>
> **Gim Huay Neo,** Managing Director of Centre for Nature and Climate, World Economic Forum

To reach these conclusions, we first located the mines and farms across the world that produce nine important commodities:

- **Three vital metals** widely used in manufacturing, transport, infrastructure and more: iron, zinc, and aluminium (made from the mined material bauxite).
- **Three critical minerals** integral to electronics and clean-energy technologies: cobalt, copper, and lithium.
- **Three food crops** that together account for 42% of the calories people eat: maize, rice, and wheat.[1]

Next, we identified two climate-related weather perils - drought and heat stress - that are known to be potentially detrimental to production at mines and farms unless adaptive measures are taken. Heat stress can make it difficult or even life-threatening for workers to work. Drought can decimate crops and harm mining which can be heavily dependent on water (for example, over two million litres of water are required to mine one ton of lithium).

Finally, we analysed these mines’ and farms’ exposure to climate-related drought and heat stress, both at a present day baseline and in two future years: 2035 and 2050. For 2050, we examined how risk exposures vary depending on how effectively the world reduces its carbon emissions by comparing low vs high emission scenarios.[2] This enabled us to draw conclusions about the amount of current production capacity for each commodity that could be exposed to climate-driven disruption in coming years.

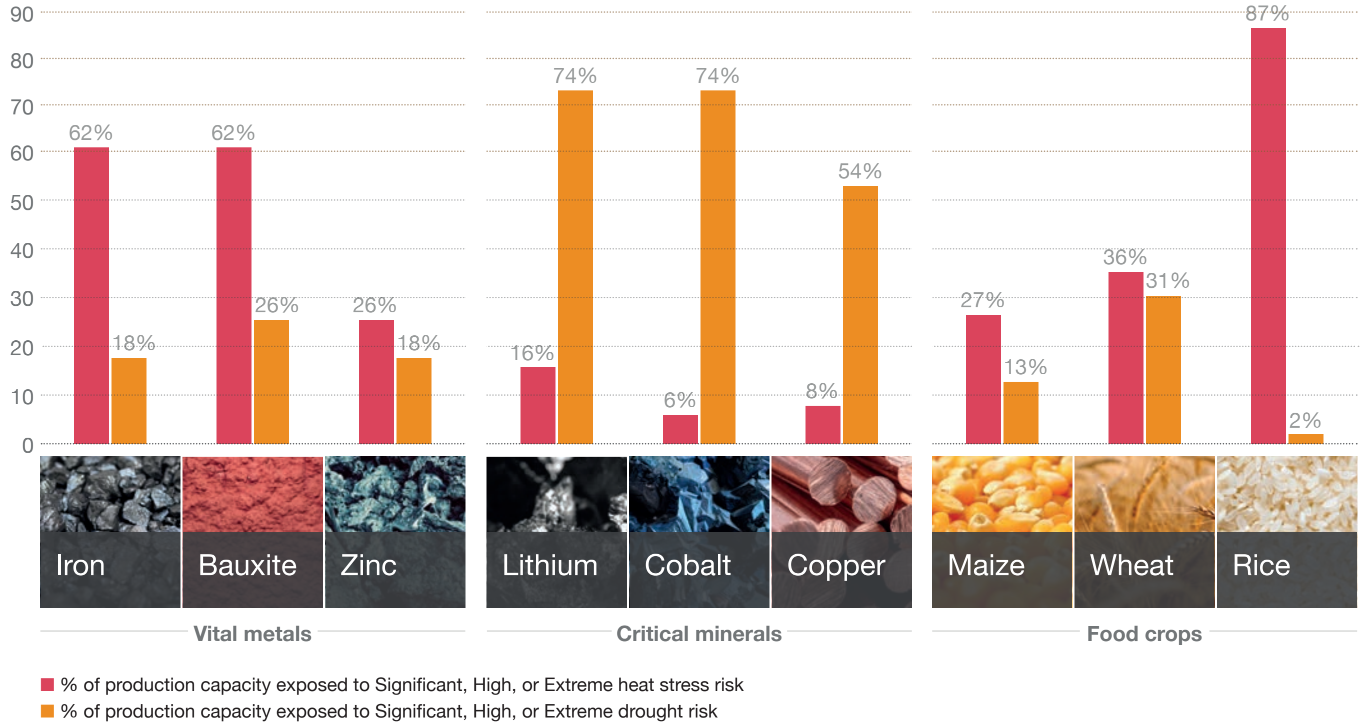
We find that:

The world relies on just a few countries to produce each of the nine key commodities. For each commodity, at least 40% of its global supply is produced from a distinct set of no more than three countries. Concentration is particularly pronounced for lithium, cobalt, iron, and bauxite, with more than 70% of global supplies sourced from no more than three countries per commodity. Within countries, production is concentrated even further. For example, more than half the world’s cobalt comes from just five mines in the Democratic Republic of Congo. This geographic concentration may heighten risks to the global supply because the more concentrated the sources of a commodity, the greater the impact that disruption in any one locale could have on global supplies.

Unless adaptive measures are taken or production is moved elsewhere, more and more of the world's capacity to produce essential commodities is likely to be exposed to climate-driven disruption - even in an optimistic low emissions scenario. The chart below shows the levels of risk exposure in a low emissions scenario.

Commodities at risk

Low emissions scenario, Year 2050



In some cases, risks are rising sharply from low levels, underlining the need to enable commodity producers to be prepared to manage increasing risks that, in some cases, they may have little experience in managing.

We can't assume that future emissions reductions will protect us from a changing climate. Even in an optimistic low emissions scenario, heat stress and drought risks will increase markedly by 2050, highlighting the importance of adapting to a changing climate while we strive to reduce carbon emissions.

Commodity producers and consumers should begin preparing for growing disruption risk. We offer three steps to help adapt to a changing climate. First, enhance resilience by identifying and managing climate risks throughout the supply chain. Next, capitalise on the opportunities to deliver products, services, or business models that help companies and communities adapt. Finally, join forces with stakeholders from governments to communities to shape collaborative outcomes and enhance adaptation at a policy and systemic level. We offer examples and case studies for each step.

How climate change threatens nine commodities we rely on

The global economy - and the world's people - depend on essential commodities like iron, rice, and wheat. As climate change hits harder, will it affect our ability to produce the commodities we need? We set out to find answers.

We identified nine essential commodities

First, we identified nine commodities that are essential to the global economy[3].

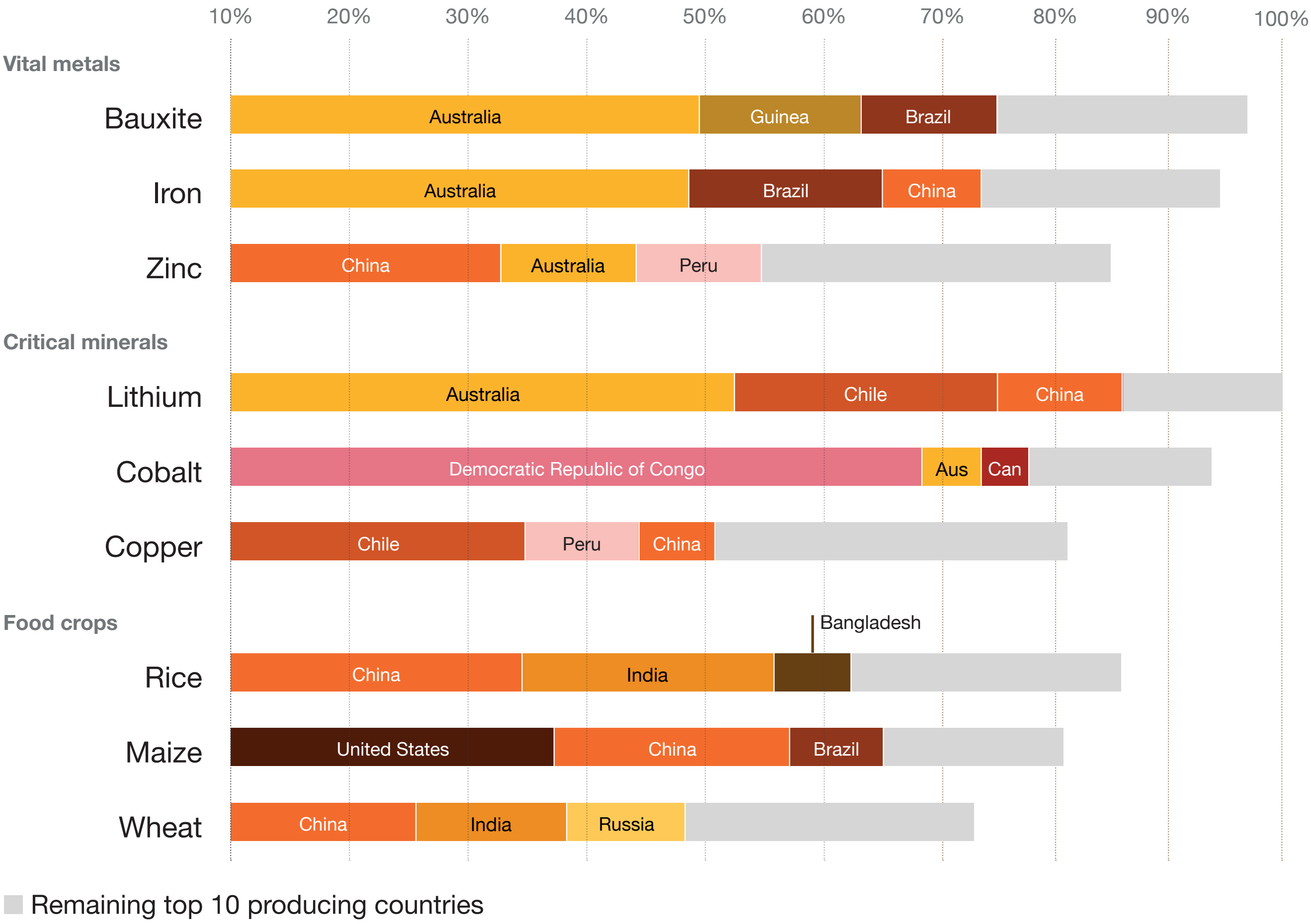
- **Three vital metals** widely used in manufacturing, transport, infrastructure and more: **iron, aluminium, and zinc**.
- **Three critical minerals** integral to electronics and clean-energy technologies: **cobalt, copper, and lithium**.
- **Three food crops** that together account for 42% of the calories people eat: **maize, rice, and wheat.**[4]

We located the mines and farms that produce these commodities and found they are geographically concentrated, potentially heightening disruption risk

Just a handful of countries, and often specific regions within countries, account for much of the global supply of each commodity. In 2020, at least 40% - and as much as 85% - of the global supply of each commodity is produced in just three countries per commodity.

Production of each essential commodity is highly concentrated

Share of global production (2020)

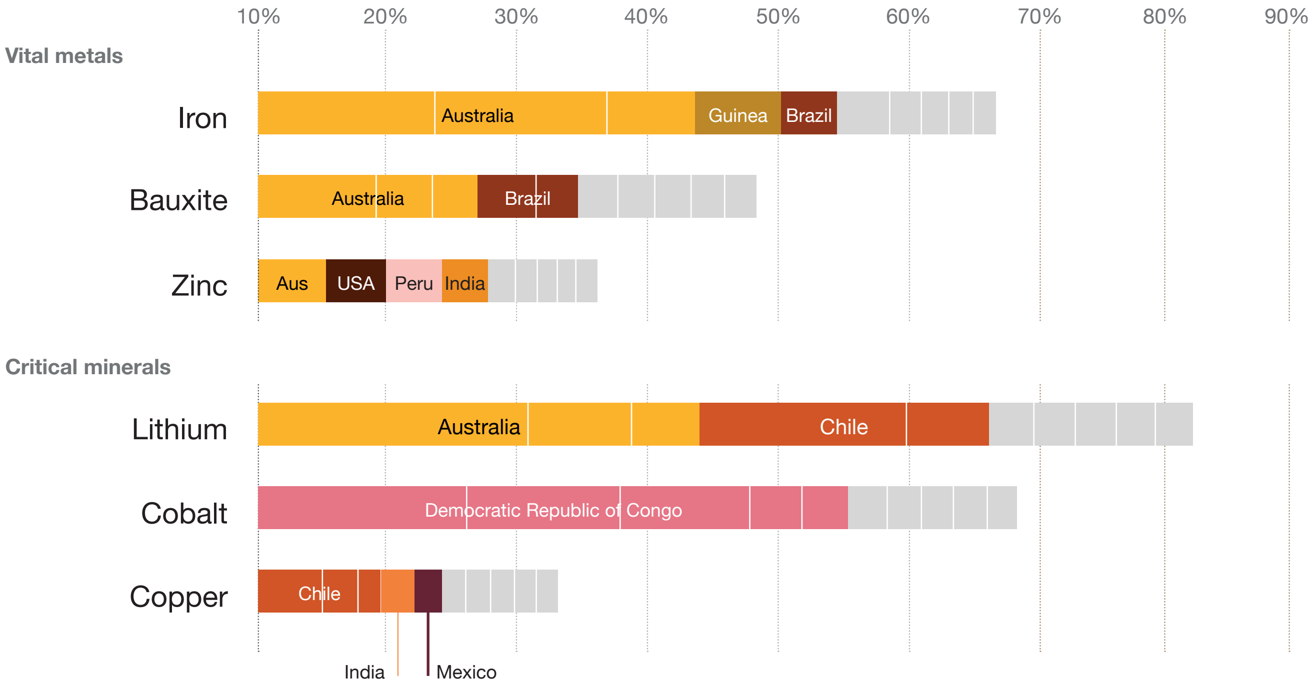


Source: CapIQ, FAO, PwC analysis

Commodity production isn't just concentrated in a small number of countries. It is also concentrated in a limited set of locations *within* those countries. A handful of mines produce most of the world's metals and minerals, and a few regions account for the majority of the world's key crops. For example, in 2020, just five mines (all in the Democratic Republic of Congo) produced most of the world's cobalt. In total, 81% of the world's lithium, 50% of bauxite, and 44% of iron were each sourced from no more than ten mines.

Global production of the six metals and minerals is highly concentrated among just a few mines

Each block represents one of the top 10 mines for that commodity



Source: CapIQ, FAO, PwC analysis

Production of key crops is also concentrated within countries. For example, in the US, the world's biggest maize producer, maize production is concentrated in just five states.[5]

These geographic concentrations **could potentially heighten risks to global supplies** because, with fewer locations providing each commodity, disruption at any single location could have a more substantial impact on global supply.

We examined how climate-driven drought and heat will affect the areas where the mines and farms in our analysis are located

Next, we sought to identify how climate change might affect production of the essential commodities at the mines and farms we have identified. Climate change can have many impacts from wildfires to cyclones. We focus on two impacts of climate change that are well known to potentially disrupt productivity at mines and farms unless adaptive measures are taken. Many other climate change hazards could affect mining and agriculture, but drought and heat stress warrant special attention because they can be particularly detrimental, as explained below.

Drought. Drought[6] presents a serious risk to both mining and farming. In mining, a lack of water undermines water-intensive operations including ore extraction, mineral processing and dust control. In farming - the world's thirstiest industry, accounting for 70% of the world's freshwater consumption in 2022[7] - drought can reduce crop yields. Water is particularly critical in the cultivation of rice, wheat and maize.[8]

We use a standard drought index[9] to define four levels of drought risk:

Risk Category	Risk Levels / Duration of Severe Drought
Moderate	**10% of time** in severe drought, over the 20 year span centred on each year being analysed
Significant	**20% of time** in severe drought, over the 20 year span centred on each year being analysed
High	**40% of time** in severe drought, over the 20 year span centred on each year being analysed
Extreme	**80% of time** in severe drought, over the 20 year span centred on each year being analysed

Note: The term significant as we use it here has no relationship to statistical significance testing.

Heat stress. Both mining and farming see productivity declines when heat stress rises, reflecting the fact that miners and farm workers often spend large numbers of hours outdoors where they are directly exposed to the impacts of heat and humidity. (We define heat stress in terms of Wet Bulb Globe Temperature [WBGT], a measure that captures both heat and humidity. For more detail, please see Appendix 1.) A relatively small change in temperature can have a big impact on productivity.

We define four levels of heat stress risk and their impacts on labour productivity[10]:

Risk Category	Risk Levels / Duration	Impact
Moderate	At least 10 days above a WBGT threshold of 25.0°C. Total days with WBGT at this level may be higher	**Limited impact on labour productivity**
Significant	At least 10 days per year with an average daily WBGT of 26.3°C. Total days with WBGT at this level may be higher.	**Reduces labour productivity by at least 25%**
High	At least 10 days per year with an average daily WBGT of 28.9°C. Total days with WBGT at this level may be higher.	**Reduces labour productivity by at least 50%**
Extreme	Each year, an average daily WBGT of 32.2°C occurs on one or more days.	**Reduces labour productivity by at least 75%** and is dangerous to outdoor workers.

Source for labour productivity impact: Rockefeller Foundation Resilience Center, 'Extreme heat: Economic and social consequences for the US," 2021

We model heat stress and drought risks at three different time periods: a **2020 baseline** (an average from 2010 to 2030, centred on 2020), and look ahead to the years **2035** and **2050**. (Note: Throughout this report, we will use 'now' or 'today' as shorthand for referring to the present day baseline period.)

In addition, for the year 2050, we compare two different scenarios for how the world's long-term efforts at reducing carbon emissions might play out. We examine both a low and high emissions scenario as defined by the Intergovernmental Panel on Climate Change (IPCC):

- A **low-emissions scenario** for 2050 in which substantive action is taken to curb emissions, keeping global average temperature increase below 2C. Even in this scenario, there will likely be a substantial increase in the proportion of some essential commodities impacted by heat stress and drought. (SSP1-2.6)
- A **high-emissions scenario** for 2050 in which no action is taken to follow a low-emissions pathway, resulting in a catastrophic rise in global average temperature of 4.4C by 2100. (SSP5-8.5)

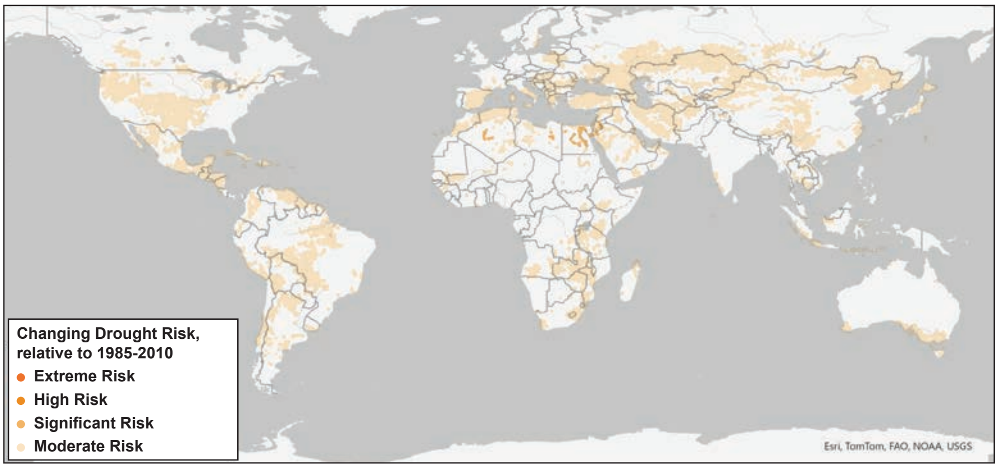
We find increasing levels of drought and heat risk across the world

The proportion of the earth's surface exposed to significant, high or extreme risk of drought is predicted to increase sharply under both high and low emissions scenarios, affecting all inhabited continents to varying degrees.

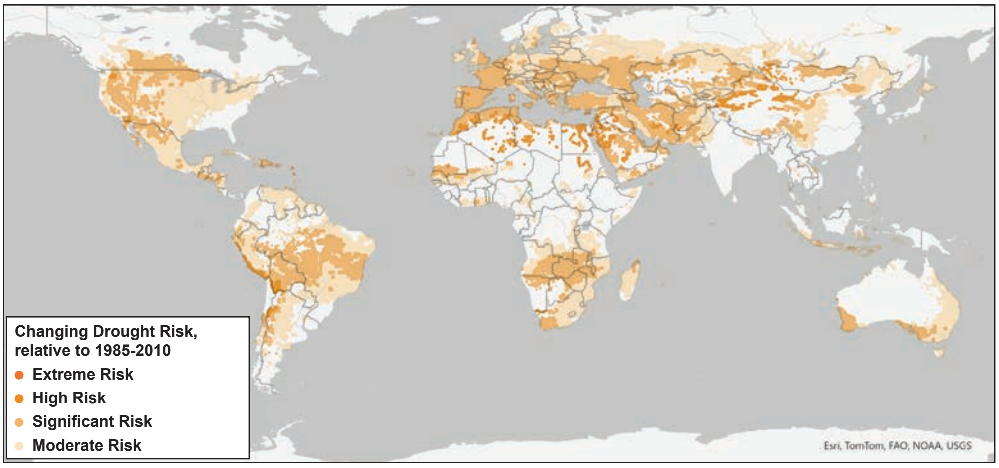
Our drought risk model uses historical period data (from 1980-2015) to calibrate what "normal" conditions are in a location. These normal conditions are then compared to a baseline scenario and future projected scenarios for the same location.

This methodological choice has the effect of drought risks appearing lower in regions that are already arid – i.e., because these conditions are considered "normal". This is why our map may not indicate a drought risk for some areas known to be arid, such as parts of Australia. This method of defining drought risk helps to highlight where drought risks are increasing beyond what areas may be accustomed to - or prepared to manage.

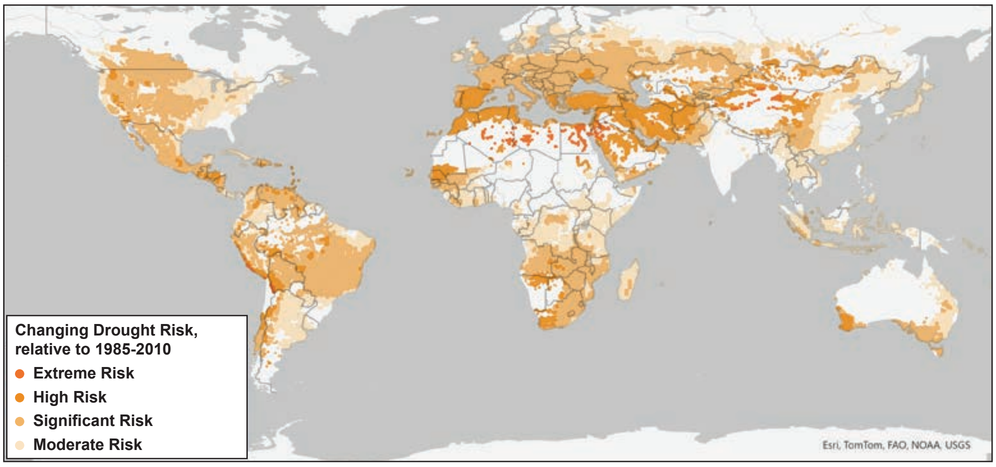
Global model of drought risk: Baseline 2020



Global model of drought risk: Low emissions 2050



Global model of drought risk: High emissions 2050

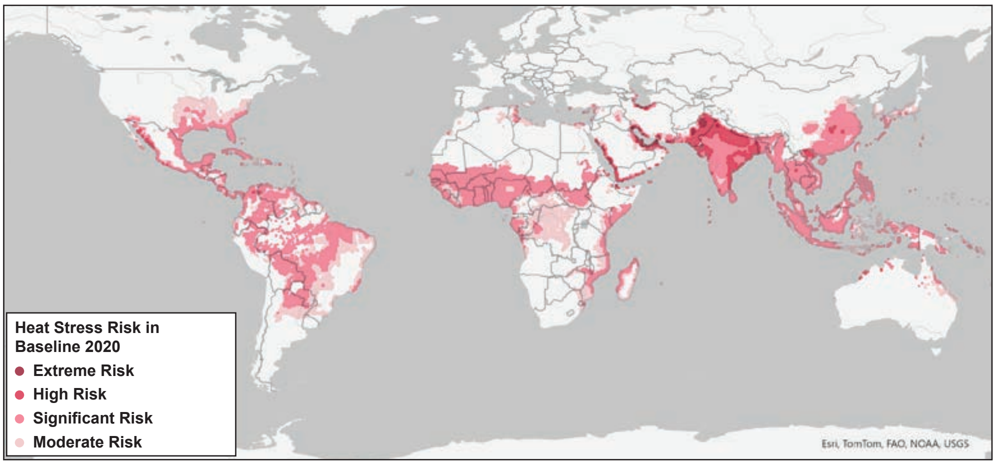


Heat stress is increasing too. Our analysis shows that, under both low and high emissions scenarios, the proportion of the earth's surface exposed to significant, high or extreme risk of heat stress is predicted to increase, particularly in North America, South America, Africa and Asia.

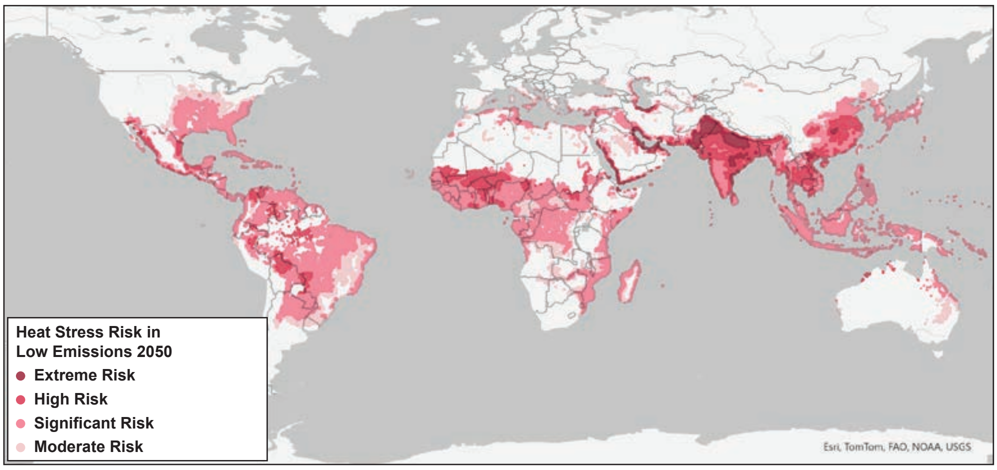
As we have seen, heat stress risk levels are based on Wet Bulb Globe Temperatures, a combined measure of heat and humidity. Anyone who has spent time outside on a day that is both hot and humid may have noticed how humidity magnifies the impact of heat, so this combined measure better reflects the true impact of heat and humidity on human physiology.

This means that some areas we may typically think of as hot (like the Sahara for example) but that have very low humidity do not experience the combined effects of heat and humidity that our analysis seeks to explore. The chart in Appendix 1 gives more details of how heat and humidity interact and the resulting heat stress risk category levels.

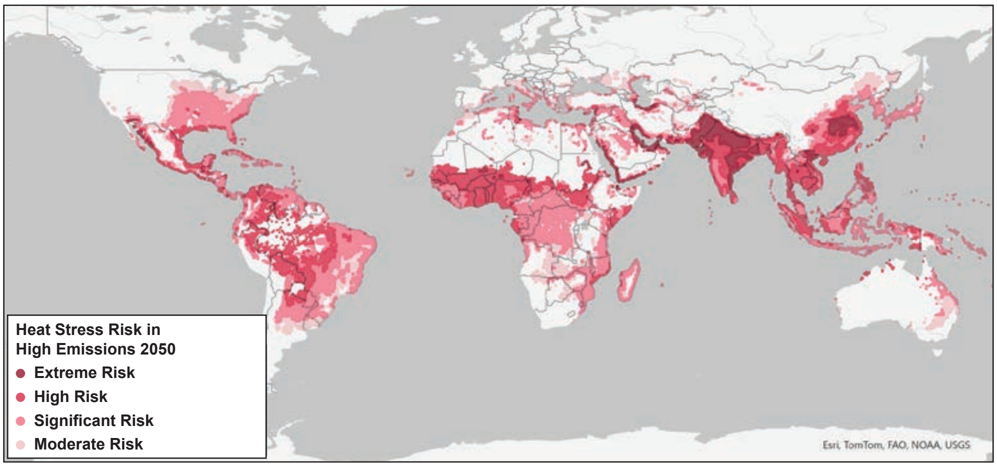
Global model of heat stress risk: Baseline 2020



Global model of heat stress risk: Low emissions 2050



Global model of heat stress risk: High emissions 2050



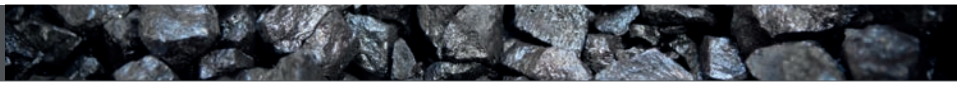
We find increasing climate risks to sites that produce each of the nine commodities

Below we examine how increasing heat stress and drought risks may affect sites that produce the essential commodities unless adaptive measures are employed. Please note that we focus on only the strongest levels of risk: Significant, High, and Extreme.

Vital metals

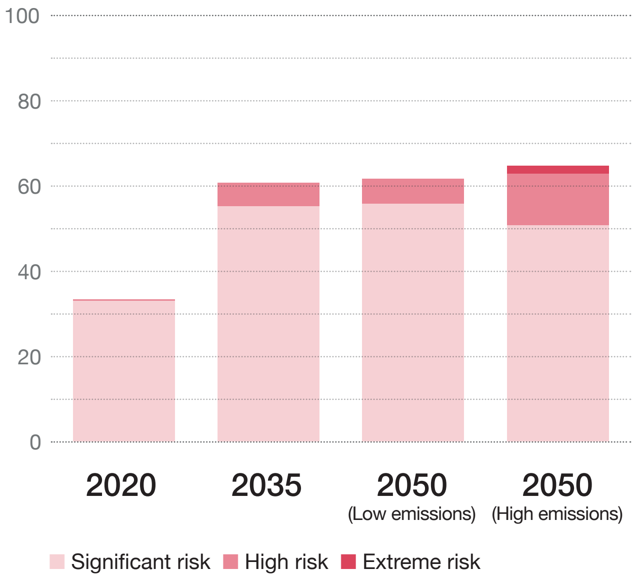
We find that all the vital metals we analyse face increasing amounts of risk from both heat stress and drought. Mining of vital metals is currently dependent on China, Brazil and Australia which all face rising risks of drought and heat stress. Our research indicates that over 60% of the world's bauxite and iron production may face significant or greater heat stress risk by 2050 even in a low emissions scenario, while in a high emissions scenario in 2050, 40% of the world's zinc production may face significant or greater drought risk (up from zero significant drought risk today).

Iron



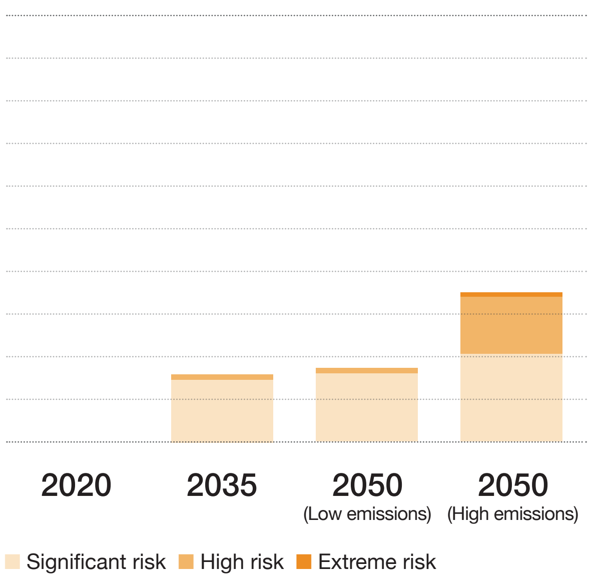
Heat stress

% of **Iron** production capacity exposed to heat stress risk



Drought

% of **Iron** production capacity exposed to drought risk



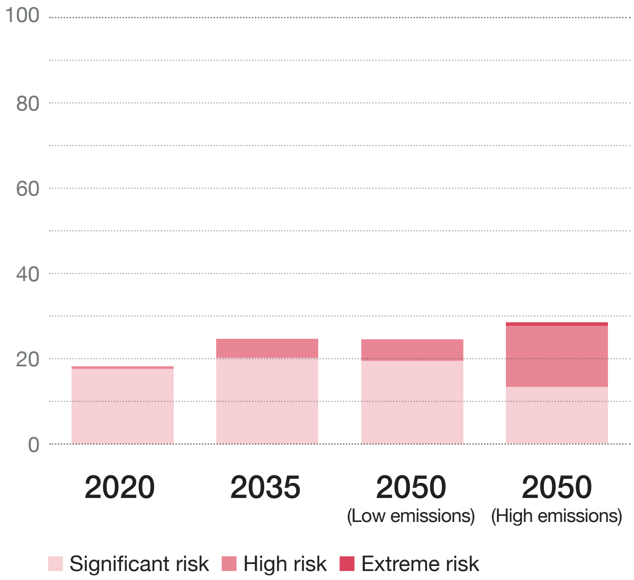
60%

of the world's bauxite and iron production may face significant or greater heat stress risk by 2050 even in a low emissions scenario.

Zinc

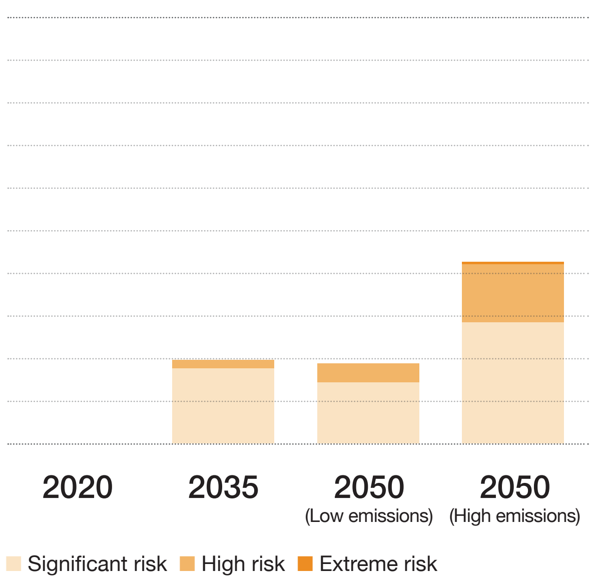
Heat stress

% of **Zinc** production capacity exposed to heat stress risk



Drought

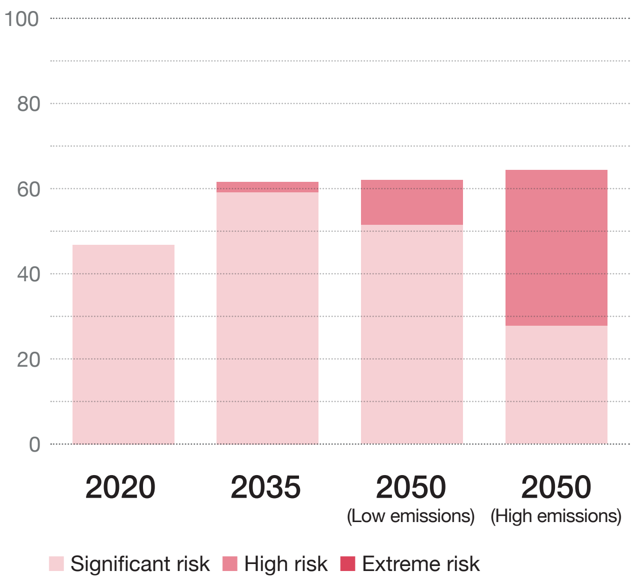
% of **Zinc** production capacity exposed to drought risk



Bauxite

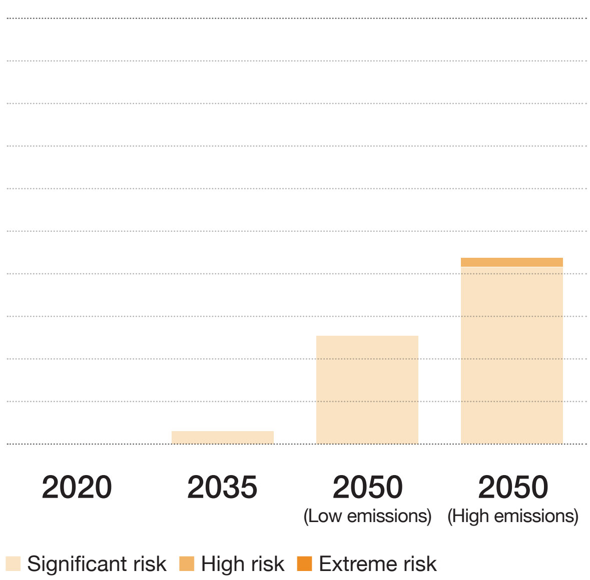
Heat stress

% of **Bauxite** production capacity exposed to heat stress risk



Drought

% of **Bauxite** production capacity exposed to drought risk



Critical minerals

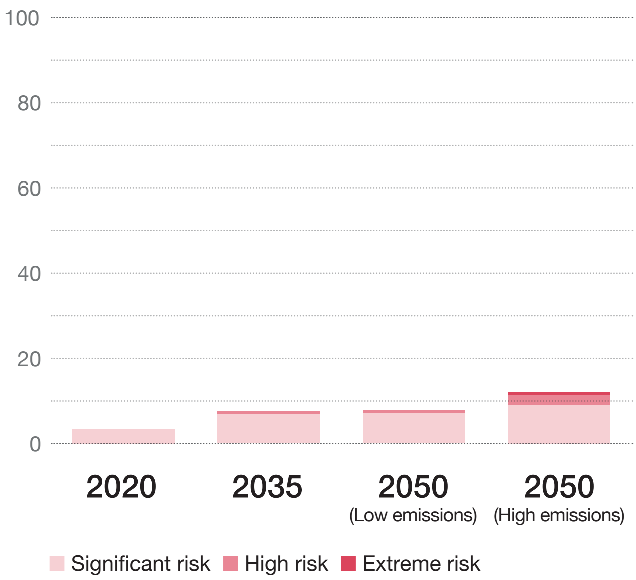
Our research shows that both heat stress and drought have the potential to constrain supply of critical minerals, with drought posing a much larger risk than heat stress. Critical mineral production is heavily dependent on Australia, the Democratic Republic of Congo, Chile and Peru - all of which will see rising drought risks.

By 2050, even if the world substantially reduces its carbon emissions, over 70% of cobalt and lithium production could face significant, high, or extreme drought risk - up from near zero today. That could pose challenges for lithium mining because it is exceptionally dependent on water, requiring more than two million litres of water to mine one ton of lithium.[11] Similarly, less than 10% of copper production faces significant or greater drought risk today, rising to over half in a 2050 low emissions scenario. The methods currently used to mine critical minerals in arid areas may need to be more widely deployed - and may need to manage even tougher conditions.

Copper

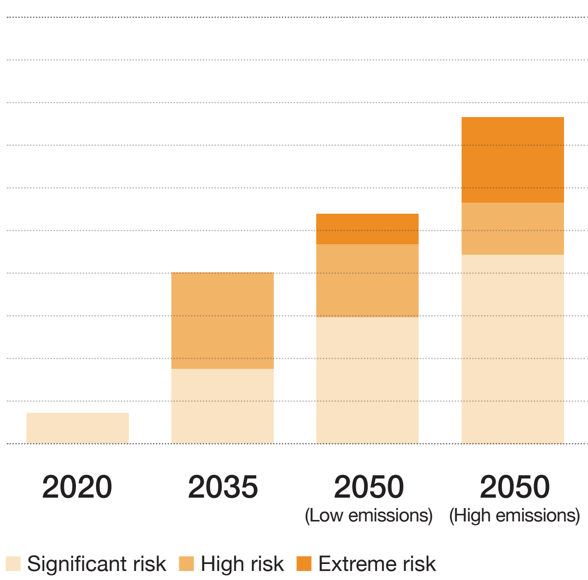
Heat stress

% of **Copper** production capacity exposed to heat stress risk



Drought

% of **Copper** production capacity exposed to drought risk



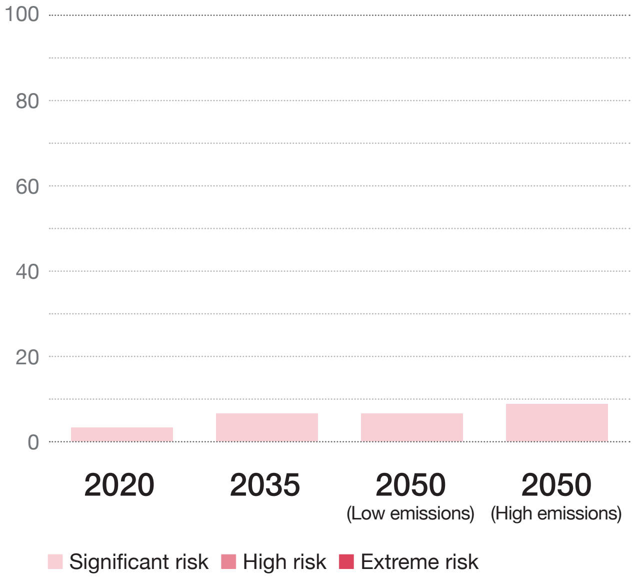
10%

of copper production faces significant or greater drought risk today, rising to over half in a 2050 low emissions scenario.

Cobalt

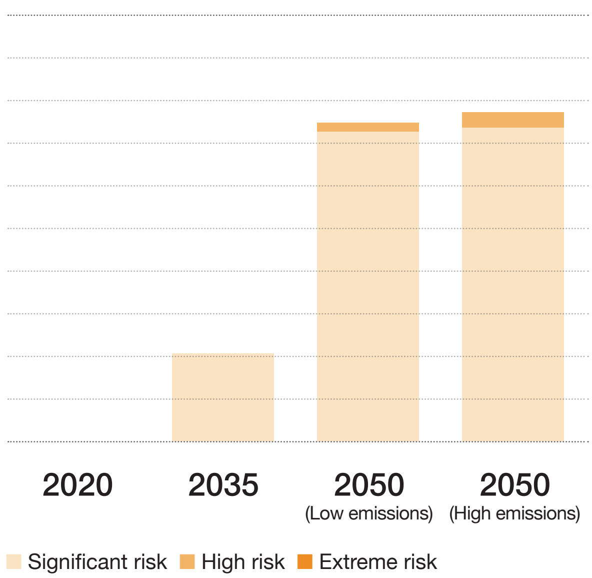
Heat stress

% of **Cobalt** production capacity exposed to heat stress risk



Drought

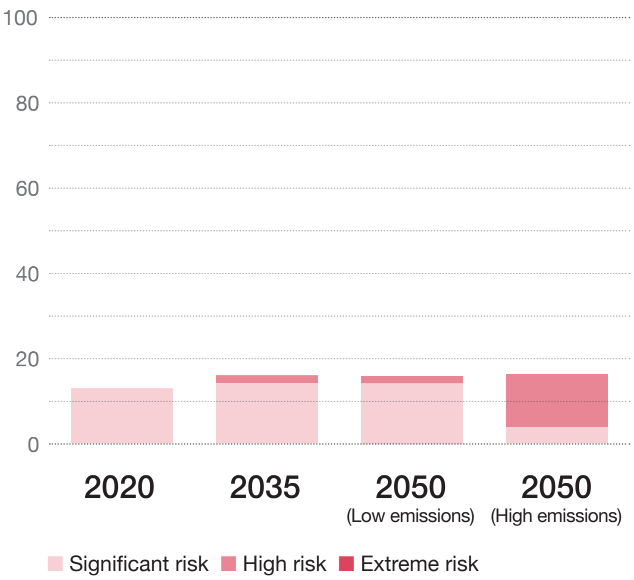
% of **Cobalt** production capacity exposed to drought risk



Lithium

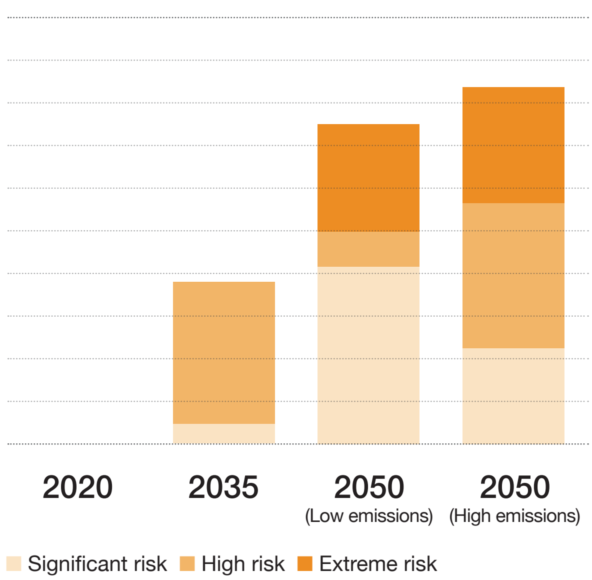
Heat stress

% of **Lithium** production capacity exposed to heat stress risk



Drought

% of **Lithium** production capacity exposed to drought risk



Key crops

All three crops face growing risks from both heat stress and drought. The most widespread and serious risk is to rice, around 90% of which will face significant or greater heat stress risk by 2050 in a high emissions scenario. Over 90% of rice is grown in Southeast Asia, a region that will see sharp increases in heat stress in the coming years.

Already today, over 75% of rice is grown in conditions of significant or greater heat risk, showing that it is not just the level of risk that matters, but rather how well prepared producers are to adapt. However, we shouldn't be too quick to assume that today's adaptation measures will be sufficient. The percentage of rice produced under high heat stress risk will more than triple by 2050 under a high emissions scenario, and around a quarter of rice will face extreme heat stress risk (up from zero today) driven by rising heat levels across Southeast Asia.

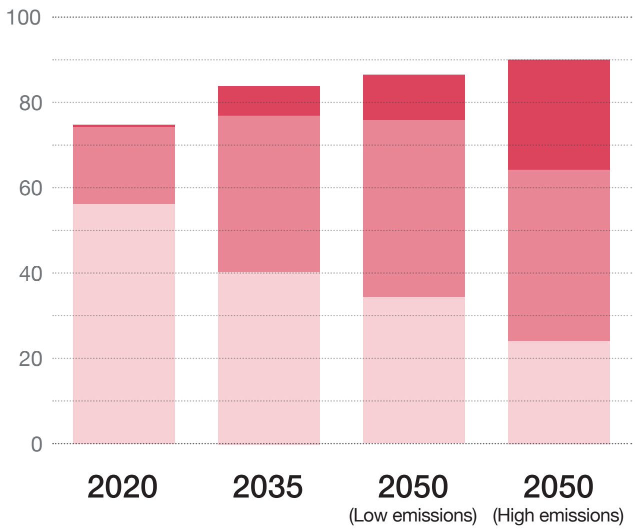
Today's methods of rice farming in hot conditions may well be sufficient for the hotter days ahead, but the case of rice underlines a key point of this report: we must prepare for what's coming.

Drought risk is also increasing sharply for key crops. At our present day baseline, less than 1% of maize and wheat face significant or greater drought risk, rising to over 30% and 50% respectively in a 2050 high emissions scenario.

Rice

Heat stress

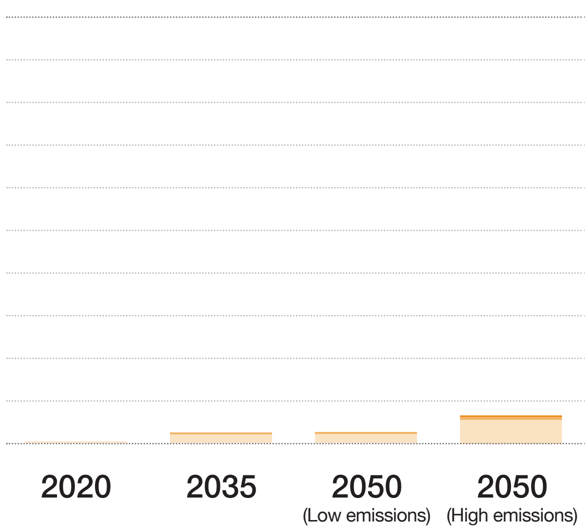
% of **Rice** production capacity exposed to heat stress risk



Significant risk High risk Extreme risk

Drought

% of **Rice** production capacity exposed to drought risk

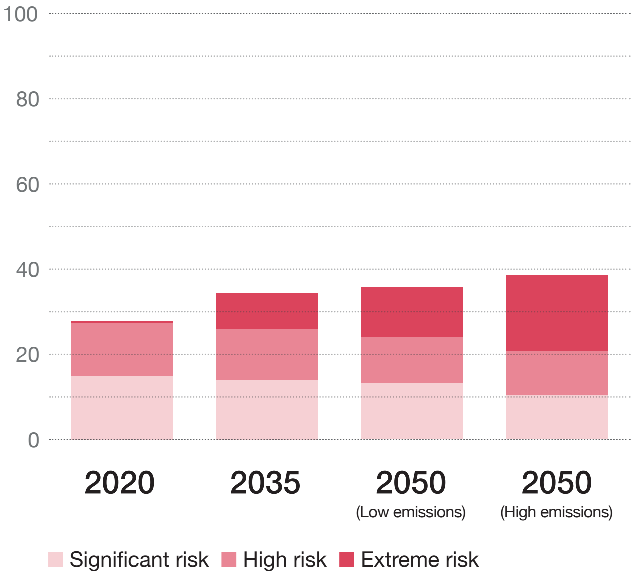


Significant risk High risk Extreme risk

Wheat

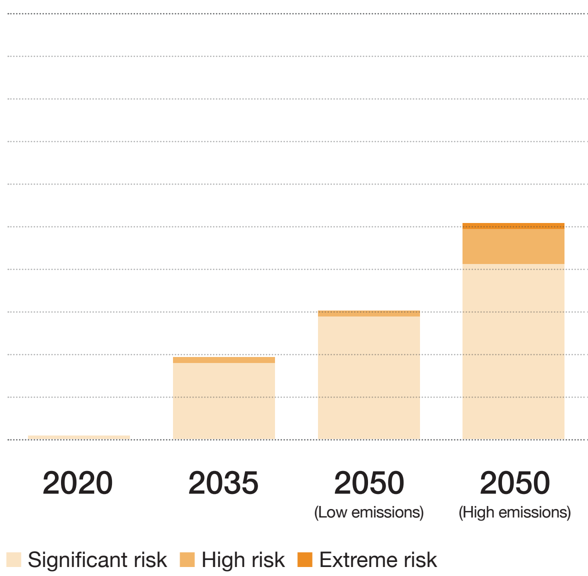
Heat stress

% of **Wheat** production capacity exposed to heat stress risk



Drought

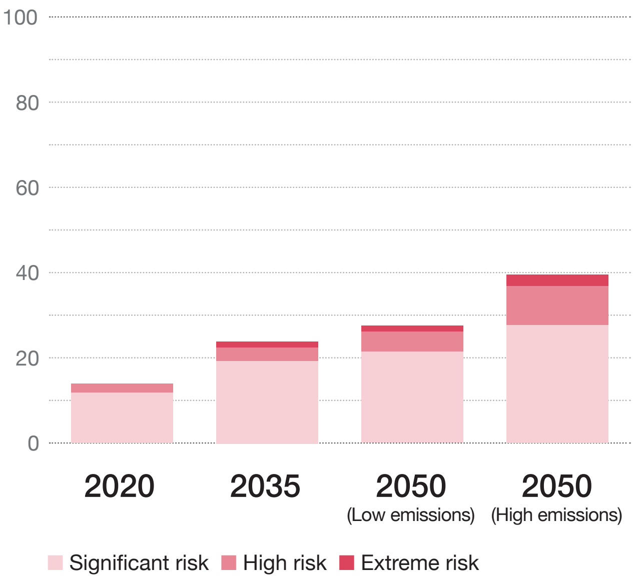
% of **Wheat** production capacity exposed to drought risk



Maize

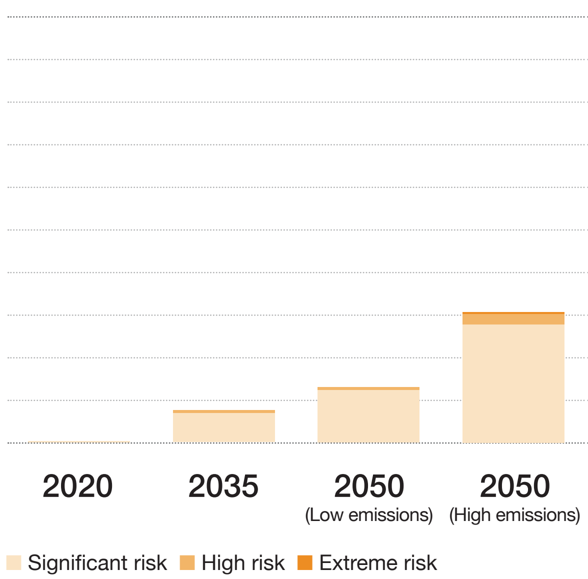
Heat stress

% of **Maize** production capacity exposed to heat stress risk



Drought

% of **Maize** production capacity exposed to drought risk



Case study: Drought risk to maize production in East Africa

Drought risk to maize farming in East Africa illustrates the perils of accelerating climate change, the need to adapt, and the challenges of adapting successfully.

Maize is critical for food security globally and plays a central role in agricultural production and dietary consumption in East Africa. Nearly a quarter[12] of arable land in East Africa is used for growing maize, and, unlike many other regions, maize grown here is used primarily[13] for direct human consumption rather than livestock feed.

Maize farming in East Africa is predominantly rain-fed,[14] making maize production in the region particularly vulnerable to the kind of extreme weather events that are now becoming more frequent. East Africa is currently experiencing what may be the world's worst acute food insecurity emergency after five consecutive seasons of drought resulted in multiple failed harvests.[15]

Upgrading the region's irrigation infrastructure might seem the obvious way to mitigate against future climate impacts, but challenges include high costs, insufficient stocks of water, high demand and competition for water, inaccessibility of soil water-monitoring tools, and lack of local climate data and soil–water parameters.[16] Farmers in several Sub-Saharan African countries have also tried shifting their crop-planting dates to try to anticipate the year-on-year variability in the onset of the rainy season, but access to accurate climate forecasts has made this challenging.[17]

One promising solution is drought-tolerant maize[18] that is better able to withstand periods of acute soil-drying. A UN General Assembly resolution stressed the importance of developing such varieties.[19] Increasingly, their use and availability is seen as crucial with the Drought Tolerant Maize for Africa project[20] promoting, for example, the BH661 variety, which offers enhanced drought tolerance (plus greater resistance to major diseases, higher yield potential and wide adaptability).

In conclusion

Our analysis of growing heat stress and drought risk leads us to three conclusions:

Many locations that produce essential commodities are likely to experience more frequent spells of intense drought and heat stress, increasing the risk of climate-related disruption. Even in an optimistic low emissions scenario, regions that produce large shares of key commodities will see many more days of scarce water availability and heat stress. There is a clear need for commodity producers - and consumers - to take steps to adapt to a changing climate. Some mines and farms already employ measures to operate successfully in hot and dry conditions. For example, due to worsening droughts in Chile, some mining firms use desalinated seawater in their operations.[21] Our analysis underlines the importance of adaptation measures like these.

In some cases, risks are rising sharply from low levels, underlining the need to enable commodity producers to be prepared to manage increasing risks that, in some cases, they may have little experience in managing in their locale.

We can't assume that future emissions reductions will protect us from a changing climate. Even in an optimistic low emissions scenario, heat stress and drought risks will increase substantially by 2050, highlighting the importance of adapting to a changing climate while we strive to reduce carbon emissions.

Next steps: How businesses can manage climate risks

Companies are rapidly realising the need to manage the impacts of climate change

PwC's 27th Annual Global CEO Survey in 2024 finds that 47% of CEOs are taking proactive measures to safeguard their workforces and physical assets from climate change.

Companies are wise to take action to adapt to a changing climate. As we have seen, climate-driven risks are rising at sites that produce nine essential commodities. Without preventive action, there may be increased disruption to global production of these commodities with knock-on effects for all nations and industries that depend on them.

In this chapter, we offer practical actions companies can take to adapt to the physical impacts of climate change. While this report so far has focused on one specific case of climate impacts (heat and drought threats to mines and farms), in this chapter we will survey a range of ways that companies in many industries are adapting to physical climate impacts. We trust this will make the chapter more useful to companies in a variety of sectors that would like to manage the full spectrum of ways that physical climate change impacts may affect their business.

Three pillars to adapt to a changing climate

How can companies take action to protect their operations, people, and supply chains from the effects of climate change? Below, we explore possible actions, grouped under three pillars, that businesses can take to help enable their business to be prepared for what lies ahead: 1. Enhance resilience by identifying and managing risks, 2. Capitalise on opportunities and 3. Shape collaborative outcomes.

Business case	**Avoid economic losses**	**Increase revenue, cost savings and sustainability**	**Protect communities and ecosystems**
Pillars	**Enhance resilience**	**Capitalise on opportunities**	**Shape collaborative outcomes**
Core actions	Assess the impacts of climate risks on business and act to adapt and build resilience	Leverage products, services and business models that help businesses, communities and ecosystems adapt to and build resilience	Participate in multistakeholder efforts that promote action on climate change adaptation
	Work with suppliers and communities connected to the value chain to enhance business resilience	Pursue adaptation opportunities that contribute to efficiency, sustainabiity and climate change mitigation	Deliver transformative projects to build community and ecosystem resilience
Enabling actions	Establish a climate strategy that integrates climate change adaptation and net-zero transformation		
	Mainstream climate risk considerations into business decision-making		
	Make comprehensive and transparent climate disclosures		

These three pillars come from a framework that PwC developed with the World Economic Forum to accelerate business action on climate change adaptation. We will focus most on Pillar 1 because our report is primarily about adapting to climate risk, and so this is where we will share the most examples of action to take. However, Pillars 2 and 3 are also important in the wider picture so we also include some examples to illustrate these steps.

Pillar 1: Enhance resilience

Adapting to climate change - the ability to anticipate, manage, and recover from climate impacts - starts with clearly identifying climate-linked risks throughout the value chain. Climate risk analysts can identify current and future risks of heat, drought and other climate change perils to every square mile of the earth's surface. In this way, analysts can identify physical climate risks to every location in a company's value chain.

Climate change can have knock-on effects far beyond its direct physical impacts. For example, government actions to safeguard supplies can have consequences for global prices and availability. In 2023, for example, the Indian government banned exports of non-basmati white rice, partly due to fears of domestic rice shortages caused by the disruption from El Nino, the weather event that causes sea temperatures to rise. This has caused global rice prices to rise sharply as available supplies are reduced.[22] Companies should consider these complex knock-on risks as well as direct physical ones.

With climate risks identified, companies can plan adaptation measures and work in partnership with suppliers and communities across the value chain to adapt to climate change. Finally, companies can implement these measures, monitor progress and evaluate their effectiveness.

Together, these actions can make a dramatic difference to a company's resilience to a warming climate. Below, we share examples of how both producers and consumers of essential commodities are adapting to climate change.

How commodity producers are enhancing resilience

As water scarcity and unpredictability intensifies with climate change, some leading companies are adapting by leaning into next generation technology, for example by adopting advanced water management systems to prevent wastage. Such systems can help decision makers predict water needs, optimise usage, and promote sustainable consumption across all stages of production. Other businesses are considering adaptation to infrastructure; for example, building elevated storage facilities in areas prone to flooding or investing in structures to provide shade.

Case study: Chilean mines have combated water scarcity with desalination plants

Chilean mines in 2020 produced 154,000 tons of lithium, equal to 25% of the global total. However our analysis shows that by 2025 many face a high risk of drought. In addition, intensive water use by Chilean mines has increased water stress in some local communities. In anticipation of rising drought risk, several mining companies in Chile have invested in desalination plants. There are 22 such plants currently in operation in Chile, with plans for a further nine.

Strategic investment in desalination has enabled Chilean mines to prepare for rising risk exposures and has supported production at scale in drought prone regions. Building a large desalination plant is a costly solution but investment may create a competitive edge in the longer term.[23]

Some commodity producers are partnering with others in their industry to develop methods of protecting operations from climate perils like extreme heat:

Case study: Aluminium industry collaborates to minimise climate impact on workers in mines and refineries and their communities

The International Aluminium Institute has embarked on a project to understand the potential impact of climate-related risks on the health of aluminium industry employees, and what actions can be taken to mitigate this.

The project's researchers found that temperatures produced by climate change can affect aluminium production by, for example, causing heat-related illnesses, vector-borne diseases and drought-related impacts. Climate change also causes an increased frequency of extreme weather events which can damage infrastructure, prevent employees from getting to work and even cause serious injuries or deaths to the workforce and communities.

A reliable labour force is essential to the operation and profitability of the aluminium industry and so these risks need to be properly managed. Adaptation options may include introducing new work practices such as providing shade or cooling for workers engaged in strenuous labour in high temperatures, and providing protective clothing and training workers to spot the early signs of heat-related illness.

The project has created an action plan for mine and refinery owners and communities to follow to enable them to easily identify and assess climate-related impacts on workers, and then put in place adaptations to minimise these impacts.

In farming, adaptation strategies include, for example, introducing drought-resistant crop varieties, alternative cropping patterns, biologicals (crop protection products derived from living organisms), and automation and digital technologies. Policy makers can help to provide funding to widen access to adaptive measures as shown in the case study below:

Case study: Building climate resilience by widening access to funding for farming machinery

Much of the rice in Asia is produced on smallholder farms. As we have seen, rice production in Asia is likely to be especially hard hit by rising heat stress in coming years. Machinery could help reduce the impact of heat stress while also increasing efficiency. For example, self-propelled rice transplanters reduce the need for physical human labour, helping to protect rice farmers from the potentially dangerous effects of working in the heat. However, cost can be a barrier. A rice transplanter typically costs $6,000-$9,000, a formidable sum for many farmers. This means a rice transplanter can take between three and 12 years to turn a profit for a rice farmer.

While many Asian countries have subsidy programmes, these are often not targeted at smaller farms. For instance, Nepal provides subsidies for farm machinery to farms of 10 hectares or more in some regions. Similarly, only farms with at least 50 hectares of land are eligible for the Philippines' Rice Competitiveness Enhancement Fund Mechanization Program. Broadening access to these initiatives in impacted countries could help reduce the impact of heat stress on production in these countries.[24]

With a clear picture of their climate risks, commodity producers can build a plan to manage them, as for example Mosaic did:

Case study: PwC helped Mosaic manage climate change risks to its operations

Mosaic is a leading producer of concentrated phosphate and potash and wanted to better understand how physical climate change risks could potentially impact its global operations. The PwC US team of climate risk specialists began by undertaking a broad qualitative risk assessment that outlined some of the most important potential climate-related risks to Mosaic's operations. Using future climate scenarios from a variety of established models and third party expert data sources, they then evaluated the potential business impact of each risk.

Together, Mosaic and PwC identified some of the highest-priority climate-related risks across the business, ranked by estimated likelihood of occurrence and severity of impact. Following this initial workshop, Mosaic identified four physical risks to study further. PwC analysed potential risk levels and associated business impacts of the largest physical risks to Mosaic. It leveraged 2°C and 4°C warming scenarios to examine the potential risks to the business under both a low-carbon economy and a high-emissions scenario, creating a risk spectrum for the company's assets. PwC then integrated Mosaic's future plans and mitigation efforts to give increased focus to the analysis.

The exercise helped Mosaic refine its estimates of the potential impacts that certain physical risks could have on its global operations. It will also enable it to make more informed decisions in the future.

How commodity consumers are enhancing resilience

Commodity consumers rely on a web of commodity producers, processors, shippers, and other players across the value chain - all of whom can be affected by climate impacts. For commodity consumers, adaptation starts with a crystal clear understanding of climate change risks throughout the value chain, considering both direct and indirect climate impacts - some of which may not be apparent without careful investigation. Here is how PwC uncovered climate risks throughout the global supply chain of a hypothetical manufacturer:

Case study: Tracing climate risks to the global supply chain of a smartphone maker

Global supply chains can be highly vulnerable to the impact of physical climate risks, sometimes in ways we may not even be aware of. To highlight the wide range of physical climate risks that businesses face, PwC looked at their potential impact on the manufacture and supply of a typical smartphone. Researchers mapped the value chain of a notional smartphone and used this to create a simplified composite view of the physical climate risks involved at each step. They then studied the impact of seven climate hazards - floods, extreme rainfall, extreme wind, high heat, hail and thunderstorms, droughts, and wildfires - on these locations.

At every stage of the value chain, they found increased signs of physical climate risk that threatened the ability of the business to function reliably, even when the average global temperature was just 2C° higher. Higher temperatures at mines where the raw materials are sourced, for example, increase the likelihood of heat-related illness amongst workers, potentially raising the mine's operating costs as it seeks new ways to cool the mine and keep workers safe. Manufacturing and assembly of the smartphones in countries such as Japan and China, meanwhile, could be affected by heat and extreme rainfall, causing extensive flooding which damages factories and workers' homes.

Extreme heat could also affect the transportation of the smartphones by disrupting the operations of a port, while drought-fueled wildfires are a risk to warehouses. Finally, high wind poses a risk to distribution and retail sites, such as on Florida's Gulf Coast. At each stage of the value chain the physical climate threat comes both from the direct effects of the peril itself, such as a flood that knocks out a manufacturing site, and the indirect effects which arise for example from a flood destroying bridges to the manufacturing site.

Many commodity consumers have used the Taskforce on Climate-related Financial Disclosures (TCFD) framework which is designed to help organisations analyse their climate-related risks and opportunities. For example, PwC France helped a large supermarket chain apply TCFD to assess the potential impact of climate-related changes to the supplies of fresh agricultural produce to its stores:

Case study: Supermarket chain assesses the reliability of its raw produce supply chain

A large French supermarket chain wanted to better understand how climate change could impact the supplies of the most important agricultural crops being sold in its supermarkets, across cereals, fruit and vegetables.

The company asked PwC France to support it in conducting a thorough analysis of climate change risks and opportunities for these crops according to the recommendations from the Taskforce on Climate-related Financial Disclosures (TCFD).

The first step was to identify the biggest-selling agricultural products across the supermarket chain by assessing the supplies going to its largest supermarkets. These were found to be wheat, maize, potatoes and strawberries.

PwC France then identified the main geographical areas where these four crops were grown in France, using geographical data from the French government and other public sources to identify the material climate hazards to these crops in the short and medium term up to 2050, according to different IPCC scenarios. These findings were used to highlight the climate risks for each region and type of produce.

Through this analysis we identified several different climate hazards that could affect and damage the crops, especially drought caused by rising temperatures and water scarcity.

PwC France's work with a global steel company demonstrates how the Taskforce for Climate-related Financial Disclosures framework can be used not just to identify risks but also to seize opportunities:

Case study: TCFD provides roadmap for climate-related risks and opportunities assessment

The Taskforce on Climate-related Financial Disclosures (TCFD) can be an immensely useful framework for companies seeking to have a better understanding of how their business will be affected by physical and transition risks (and opportunities) brought about by climate change.

Our client, a global player in the stainless, electrical and specialty steel markets that operates in more than 40 countries, wanted to apply the TCFD framework to assess how climate changes could impact all areas of its business.

PwC supported the company in collecting data for the company's main sites including steel production facilities and storage facilities for iron ore, and then conducting a risk assessment according to different metrics. This data was then used to create hazard dashboards and maps to indicate the level of exposure of these sites to climate-related changes.

In addition the most important activities of the company were mapped and sensitivity profiles were created in order to decide which activities to focus on. PwC helped the steelmaker to identify adaptation plans for the business with the use of a vulnerability questionnaire to better understand the context and preparedness of the company.

As a result of the assessment, the client understood how its business can be affected by climate risks through the lenses of the TCFD standard, and its teams were trained to perform further evaluation of 80+ sites worldwide. PwC integrated these results with their risk management team and financially quantified the most material physical and transition risks to enhance public disclosure.

Uncovering climate risks throughout the value chain can help to create urgency to adapt, while providing the granular information needed to take the right protective actions - as PwC learned when we took the time to examine our own climate risks:

Case study: PwC uncovered climate risks to our own offices

Too often the impacts of climate change can feel distant, even abstract. At PwC, when we took the time to clearly understand how climate change might affect our own offices, the risks became tangible, immediate and personal. Our climate risk teams showed us exactly how much each of our hundreds of offices worldwide are likely to be exposed to climate hazards such as drought and extreme heat.

When we could see that certain PwC offices from Tokyo to Tampa are likely to face up to 200 days a year of potentially deadly temperatures, climate change feels very real, very quickly. This stark picture of our risks helped to galvanize action and, more importantly, give our people the granular information they need to take steps to adapt. Having clear data on our own risks helped to dispel misunderstandings that climate change's effects will happen only in the distant future, elsewhere, and to other types of businesses. We made public highlights of our climate risks, in part to encourage other companies to examine theirs.

With climate risks identified, what can companies do next to adapt? Some forward-looking businesses are adapting their sourcing and operational strategies, diversifying their supplier bases, and developing contingency plans to safeguard their supply chains. Businesses are adopting measures such as inventory planning, contractual climate resilience clauses, dynamic pricing mechanisms, transport resilience measures, quality assurance and adaptability, and climate risk insurance.

The experience of Nestle, a major consumer of agricultural commodities, demonstrates how to use a clear picture of climate risks to develop a comprehensive climate strategy to manage risks and maintain business continuity:

Case study: Nestlé's climate resilience strategy

Nestlé, a global food and beverage company, undertook climate change risk assessments at the site, project and supplier levels. Having identified climate change as a key risk, the company used these assessments to better understand and manage climate-related risks and opportunities. It also used climate scenario analysis to better understand the impact of climate change over long time horizons.

Nestlé simulated physical climate risk for the period 2025 to 2040. The analysis considered a temperature rise beyond the 1.5°C target by 2040 to analyse impacts on direct operations due to damage to facilities and production issues due to input supply shocks. Informed by the climate risk assessment and scenario analysis, Nestlé developed a comprehensive climate strategy outlining its efforts to mitigate the physical risks of climate change to its business. The company also developed site-specific loss prevention, business continuity and water reduction strategies as measures to manage risks to facilities. It promoted sustainable sourcing, including promoting regenerative agriculture in the value chain. This climate strategy has been integrated into Nestlé's existing systems and processes, including risk management and executive compensation.

Tesla, a major consumer of lithium and cobalt, uses a range of adaptation strategies including collaborating with other battery makers:

Case study: Tesla's strategy to protect its supply of critical minerals

Tesla is one of the largest manufacturers of electric vehicles in the world and relies on regular supplies of lithium and cobalt to make the batteries for its cars. Both lithium and cobalt play an essential function in improving vehicle range and safety performance.

The company has therefore adopted a multi-pronged strategy to build vertical integration and help it establish a reliable lithium supply chain. It is currently building its own lithium refinery in Texas and has signed agreements with lithium and nickel producers in the United States and Canada to grow its supplier base. It is also collaborating with other battery makers to facilitate consistent supply. In addition to its own cell manufacturing operations, the company currently uses cells from four different suppliers with three different battery chemistries.

Tesla conducts an annual Enterprise Risk Assessment to identify physical climate-related risks to the business including site-specific reviews of its gigafactories and other facilities. Using the results from these analyses, Tesla is looking at ways to protect its manufacturing activities against medium-term and long-term climate impacts.

PwC helped a global consumer packaged goods company to quantify the value of commodities at risk and model the impacts of climate change on future prices of key commodities:

Case study: PwC quantified the value at risk and impact on future prices for a global consumer products company

The procurement team at a global consumer packaged goods company asked PwC to help it understand the potential impact of climate change on its ability to source 12 priority crops, including maize, soybeans and oranges. It also wanted to understand the potential impact of climate change on future orange yield and orange juice prices.

PwC performed extensive research, data acquisition and statistical analysis to arrive at future climate impacts for each of the 12 crops. To develop value at risk metrics, PwC identified crop-specific growing regions through satellite imagery and client-provided data. We then identified regions highly exposed to drought, extreme heat and extreme cold under low and high emissions scenarios by 2050 using output from IPCC climate models.

PwC then quantified the value at risk to the client by incorporating the client's procured volume and procurement spend for each crop and the climate exposure of their respective sourcing countries.

The client also had growing concerns about oranges due to their exposure to climate change and Citrus Greening disease, which is linked to rising temperatures caused by climate change. To address this PwC developed climate metrics for orange growing seasons in both Northern and Southern hemispheres as well as for the future prevalence of Citrus Greening disease. We then projected these metrics using IPCC climate model output under low and high emissions scenarios to map the changing suitability of growing oranges in different regions and the future likelihood of Citrus Greening disease.

PwC also developed a model using historical country-level yield data and projected changes in orange juice prices due to a potential spread in Citrus Greening disease under different climate scenarios to represent the financial impact of the disease on the future orange juice prices.

Pillar 2: Capitalise on Opportunities

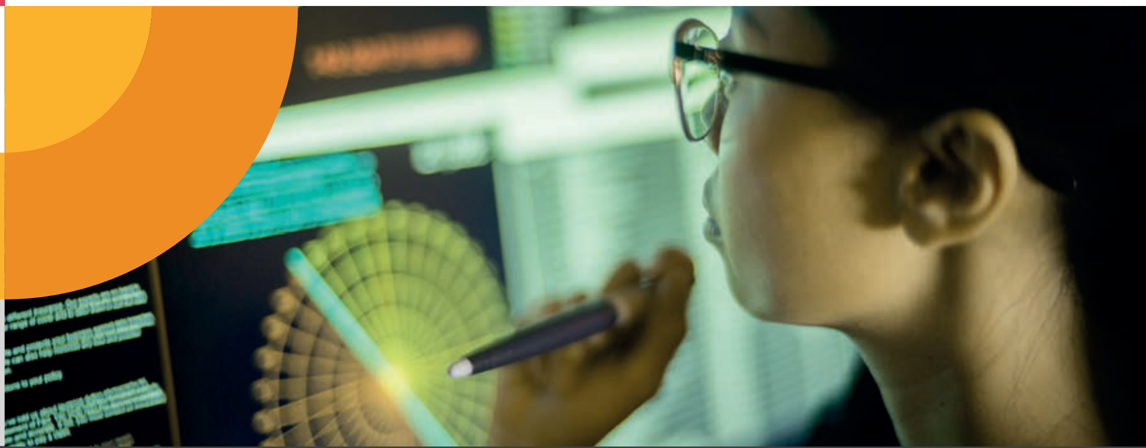
At the same time as managing their own climate risks, companies can seize opportunities to help the wider business community and ecosystem adapt. This is true for both producers and consumers of commodities. Companies can, for example: review how their existing or new products and services can support adaptation; invest in adaptation solution research, development and innovation; and collaborate with other businesses and stakeholders to develop and deploy new adaptation solutions at scale. The underlying aim is to seize opportunities to build society's shared arsenal of adaptation solutions, benefitting both a company and its wider community.

Below we share two case studies that show how forward-thinking companies are creating platforms that help thousands of other businesses adapt to a changing climate.

Case study: Agricultural machinery company helps farmers build climate resilience

Mahindra & Mahindra, an agricultural machinery manufacturing business, has provided free advisory, digital and precision-farming solutions to farmers through an initiative called Krish-e, designed to help prevent detrimental climate change impacts on agricultural productivity. These solutions have been offered through physical centres or through an easy-to-use digital app available in eight local languages.

Krish-e helps farmers transition to sustainable agricultural practices by providing personalized support on crop planning, seed selection, nutrient management, irrigation planning, disease and pest/insect management, weed planning and other operational aspects. This can enhance productivity and thereby reduce the vulnerability of farmers to climate change. Information on extreme weather alerts, the onset of seasons, disease and insect forecasts, among others, can help farmers plan their crops in ways that help them avoid crop damage and loss. Krish-e has actively engaged with more than 500,000 farmers.



Case study: Digital twin helps companies foresee and manage climate risk

One Concern, a resilience analytics technology company, has built a digital twin of the United States and one of Japan, capturing the details of every piece of infrastructure in the countries, over a trillion data points. The digital twins serve as a multi-hazard platform that captures climate risk and extreme event impacts at the asset, community and portfolio levels. The platform also identifies the ripple effects of a hazard across complex networks. The One Concern platform helps businesses visualise and analyse how climate change impacts their assets and networks. It also allows businesses to compare resilience across assets in their own portfolio, consider external vulnerability at scale and measure themselves against industry benchmarks. Using such advanced risk analytics, businesses can make informed decisions for resilience building and modify existing valuation and risk processes to incorporate climate and natural disaster resilience. This can also help organizations reduce their emissions through precision mitigation. The platform has helped multiple clients from the insurance, banking, commercial real estate and infrastructure industries as they engage their enterprise customers in adaptation planning.

Pillar 3: Shape collaborative outcomes

Many companies are collaborating on climate action with a range of stakeholders from governments and investors to academics and local communities. Companies are working within these ecosystems to develop new measures that will support their operations for the long term. In so doing, they are protecting both their own strategic interests and the interests of future generations.

For example, mining and farming companies are tapping into academic and research insights, aligning with technological innovators, talking with regulators and investors, and working to understand local community perspectives. Car makers are collaborating with other industry players to secure supplies of materials to their manufacturing processes. Food producers are working with their suppliers to enable consistent supplies while helping those suppliers protect their own livelihood. By joining forces, companies can work towards establishing unified standards, consolidating research efforts, and fortifying links across the global supply chains.[25] All these efforts recognise that a richer dialogue and a shared sense of purpose will spur more innovation and help companies thrive in new operating environments.

Below are two case studies that show what shaping collaborative outcomes looks like in practice, and how pragmatic action on this front can help further adaptation for all involved. First, PepsiCo's experience shows the value of partnerships between commodity producers and consumers:

Case study: PepsiCo's Regenerative Agriculture Strategy

PepsiCo, one of the world's largest food companies, relies on a secure supply of more than 30 agricultural crops and ingredients - including maize, wheat and rice - from approximately 60 countries. In order to enable these supplies to be protected from the impact of climate-related risks PepsiCo works with its farmers to adopt regenerative agriculture practices — a set of techniques designed to improve and restore ecosystems in areas which could be affected by climate change to make soil healthier, capture carbon, improve watershed health, protect and enhance biodiversity and strengthen farmer livelihoods by optimizing their long-term yields and farm income.

The company supports a wide range of regenerative practices including planting cover crops to protect the soil, reducing tillage to maintain soil health and fertility, and encouraging livestock and other diversity onto farms. These practices help maintain and add nutrients, improve fertility, maintain soil carbon, control pests and weeds through sustainable management, improve biodiversity, maintain water quality and protect watersheds. By supporting farmers in this way, PepsiCo aims to help secure its supply while helping farmers address the challenges of climate change and prepare for agricultural challenges of the future.

The New Zealand tourism industry is heavily reliant on the country's natural resources in the form of its landscapes, scenery, and outdoor adventure opportunities. PwC New Zealand's work with the New Zealand tourism industry demonstrates the value of convening a multi-stakeholder community (in this case including scientists, government, financiers, Indigenous communities, and more) to co-create an effective adaptation strategy:

Case study: PwC New Zealand identified climate-related risks and opportunities for New Zealand's tourism sector

New Zealand, also known by its Māori name Aotearoa, is recognised around the world for its pristine landscapes and outstanding geographical features. However, growing concerns around climate change and environmental degradation are threatening the tourism industry and challenging the country's iconic brand, 100% Pure. Rising temperatures are shortening snow seasons while floods and droughts along with coastal erosion, biodiversity loss and melting glaciers are compromising the country's status as a clean, green destination.

In collaboration with The Aotearoa Circle, PwC New Zealand championed a multi-stakeholder project that showed the industry how different climate change scenarios might shape the course of its future. To do so, it drew on specialists from the fields of climate and land science, conservation, government, and sustainable finance to both illuminate problems and identify possible paths. PwC New Zealand also analysed the consequences, likelihood and severity of the climate risk and conceived a roadmap for adapting to them.

Over a nine-month period, PwC New Zealand co-designed an adaptation strategy and roadmap for New Zealand tourism with respect to Indigenous considerations, including involvement from a leading elder and PwC New Zealand's National Cultural Lead.

These very different examples show that shaping collaborative outcomes can take a variety of forms and involve a range of different stakeholders for each scenario. However, in each case organisations and stakeholders are working together to develop new measures that will support resilient operations for the long term.

Appendix 1: Research Design

In this Research Design appendix, we provide a fuller discussion of why the nine commodities are essential to the global economy, how we designed our research to analyse climate risks to production of these commodities, and limitations to our analysis.

Why we chose these nine commodities as essential to the global economy

Vital metals

Aluminium (made from the mined material bauxite), and iron ore and zinc are vital metals, essential for construction materials, manufacturing, and steel production. Demand for aluminium, iron and zinc is projected to increase due to their role in the production of renewable technologies.[26]

- **Iron.** Iron ore is the world's most mined mineral, accounting for 93% of the volume of minerals mined in the world in 2021, with 2.6 billion tonnes extracted.[27] Given 98% of iron ore is converted into pig iron for making steel, iron ore is hugely important to the construction industry, which generated over half the world's steel demand due to its unique combination of strength, formability and versatility.[28]
- **Aluminium / Bauxite.** Bauxite is the raw material used to produce aluminium for metal production. Aluminium is used extensively in transportation, construction and packaging, among other industries. Bauxite is a key source of rare metals needed in making green technologies, and bauxite residues also contain trace amounts of rare earth metals.
- **Zinc** is the world's fourth most used mineral. Three quarters of zinc is used to give metals specific properties, such as galvanising steel or iron to prevent them from rusting. Zinc is therefore a key input for construction and automotive manufacturing.[29] Zinc is also widely used in the agricultural, rubber and chemical industries.

Critical minerals

Cobalt, copper and lithium are critical minerals that are vital components in technologies that form part of the green energy transition. These include electric vehicles and many forms of renewable energy generation and storage.

- **Lithium** is a key component for the production of batteries, which represents 65% of the lithium market, propelled by the growing market for electric vehicles, portable electronic devices and energy stores. Demand for lithium is expected to surge in response to a global shift towards electric vehicles and renewable energy storage. The International Energy Agency says that investments in technologies to keep global temperatures “well below 2°C” by 2040 would see lithium demand grow by 43 times compared to 2020.[30] Lithium is also a substantial input in national defence, medicine, and industrial applications.[31] Lithium features in the European Commission’s list of critical raw materials, together with cobalt and copper.[32]

- **Cobalt** has become an essential input for certain specialist manufacturing due to its distinctive properties. Cobalt is used extensively in the manufacture of high-speed cutting tools, powerful magnets, and high-strength alloys for jet engines and gas turbines.[33] Cobalt has also become increasingly central to the green energy transition due to its role in the production of batteries in electric cars, computers and cell phones. Demand for cobalt is forecast to more than double between 2022 and 2030, according to the Cobalt Institute’s latest market report.[34] Between 60-70% of the increase in cobalt demand is unavoidable if countries are to meet the renewable energy goals set out in the Paris Agreement.[35]

- **Copper** is the third most-used mineral on earth. Copper’s high conductivity, low resistance and broad availability make it ideal for electrical wiring and circuitry. Applications in electronics account for nearly half of copper’s demand. Demand for copper is expected to double from 25 million metric tons in 2022 to about 50 million metric tons in 2035, a record-high level that will be sustained and continue to grow to 53 million metric tons by 2050.[36] Efforts to achieve the Paris agreement’s promised carbon reductions are forecasted to drive over 40% of total copper demand over the next two decades.[37] Copper is also fundamental to the production of industrial machinery, vehicles, and green technology.[38]

Key crops

Maize, rice and wheat are the three cereal crops most consumed by people, accounting for 42% of human calories, 37% of protein consumed by people, and 90% of all cereal crops grown in the world.[39, 40] These three crops will remain the primary source of food for billions of people through 2050. The OECD agricultural outlook for 2023-32 suggests that the global demand for wheat and rice will rise by 11% between 2023 and 2032, while global maize demand will increase by 12% over the same period.[41]

- **Maize** is, after sugar cane, the second most produced crop in the world and the most produced cereal. 80% of maize is used to feed humans and animals. After rice and wheat, maize is the third most consumed cereal by humans. The indirect channel (via animals) through which humans consume maize make this a key global crop.[42]

- **Rice** is the second most produced cereal in the world. Rice supplies 20% of the world’s dietary energy and is the primary source of nutrients for more than 3 billion people.[43] Global rice production more than trebled between 1961 and 2021, with production in Africa increasing more than eightfold over the period. [44]

- **Wheat** is the third most produced cereal and the second most produced cereal for human consumption.[45] In 2018, wheat was grown on about 217 million hectares of land around the world, the most of any crop.

Heat stress can potentially disrupt production at mines and farms

Heat stress can be expressed as a Wet Bulb Globe Temperature (WBGT), which reflects the combined impact of temperature and humidity on human physiology (Figure 3). Anyone who has spent time outside on a day that is both hot and humid may have noticed how humidity magnifies the impact of heat. The WBGT captures this combined effect.

Both mining and farming see productivity declines when the WBGT rises, reflecting the fact that miners and farm workers often spend large numbers of hours outdoors where they are directly exposed to the impacts of heat and humidity.[46] Over the next 30 years, many regions will see an increase in the duration, frequency, and average temperature of hot days, according to the Intergovernmental Panel on Climate Change (IPCC). In fact, this is already happening.[47] The World Meteorological Association reported that 2023 was the warmest year on record with an average global temperature increase of 1.45C° above pre-industrial levels, nearly breaching the 1.5C° limit set out in the Paris Agreement.[48] The speed of heating is astonishing. Days with an average global temperature above 1.5C° above pre-industrial levels were first recorded in 2015; in 2023 nearly half of the days were this hot.

The International Labour Organisation (ILO) reports that workers in the agricultural sector are particularly at risk from heat stress, and the IPCC says that "climate change will increasingly expose outdoor workers…to heat stress, reducing labour capacity".[49]

Wet Bulb Globe Temperature from temperature and relative humidity

Relative Humidity (%) \ Temperature (°C)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	10	11	11	12	13	13	14	14	15	16	16	17	17	18	19	19	20	20	21	21	22	23	23	24	24	25	26	26	27	27	28
5	10	11	11	12	13	13	14	15	15	16	17	17	18	19	19	20	20	21	22	22	23	24	24	25	26	26	27	28	28	29	30
10	11	12	12	13	14	14	15	16	17	17	18	19	19	20	21	21	22	23	24	24	25	26	26	27	28	28	29	30	31	31	32
15	12	12	13	14	15	15	16	17	18	18	19	20	21	21	22	23	24	24	25	26	27	27	28	29	30	30	31	32	32	33	34
20	12	13	14	15	15	16	17	18	19	19	20	21	22	22	23	24	25	26	26	27	28	29	29	30	31	32	33	33	34	35	36
25	13	14	15	15	16	17	18	19	19	20	21	22	23	23	24	25	26	27	27	28	29	30	31	31	32	33	34	35	36	36	37
30	14	14	15	16	17	18	19	19	20	21	22	23	24	24	25	26	27	28	28	29	30	31	32	33	33	34	35	36	37	38	38
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45	15	16	17	18	19	20	20	21	22	23	24	25	26	27	28	28	29	30	31	32	33	34	35	35	36	37	38	39	40	41	42
50	16	16	17	18	19	20	21	22	23	24	25	26	26	27	28	29	30	31	32	33	34	35	35	36	37	38	39	40	41	42	43
55	16	17	18	19	20	21	22	22	23	24	25	26	27	28	29	30	31	32	33	33	34	35	36	37	38	39	40	41	42	43	44
60	17	17	18	19	20	21	22	23	24	25	26	27	28	29	30	30	31	32	33	34	35	36	37	38	39	40	41	42	43	43	44
65	17	18	19	20	21	22	23	24	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	40	41	42	43	44	45
70	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	35	36	37	38	39	40	41	42	43	44	45	46
75	18	19	20	21	22	23	24	25	26	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
80	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	45	46	47
85	19	20	21	22	23	24	25	26	27	28	29	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
90	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
95	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	48	49
100	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

WBGT temperature thresholds for each risk level:

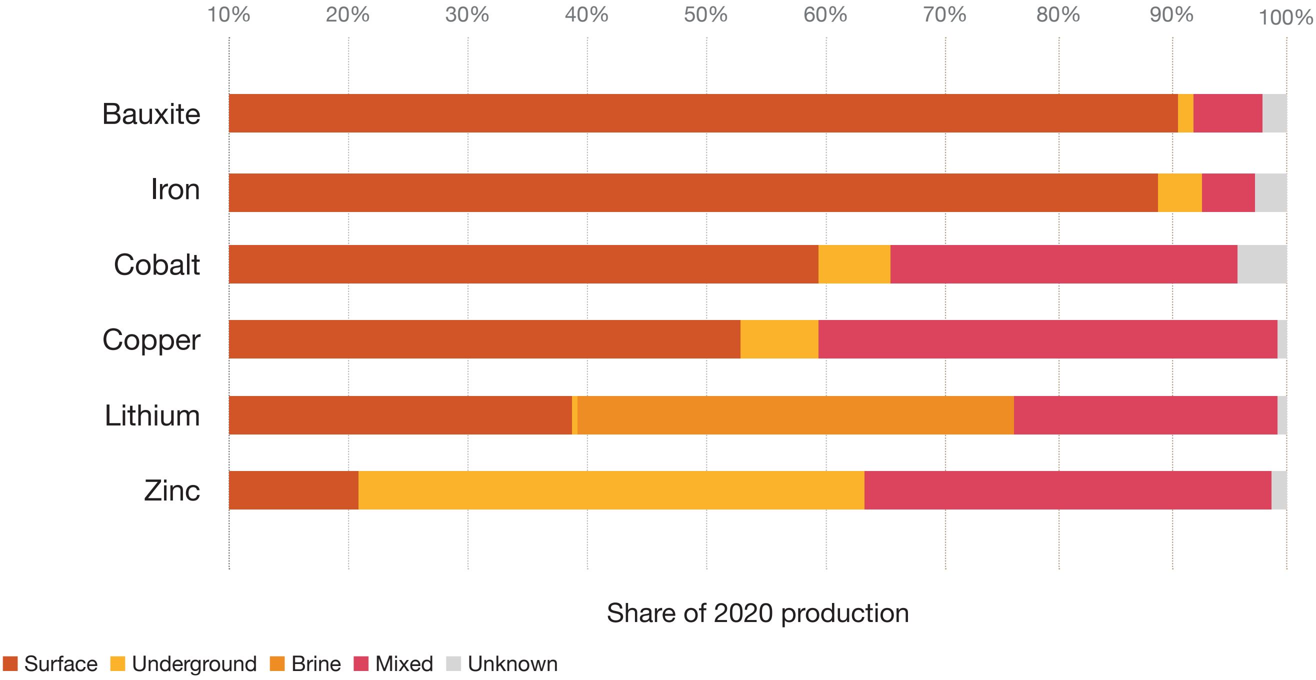
Significant risk ■ High risk ■ Extreme risk

A relatively small change in temperature can have a big impact on productivity. International Labor Organization (ILO) research shows a global temperature rise of 1.5°C could result in a 2.2% reduction in total labour hours in the shade by 2030. This is equivalent to a productivity loss of 80 million full-time jobs. An equivalent surface temperature increase in full sun could lead to a 3.9% loss in working hours, or 136 million full-time jobs.[51]

These impacts are already being felt in agriculture and mining. For example, one study found that the annual US crop worker death rate due to heat was 19 times higher than that of all US civilian workers.[52] Moreover, the US National Institute for Occupational Safety and Health (NIOSH) reports multiple cases in which migrant farm workers died from heat stroke after hand-harvesting crops in extreme heat.[53] By 2050, the US agricultural sector could see a more than 3.5% gross value-added loss through heat-induced reduced worker productivity, according to the Atlantic Council think tank.[54]

In mining, workers are also often exposed to heat stress risk, with the specific impact contingent on the type of mine (see chart below). Most of the mining of our essential commodities takes place in surface or open pit mines which are more likely to be exposed to direct sunlight, leading to a higher WBGT and accompanying heat stress.[55]

The share of 2020 production of each mineral by type* of mine



Source: CapIQ, PwC analysis

* 'Surface' mines include open-pit and dredging mines. The 'mixed' category includes production from sites that use a combination of surface, underground and/or brine mines (i.e. mixed mines use a combination of at least two of these categories).

Note: Heat stress can also potentially hurt crop yields. These effects can vary across our three crops of interest (rice, wheat, maize), so in this paper we focus on how heat stress affects one thing all three crops have in common: dependence on human labour to produce them. Please see Appendix 2 for a detailed map of the ways in which heat stress can affect production at mines and farms.

How we define heat stress risk

We define four levels of heat stress risk based on WBGT, with rising levels of impact on labour productivity. For WBGT values of 32.2°C and above, for example, most current guidelines state that workers should rest for 45 or more minutes for every 15 minutes of moderate work in the sun.[56, 57, 58] The implication for employers is that as the WBGT rises, they are likely to see substantial reductions in labour capacity per worker and increased costs unless adaptive measures are used to protect workers.

Heat stress risks increase in line with the WBGT, leading to lower levels of labour productivity

Risk Category	Risk Levels / Duration	Impact
Moderate	At least 10 days above a WBGT threshold of 25.0°C. Total days with WBGT at this level may be higher	**Limited impact on labour productivity**
Significant	At least 10 days per year with an average daily WBGT of 26.3°C. Total days with WBGT at this level may be higher.	**Reduces labour productivity by at least 25%**
High	At least 10 days per year with an average daily WBGT of 28.9°C. Total days with WBGT at this level may be higher.	**Reduces labour productivity by at least 50%**
Extreme	Each year, an average daily WBGT of 32.2°C occurs on one or more days.	**Reduces labour productivity by at least 75%** and is dangerous to outdoor workers.

How drought can affect mining and agriculture

Drought presents a serious risk to both mining and farming.[59] In mining, a lack of water undermines water-intensive operations including ore extraction, mineral processing, and dust control, while in farming it can reduce crop yields.

The critical mineral lithium is particularly exposed to drought risk[60] since traditional lithium mining through brine extraction (as used in the Lithium Triangle in South America) tends to be particularly water intensive,[61] requiring exceptional volumes of water for exploration, extraction, and processing.[62] The amount of water required to mine one kilogram of lithium varies, but can be thousands of litres or more.[63]

Drought is already affecting mining. For example, the South African mining industry faced severe drought in 2015-2017, when water scarcity led to mine closures, productivity declines, and economic losses.[64] That said, modern surface mining techniques are typically more water efficient than traditional open-pit or underground mining, and there are numerous examples of minerals being mined in arid locations. Indeed, over 50% of current lithium production is in water-stressed regions, and 80% of Chile's copper output originates from dry areas.[65] A key implication of this report is that methods of adapting to drought may need to be used more widely.

Turning from mining to agriculture, farming is the world's thirstiest industry, accounting for 70% of the world's freshwater consumption in 2022.[66] In this context, the absence of water for irrigation poses an existential threat. Water is particularly critical in the cultivation of rice, wheat, and maize.[67] Please see Appendix 2 for a detailed map of the ways in which drought can affect production at mines and farms.

How we define drought risk

We use a standard drought index[68] to define four levels of risk.

Drought risk categories[69]

Risk Category	Risk Levels / Duration of Severe Drought
Moderate	**10% of time** in severe drought, over the 20 year span centred on each year being analysed
Significant	**20% of time** in severe drought, over the 20 year span centred on each year being analysed
High	**40% of time** in severe drought, over the 20 year span centred on each year being analysed
Extreme	**80% of time** in severe drought, over the 20 year span centred on each year being analysed

We examine today's and tomorrow's heat and drought risk, for both high and low emissions scenarios

We model heat stress and drought risk to sites that produce the nine commodities at three different time periods: a **2020 baseline** (an average from 2010 to 2030, centred on 2020), and in two future years: **2035** and **2050**. (Note: Throughout this report, we will use 'now' or 'today' as a shorthand for referring to the present day baseline period.)

In addition, for the year 2050, we compare two different scenarios for how the world's long-term efforts at reducing carbon emissions might play out. We examine both a low and high emissions scenario as defined by the IPCC.

- A **low-emissions scenario** for 2050 in which substantive action is taken to curb emissions, keeping global average temperature increase below 2C. Even in this scenario, there will likely be a substantial increase in the proportion of some essential commodities impacted by heat stress and drought. (SSP1-2.6)
- A **high-emissions scenario** for 2050 in which no action is taken to follow a low-emissions pathway, resulting in a catastrophic rise in global average temperature of 4.4C by 2100. (SSP5-8.5)

Limitations to our analysis

While our approach provides a useful insight into how different commodities may become more exposed to different climate perils in the future, the reader should keep a few important caveats in mind when interpreting its findings.

- **We do not estimate potential changes in production.** Our findings show which parts of the world are exposed to climate perils in the historical baseline (see Appendix 1.1) and their projected exposure through 2050. We discuss potential consequences arising from each commodity being exposed to different climate perils. But we do not attempt to quantify how production of each commodity might change when exposed to a climate peril or other climatic variables. This will vary depending on local economic, physical, and regulatory conditions - and, crucially, the degree to which adaptation measures are employed.

- **We consider the physical risks of climate change, not transition risks.** Physical risks are the direct impacts of climate change on assets and infrastructure. Transition risks encompass the change in markets, policies and technology that will occur as the world mitigates against and adapts to climate change. While we suggest what some transition implications could be for the availability and demand of essential commodities, our analysis focuses on the change in physical risk, based on baseline (see Appendix 1.1) production, for the essential commodities between baseline and 2050.

- **We cannot predict future actions to adapt.** Our analysis looks at exposures only. We do not, and cannot, predict what steps will be taken to manage these exposures. Countries around the world are taking steps to adapt to climate risks. Other businesses and countries may have begun mitigating against future climate risks, breaking the connection between hazard occurrence and impacts on production. Our analysis underlines the importance of adaptation measures.

- **We base estimates of exposure on 2020 production quantities of each commodity.** We project how each essential commodity will likely be exposed to climate perils in 2050 based on production in 2020. We do not explore how each country's reserves or other factors (such as ammonia production for crop fertilisation) may affect how much of each commodity can be produced in the future. There may only be marginal changes in the profile of future producers, given that many of the largest current producers of these critical minerals also have the largest proven reserves. Additionally, areas that were once less suitable for production of a commodity may become more suitable due to climate change. For example, as the average temperatures increase in Canada, some parts of the country will become more suitable for growing maize.[70] In addition, we cannot predict the range of factors that may affect production levels in the future, such as shifting demand (for example, if new models of battery no longer require cobalt or lithium).

Appendix 2: Geographic concentration of commodity production

Key takeaways

- **At least 40% - and as much as 85% - of the global supply of each commodity is produced in just three countries per commodity.**
- **In addition, production is often concentrated to specific sites within countries. For example, just 15 mines produced more than half of the world's lithium, cobalt, and bauxite in 2020. Production of all key crops is concentrated to certain regions within the top producing countries.**
- **This geographic concentration may heighten risks to the global supply. The more concentrated the sources of a commodity are, the greater the impact that disruption in any one locale might have on global supplies.**

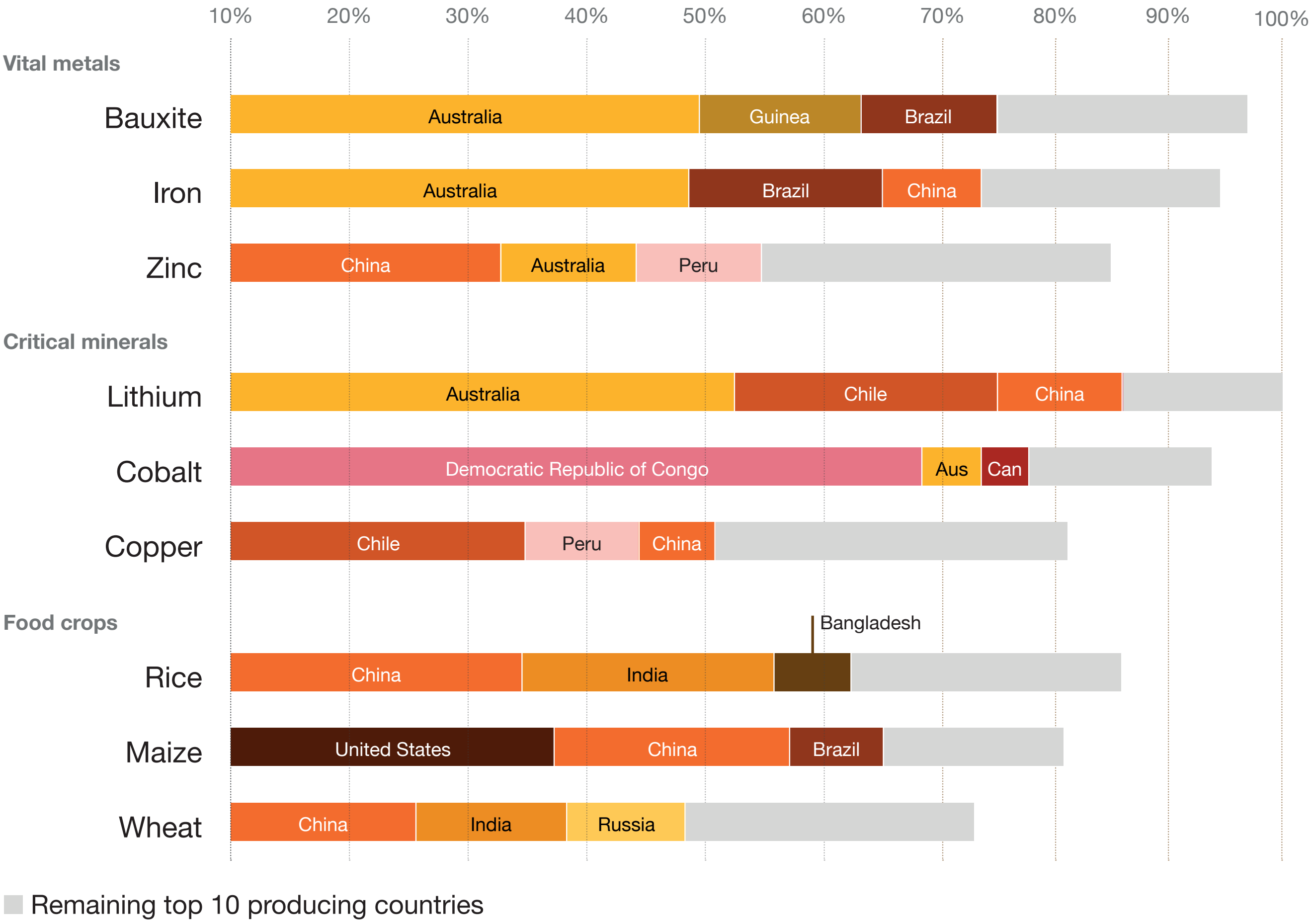
In this Appendix, we give a fuller discussion of the geographic concentration of production of each of the nine commodities.

Production of the nine commodities is concentrated to a few countries

Just a handful of countries, and often specific regions within countries, account for much of global supply. In 2020, just three countries were responsible for the supply of at least 40% of each of the nine commodities. And just ten countries produced at least 70% of each commodity (see chart below). This geographic concentration could potentially heighten risks to global supplies because, with fewer sources for a commodity, disruption at any single source has a more substantial impact on the global supply.

Production of each essential commodity is highly concentrated

Share of global production (2020)



Source: CapIQ, FAO, PwC analysis

Below we examine geographic concentration for each set of commodity.

Vital metals

In 2020, Australia, Guinea, and Brazil produced about 70% of the world's bauxite, the base metal for aluminium, and ten countries accounted for over 97% of production. The same number produced 93% of iron. Australia is the world's largest producer of extracted materials, accounting for 45% of bauxite and 44% of iron ore. It also has 20% of iron ore reserves, the largest share in the world. China is the biggest producer of zinc, accounting for about 26% of production. It holds 13% of the metal's reserves.[71]

Critical minerals

Between 2020 and 2022, ten countries accounted for over 97% of lithium production and more than 93% of cobalt production. Australia accounted for 48% of lithium production while the Democratic Republic of Congo accounted for 66% of cobalt production and had 43% of reserves. Chile was a major producer of lithium and copper, accounting for 25% and 28% of global production respectively.

One notable caveat to production concentration is that some countries with large critical mineral reserves do not now mine them at scale. Five countries have larger reserves (both economically viable and nonviable deposits) of lithium than Australia. Argentina, for example, is home to 43% of global lithium reserves.[72] If or when these countries start production, concentration risk may fall. Indeed, deposits are still being discovered, including a large lithium deposit in the United States, found in the summer of 2023.[73] Still, based on the pipeline of future mining projects, the near-term concentration of critical mineral production is likely to remain largely unchanged given long time periods required to get new mines up and running.[74]

Key crops
Production of key crops is also concentrated in a few countries. China and India together produce 52% of the world's rice, 32% of wheat, and 25% of maize. That said, production of crops is more dispersed than production of metals and minerals. In 2020, countries outside the top 10 produced 22% of the world's rice, wheat, and maize. By contrast, countries outside the top 10 produced only 9% of the six metals and minerals.

Global rice production is highly concentrated by region. Around 90% of the world's rice is grown in Asia, and a large proportion (48% of the total) is produced in Southeast Asia, reflecting favourable conditions in that region. All told, there are more than 200 million rice farms across Asia, most of which are smaller than one hectare.[75]

Maize is the world's second most widespread crop, covering 197 million hectares of land, equivalent to the total landmass of Mexico. In 2020, about a third of the world's farms grew the crop, which is used to feed both humans and animals.[76] Globally, there is a large variation in yields, with North American yields five times higher on average than African yields and twice as high as Asian yields. This is partly due to the commercialisation of maize farming in North America, involving high-yield varieties and advanced crop management.[77]

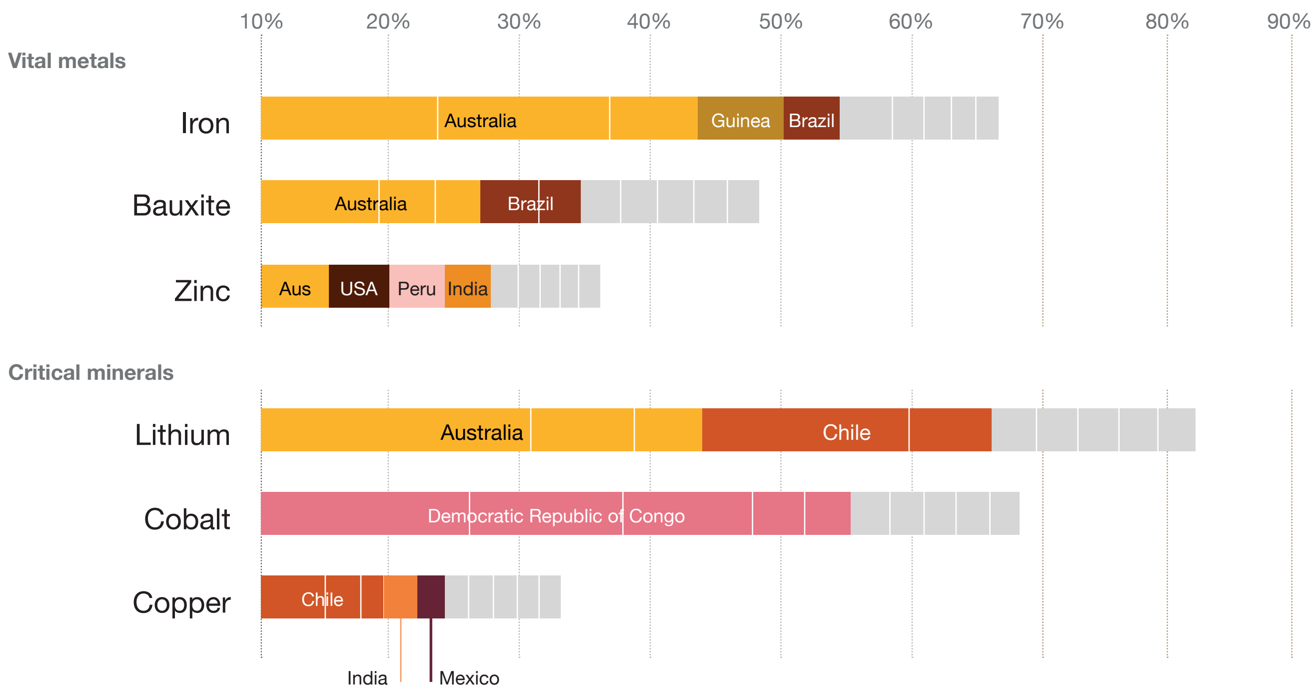
Production of wheat is the least concentrated of the nine essential commodities. Ten countries account for 71% of global production, with China, India, and Russia being the largest producers. Wheat is the most widespread crop, covering 216 million hectares of land. It is cultivated on about 20% of the world's farms.[78]

Production is also concentrated *within* countries

Not only is production of the nine essential commodities concentrated among countries, it is also concentrated to specific sites within countries. A handful of mines produce most of the world's metals and minerals and a few regions account for the majority of the world's key crops (see chart below).

Global production of the six metals and minerals is highly concentrated among just a few mines

Each block represents one of the top 10 mines for that commodity



Source: CapIQ, FAO, PwC analysis

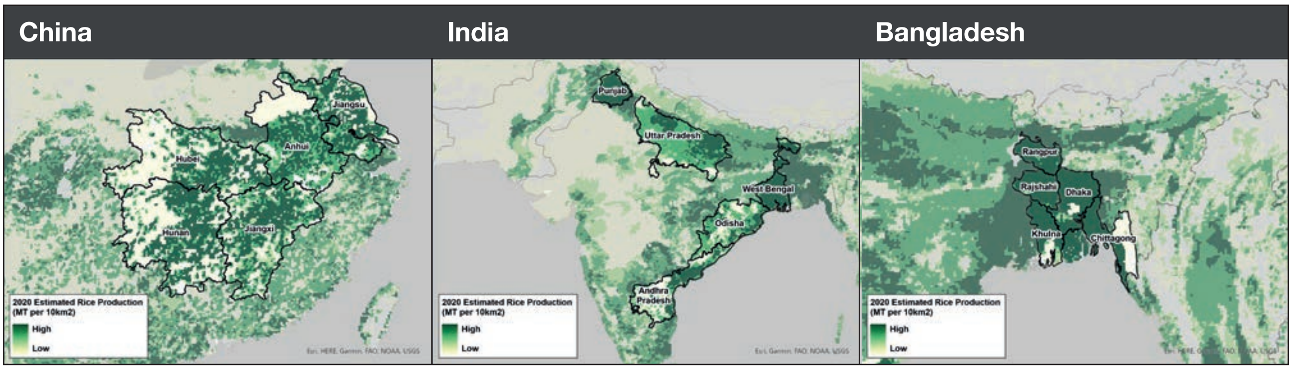
In 2020, just five mines (all in the Democratic Republic of Congo) produced most of the world's cobalt. 81% of the world's lithium, 50% of bauxite, and 44% of iron were each sourced from no more than ten mines.

Some top producing mines are in close proximity to each other. In Democratic Republic of Congo, four mines, producing 47% of the world's cobalt, are located along a single 100 kilometre stretch of road. Chile's two largest lithium mines are on the Salar de Atacama salt flat. That said, commodity production is less concentrated in Australia, where the largest lithium, bauxite, and zinc mines are spread across the west and north of the country.

Production of most of the world's key crops is also concentrated within countries. Five provinces in China produce more than 50% of the country's rice, despite covering just 8% of the land. Similarly in India, five states produce 54% of the country's rice but account for just 21% of the land (see first map below). In China, India and Bangladesh, the top five producing regions collectively supply nearly a third of the world's rice. Meanwhile in the US, maize production is concentrated in just five states (see second map below). The five largest provinces in China and Brazil produce 56% and 68% respectively of each country's maize.

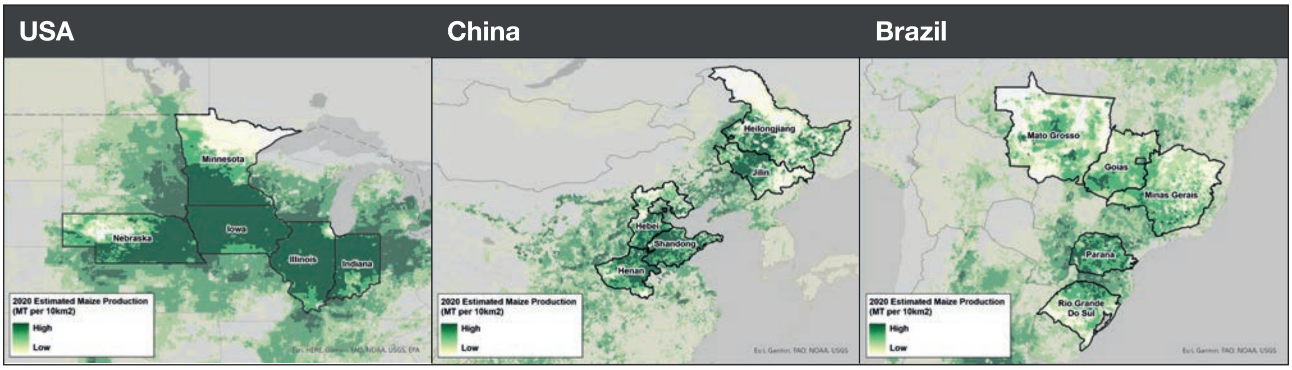
Wheat production in China, the world's largest producer, is even more concentrated than rice and maize (see third map below). In 2020, five provinces accounted for 75% of the country's wheat, or 13% of global production. Wheat production in India is mainly in five northern states, producing 85% of the country's wheat and accounting for 12% of global supply.

Rice production is concentrated to a limited number of regions in the top three rice producing countries



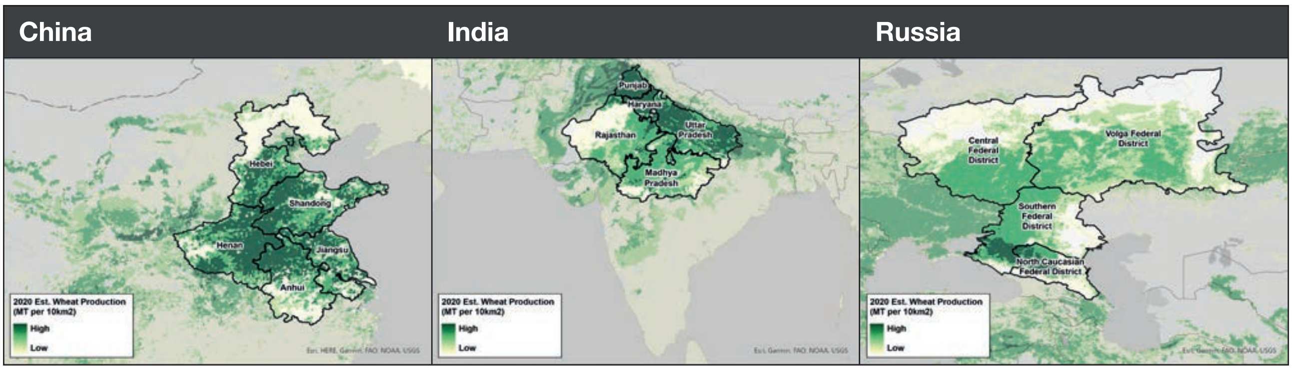
Source: IFPRI, FAO, PwC analysis

Maize production is concentrated to a limited number of regions in the top three maize producing countries



Source: IFPRI, FAO, PwC analysis

Wheat production is concentrated to a limited number of regions in the top three wheat producing countries



Source: IFPRI, FAO, PwC analysis

Appendix 3: Climate modelling methodology

This report utilises PwC's Geospatial Climate Intelligence, a web-based platform for assessing climate risk, to project heat and drought risk to areas producing essential commodities. Geospatial Climate Intelligence contains individual models of acute and chronic climate hazards developed by PwC's climate risk modelling team. Research and development for the models is carried out by a team of scientists and modellers with doctoral training in a range of scientific fields, including atmospheric science, hydrology, geophysics, applied mathematics, and environmental engineering. The models reflect the most current methodology and data available in these fields.

Climate Model Overview

The drought and heat stress models used in this report take as inputs climate conditions projected by general circulation models. General circulation models are highly complex mathematical representations of the earth's physical systems, which are used to simulate climatic conditions under different scenarios of greenhouse gas emissions. The models selected are a bias-corrected, downscaled subset of the models that participated in the World Climate Research Programme's sixth phase of Coupled Model Intercomparison Project (CMIP6)[79]. The subset of CMIP6 models chosen captures the range of possible warming arising from climate model uncertainty under different emissions scenarios. CMIP6 is used because it represents the latest generation of climate scenarios and climate model data; and is consistent with the IPCC and recent advances in climate science.

The climate emissions scenarios utilized for our hazard models are the IPCC Shared Socioeconomic Pathways (SSPs)[80], published in the Sixth Assessment Report (AR6)[81]. The foundation of the SSP scenarios is the rate of increase of the earth's surface temperature based on different societal and environmental conditions. To provide a representation of the range of potential future climate risk, the following "bookend" scenarios were chosen: SSP 1-2.6 representing the lower end scenario (herein referred to as "low emissions"), and SSP 5-8.5 representing the higher end scenario (herein referred to as "high emissions"). SSP 1-2.6, known as "Sustainability - Taking the Green Road", describes a world shifting gradually to a sustainable path that drastically reduces Greenhouse gases (GHG) emissions, limiting warming to less than ~2 °C by 2100. SSP 5-8.5, known as "Fossil-fueled Development - Taking the Highway", represents a future in which economic and social development is coupled with abundant fossil fuel use and commodity intensive lifestyles, leading to a surface temperature warming of 4-5 °C by 2100.

In the climate analysis for heat stress here, we define a "baseline" of historic heat stress (WBGT) values (labelled as 'baseline' throughout the report) as an average from 2010 to 2030, centred on 2020. The average is calculated using both historical reanalysis data from 2010 to 2015 (a blend of observations and historic looking climate model data) and CMIP6 data from 2015 to 2030. In the drought analysis, we have represented a baseline of historic climate change risk (labelled as 'baseline') as an average of CMIP6 data from 2000-2020. Therefore, baseline is not one year, but instead a historical representation of some decades. All future looking time steps are a count or average over a 20-year time frame centred at the time-step. For instance, the time-step of risk in 2040, is in fact a count or average representing data from 2030 to 2050 that is centred at 2040.

Heat Stress Methodology

Heat impacts people in outdoor or non-air-conditioned environments through a combination of temperature and humidity, which together describe the heat stress put on the human body as it tries to cool itself through evaporation.

To capture these two critical components of heat stress (temperature and humidity), we calculate and project the wet bulb globe temperature (WBGT) in baseline conditions and under high- and low-emissions climate scenarios. WBGT is calculated on a daily timescale from climate model outputs, using a standard scientific methodology that combines daily average temperature and humidity. The model's intermediate output is a time series of daily average WBGT values at a 0.5-degree resolution globally, which corresponds to approximately 50 km x 50 km grid cells at the equator.

From projections of average daily WBGT, we calculate the annual number of days that WBGT exceeds specific temperatures corresponding to thresholds of labour productivity losses. Heat stress is categorised into the following risk tiers based on daily average WBGT, where a location is classified by the highest tier for which it satisfies the following criteria:

Moderate:	at least 10 days annually above a WBGT threshold of 25.0°C
Significant:	at least 10 days annually above an average daily WBGT threshold of 26.3°C
High:	at least 10 days annually above an average daily WBGT threshold of 28.9°C
Extreme:	at least 1 day annually above an average daily WBGT threshold of 32.2°C

The thresholds for risk tiers were selected by their impact on labour productivity, where low risk of 25.0°C corresponds to the minimum WBGT at which heat stress is shown to impact worker productivity, and 32.2°C is extreme risk. The relationship between WBGT and labour productivity defines a curve in which labour productivity drops off between a WBGT of 25°C and 36°C.[82] For the purposes of this analysis, we choose temperature cut offs that define the quartiles of the same labour productivity curve. Such that:

26.3°C corresponds to a 25% decrease in labour productivity
28.9°C corresponds to a 50% decrease in labour productivity
32.2°C corresponds to a 75% decrease in labour productivity

Drought Methodology

Drought, at its most general, is concerned with decreased availability of water resources. The concept is further refined into different categories of drought that depend upon hydrometeorological variables and socioeconomic factors, as well as the nature of water demands in different regions around the world. The drought model utilised in this report focuses on meteorological drought - broadly defined as a lack of precipitation over a region for a period of time.

To calculate the severity of meteorological drought at a given location, we evaluate the Standardised Precipitation Evapotranspiration Index (SPEI), which combines climatological values (e.g. temperature, precipitation) to determine the magnitude of drought. The results of the index calculation can be designated into drought severities, where an index value of -1.5 or less is considered a "severe" drought. We calculate and project this index in baseline conditions and under high- and low-emissions climate scenarios. The model's intermediate output is a monthly time series of drought index values that represents whether a location is or is not in drought and, if so, how severe the drought is. If a month meets the definition of being in drought, then this month is counted as drought month. We then calculate the percentage of months over a 20-year period that are in drought. This is done at a 0.5-degree resolution globally, which corresponds to approximately 50 km x 50 km grid cells at the equator.

The time spent in drought then defines the risk categories used in our analysis. For example, "high" risk corresponds to 40% of a 20-year period being in drought (e.g., a 40% in 2050 means that on average from 2040-2060, 40% of months will experience drought conditions). Notably, the index takes into consideration "normal" (or historical) conditions at an individual location. As the percentage of time spent in severe drought conditions increases to 20%, 40% and so on, higher risk categories are assigned. Drought has a cumulative impact, so longer time spent in severe drought may increase the impacts to the agricultural and mining sectors.

Severity is characterised as time spent in "severe" drought (drought index value of -1.5 or lower). Higher drought classes (significant/moderate, high, and extreme) correspond to an increasing percentage of time locations will spend in severe drought conditions. For example, "high" risk corresponds to 40% of a 20-year period being in drought (e.g. a 40% in 2050 means that on average from 2040-2060, 40% of months will experience drought conditions).

Low:	10% of time in a 20-year span
Significant/ moderate:	20% of time in a 20-year span
High:	40% of time in a 20-year span
Extreme:	80% of time in a 20-year span

Exposure of the mining and agricultural commodities that were considered was calculated by understanding the drought hazard at that location. This assessment focused on the combination of temperature and precipitation that is needed to evaluate this drought index and did not assess the temperature or precipitation requirements needed for crop suitability studies.

Appendix 4: Critical commodity exposure methodology

Modelling where essential commodities were produced in 2020

This report estimates what proportion of global production of each essential commodity will likely be exposed to different future levels of heat stress and drought. The analysis in this report is based on the locations where essential commodities were produced in 2020 and evaluates the exposure of those locations to heat stress and drought at different points of time in the future. This approach implicitly assumes that mitigation does not take place during our projection horizon.

Agriculture

To estimate crop production, we use data from the International Food Policy Research Institute (IFPRI) which has published Global Spatially-Disaggregated Crop Production Statistics Data (SPAM) for 2010 (version 2.0). This provides plausible estimates of worldwide crop production within 5 arc-minute grid cells (approximately 5-10km^2 areas) in 2003-2005. For each crop, we uplifted the estimated production of each cell by the ratio of that country's crop production in 2020, versus the estimated crop production for the country in the SPAM dataset. The country-level crop data is from The Food and Agriculture Organization of the United Nations, accessed through Our World in Data.

Agriculture data

Crop	Number of unique production sites	Total production (metric tonnes, 2020)
Maize	561,762	1,209,812,938
Rice	308,425	785,689,921
Wheat	461,997	770,835,393

Source: IFPRI SPAM dataset[83], OurWorldInData/ UN FAO[84]

Minerals

CapIQ's Metal and Mining dataset shows the quantity of each mineral that was produced between 2020-2022 in 1,532 mines worldwide. We took the average production quantities for each mine for the period 2020-2022. This was to account for volatilities in production and output levels driven by the COVID-19 pandemic and anomalous years.

Minerals data

Primary Commodity	Number of mines in dataset	Total global production (metric tonnes, 2020-2022 average)
Bauxite	54	224,588,474
Cobalt	63	135,198
Copper	477	19,578,734
Iron	478	2,096,229,144
Lithium	29	621,156
Zinc	346	9,857,053

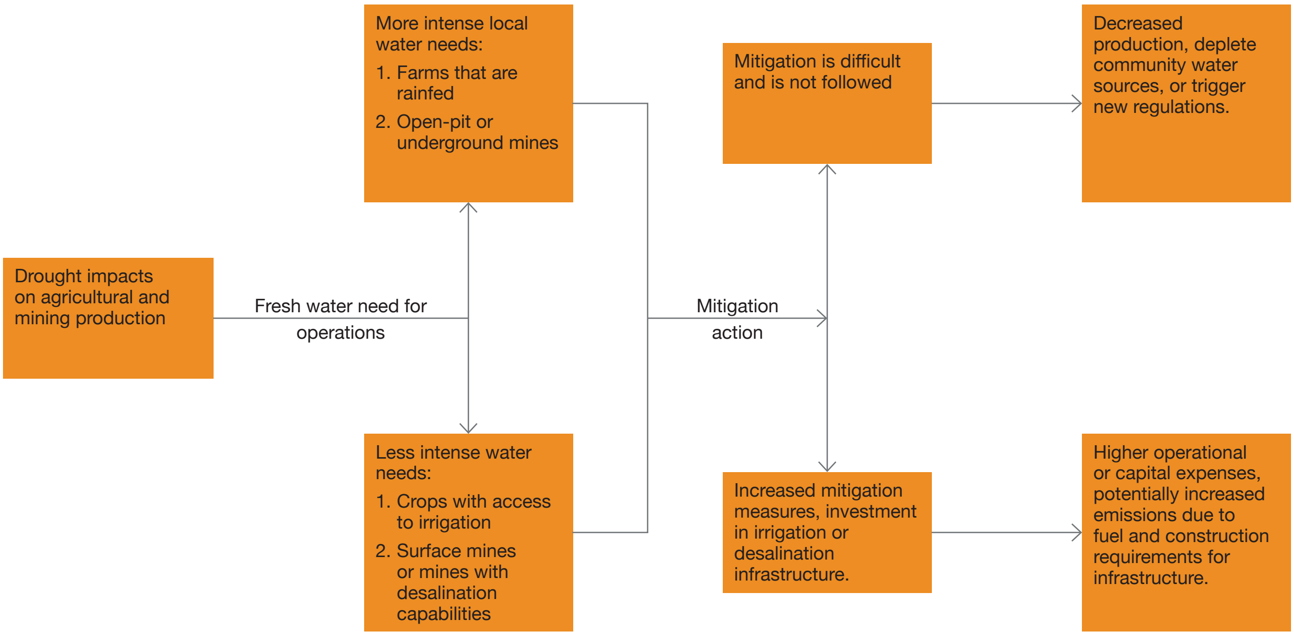
Source: S&P Capital IQ Pro Metals & Mining dataset.[85] Of the 1,532 mines, 213 did not produce any of the six minerals between 2020 and 2022. 128 mines produced at least two of the minerals.

Modelling the level of exposure of each commodity producing location to heat stress and drought in 2020, 2035 and 2050

Here we model how exposed each commodity-producing location would be to heat stress and drought in baseline, 2035 and 2050 under two climate scenarios. Appendix 1 explains the methodology that underpins the modelling done here, including the two different climate scenarios that we modelled.

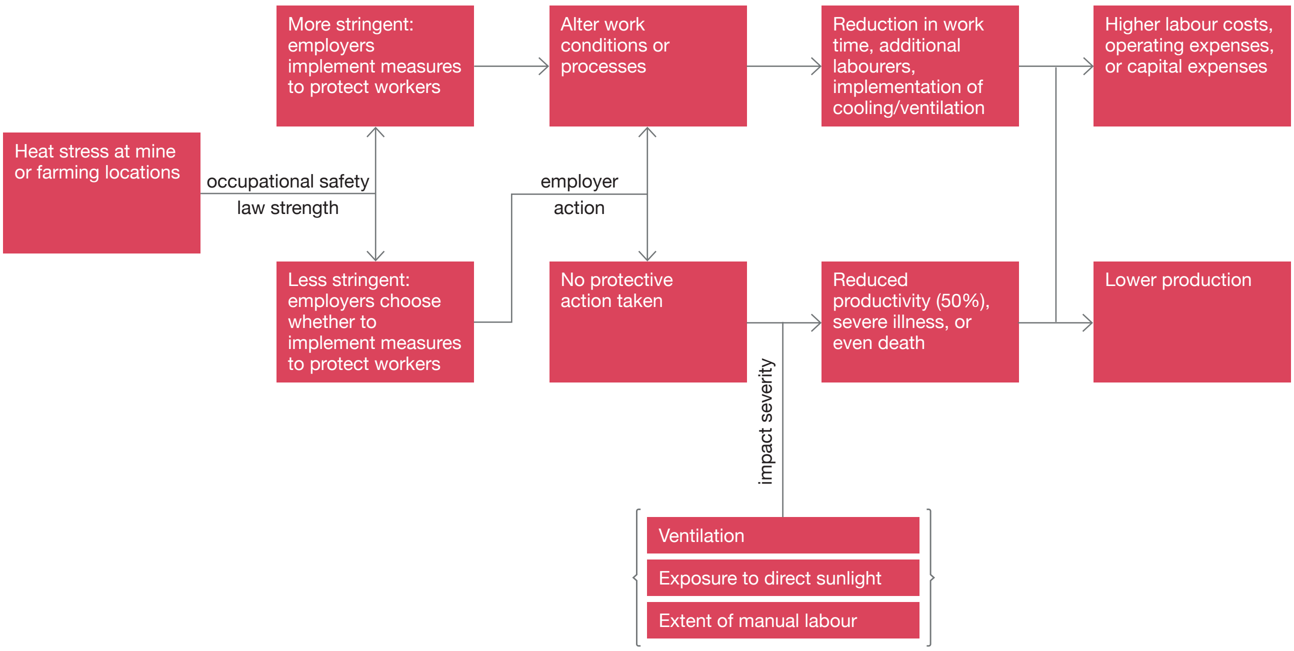
Section 2 of the report explains in detail how mines and farms that are exposed to high or extreme levels of heat stress or drought may see an impact on the quantity that they can produce. Suggested mechanisms of impact for how this may occur for each peril are given below.

Mechanism of impact for drought in agriculture and mining



Source: ILO, CDC, Atlantic Council, Ananian (2023), PwC analysis

Potential impacts of heat stress in mining and agriculture



Source: ILO, CDC, Atlantic Council[86], PwC analysis

Modelling the share of 2020 commodity production exposed to different levels of heat stress and drought in 2020, 2035 and 2050 under different climate scenarios

To estimate the share of production of each commodity that is projected to be exposed to a certain level of heat stress and drought in a certain year and climate scenario, we weight each site by the share of global production it accounted for in 2020, and then sum the production for the sites projected to see that level of exposure in the given year and climate scenario.

For example, to calculate the share of bauxite exposed to high levels of drought risk in the 2050 high emissions scenario, we:

1. Project which of the 54 bauxite mines would be exposed to high levels of drought (as defined in A2.2), in the high emissions scenario.

2. Sum the quantity of bauxite produced in 2020 by the mines identified in Step 1,

3. Divide this sum by the total quantity of bauxite produced in 2020 by all 54 mines in the dataset.

This approach indicates the share of bauxite production expected to be exposed to high levels of drought risk by 2050 under the high emissions scenario, **assuming that the production landscape in 2050 is identical to the production landscape in 2020.**

The figure below gives a further illustration of the method we used to calculate these global-level results from the individual exposures of each of the sites in our datasets.

Illustrative example of calculating the share of 2020 production of a commodity that is exposed to high levels of drought in 2050 in the high climate scenario

Site A
10 tonnes of production in 2020

+

Site B
20 tonnes of production in 2020

+

Site C
20 tonnes of production in 2020

=

Total production
50 tonnes of production in 2020

1

Step 1: Identify which sites are projected to be exposed to High levels of drought in the 2050 High emissions scenario. In this example, assume only Site A and Site C are projected to be exposed to High levels of drought in the 2050 High emissions scenario.

Site A
10 tonnes of production in 2020
Exposed to **High** levels of drought in 2050 High emissions scenario

Site B
20 tonnes of production in 2020
Not exposed to **High** levels of drought in 2050 in High emissions scenario

Site C
20 tonnes of production in 2020
Exposed to **High** levels of drought in 2050 in High emissions scenario

2

Step 2: Calculate the volume of 2020 production by sites expected to be exposed to High levels of drought in the 2050 High emissions scenario.

Site A
10 tonnes of production in 2020
Exposed to **High** levels of drought in 2050 High emissions scenario

+

Site C
20 tonnes of production in 2020
Exposed to **High** levels of drought in 2050 High emissions scenario

=

30 tonnes of production in 2020 by sites that are expected to be exposed to High levels of drought in the 2050 High emissions scenario

3

Step 3: Divide by production exposed to High levels of drought in 2020 High emissions scenario by total production in 2020. This calculates the share of 2020 production expected to be exposed to High levels of drought in the 2050 High emissions scenario.

30 tonnes of production in 2020 by sites that are expected to be exposed to High levels of drought in the 2050 High emissions scenario

÷

50 tonnes of total production in 2020

=

60%
of 2020 production expected to be exposed to High levels of drought in the 2050 High emissions scenario

Source: PwC methodology

To calculate the share of each country's 2020 commodity production that is expected to see different exposure levels to climate perils in each year and climate scenario, we use the same method as above except only including production sites within that given country.

Endnotes

1. Please see Appendix 1 for more information on why these nine commodities are critical to the world economy.
2. PCC Sixth Assessment Report: Low emissions scenario is IPCC SSP1-2.6 and a high emissions scenario is IPCC SSP5-8.5.
3. Please see the Research Design chapter for more detail on why these commodities are important to our economies and communities.
4. Please see Appendix 1 for more information on why these nine commodities are critical to the world economy.
5. Appendix 2 provides a more extensive discussion of the geographic concentration of production.
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Acknowledgements

PwC would like to thank the following for their analysis and expertise:

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