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Boston Consulting Group

Climate Adaptation: Unlocking Value Chains with the Power of Technology

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Contents

Foreword

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The accelerating pace of climate change is fundamentally altering the way businesses and organizations approach adaptation and resilience. Global temperatures soared to unprecedented levels in 2024, making it the hottest year ever recorded. Shifts in climate and extreme weather events send ripple effects across entire value chains, impacting companies far beyond immediately affected areas. In this interconnected world, a company's resilience is no longer measured in isolation but depends on the strength of its partners and suppliers. As Darwin famously noted: "It is not the strongest of the species that survives, nor the most intelligent, but the one most adaptable to change." This adaptability must now be achieved collectively, leveraging partnerships and advanced technologies.

Technology plays a transformative role in this collective adaptation, by helping organizations to understand, anticipate and respond to climate risks; but many technologies only realize their full potential when deployed through collaboration, sharing data and insights across stakeholders. By pooling resources and expertise, companies can not only enhance resilience but also unlock new opportunities for innovation and reduce costs when implementing adaptation strategies.

The Tech for Climate Adaptation Working Group, convened by the World Economic Forum's Centre for the Fourth Industrial Revolution, was instrumental in developing this report, bringing together leaders and experts from technology, industry, academia and the public sector. The report focuses on advancing practical applications and cutting-edge knowledge for climate adaptation, while emphasizing the importance of secure data-sharing, standardized metrics and collaboration with local communities. The working group's insights provide a critical foundation for organizations looking to scale-up adaptation strategies, innovate and foster partnerships within their value chains.

The case for climate action is undeniable. Organizations must move beyond fragmented approaches to climate risks and fully embrace technology as a key driver for adaptation. By investing in collaboration platforms, companies can not only protect themselves but also seize the opportunity to lead in building a resilient and sustainable future. The path forward is clear: collaborate, innovate and scale-up technologies to adapt rapidly to a changing world.

Executive summary

Climate impacts are escalating rapidly, but technology is paving the way to adaptation.

As climate-related disasters intensify, leaders have no choice but to adapt

Companies and organizations are becoming increasingly aware of the urgent need for adaptation. Supply chains, natural resources, physical assets, employees and bottom lines are being battered by an ever-rising number of climate hazards, such as severe storms, floods, droughts, wildfires, heatwaves and cold waves. Coupled with mounting pressure to measure, report and adapt to climate risks, immediate action from global leaders has become more urgent than ever.

At today's level of investment in climate action, the world will remain on its current trajectory of around 3°C warming and could incur losses of 16% to 22% in cumulative GDP by 2100.[1] Investing in mitigation remains essential. By investing an additional and relatively small portion of GDP – less than 1% – into climate adaptation measures, it is estimated that economic losses of up to 4% of GDP could be avoided in the same timeframe. To make this investment a reality, leaders in the public and private sectors must collaborate to safeguard businesses, communities and ecosystems from growing economic and environmental impacts.

Building climate resilience across value chains will unlock greater value for all

Companies must recognize that not only are they individually vulnerable, but their exposure also depends on upstream suppliers and downstream clients. Collaboration is vital because if one part of the value chain fails, such as a key supplier being disrupted by climate impacts, it is likely to have system-wide repercussions. Building resilience across value chains requires significant investment, but when companies and their suppliers adapt together, the cumulative benefit multiplies, reducing costs for all.

Technology and data are accelerating adaptation and enabling collaboration

There are still significant barriers to developing adaptation approaches at scale. For example, the value of adaptation must be demonstrated to secure investment, there is a lack of common language and metrics for cross-stakeholder collaboration, and there is limited access to data, technology and internal capabilities to deploy solutions. Frontier technologies, including artificial intelligence (AI), are pivotal in overcoming those challenges. They allow organizations to identify and anticipate impacts, respond swiftly and build long-term resilience across value chains. Technology also enhances collective investment in adaptation by enabling standardized communication, risk measurement and data sharing – key to informed decision-making.

Leaders' investment in collaboration platforms will realize collective benefits of adaptation

Value chains should collectively address adaptation by developing collaboration platforms, where technology-driven ecosystems enable stakeholders to work together to scale-up adaptation efforts, drive innovation and build resilience against future climate risks. Participants in these platforms should be able to share data, technologies and capabilities to develop and deploy adaptation solutions across the entire value chain.

When establishing collaboration platforms, global leaders:

- Engage in climate adaptation by creating or joining forums within their value chains.
- Define the value at stake to create a shared purpose for adaptation.
- Standardize adaptation through common language and metrics.
- Align on secure data-sharing protocols.
- Invest in innovation and infrastructure to host open technologies.
- Involve local communities and stakeholders to scale-up adaptation solutions.

The time to act is now – those who lead on adaptation will shape the resilient economies of tomorrow.

Introduction

In the race against climate change, organizations must shift to a value chain perspective to address adaptation.

9%

the amount emissions must decrease annually from 2024 to stay below 1.5°C.

4.7%

the amount emissions fell from 2019-20 during the COVID-19 pandemic.

United Nations Environment Programme

Current climate mitigation and adaptation efforts are clearly insufficient to prevent historic temperature increases and catastrophic impacts. However, while businesses and organizations may have been slow to act, frontier technologies can help them adapt.

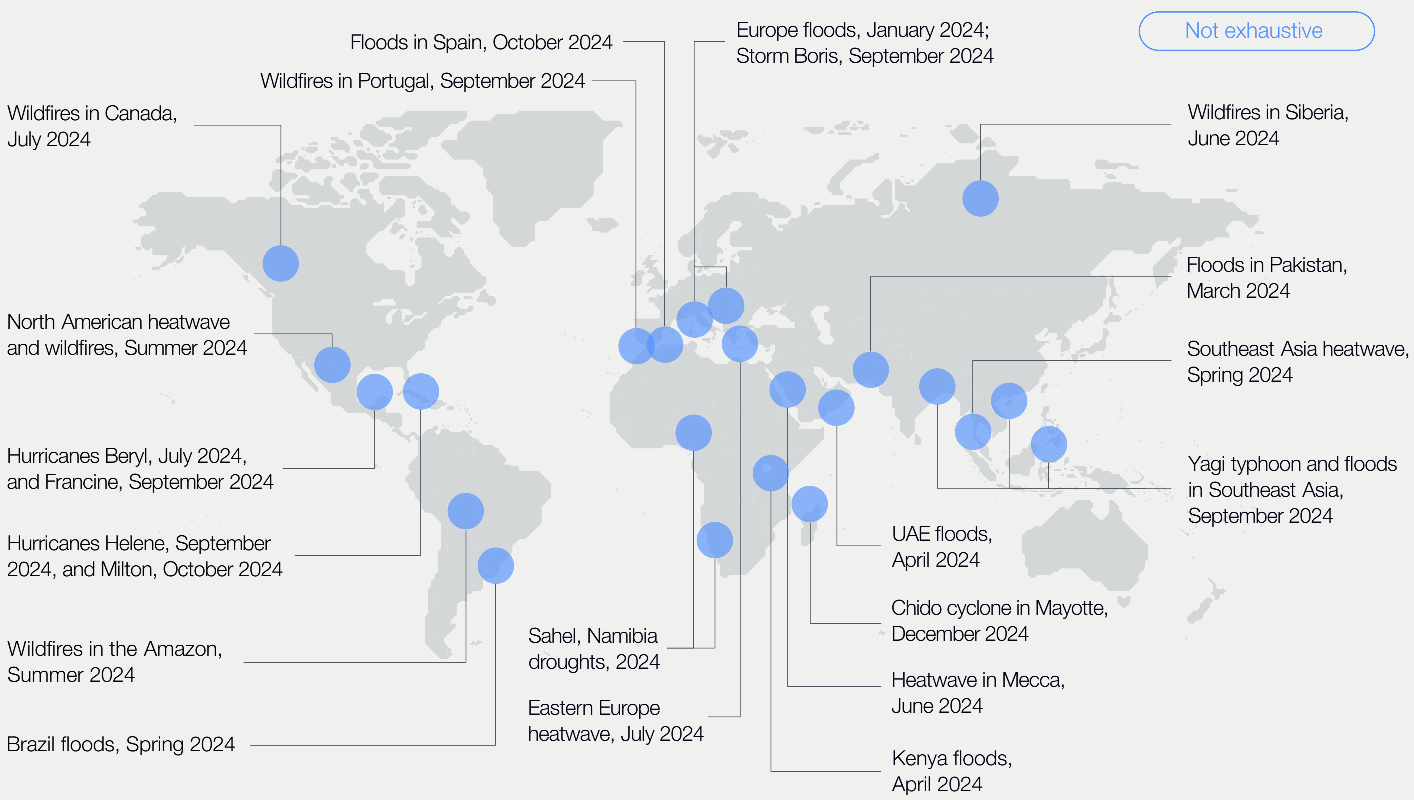
At today's investment levels, the world is on track for a 2.6-3.1°C rise in temperature over the pre-industrial average by 2100,[2] wreaking enormous damage to the global economy, natural ecosystems and human life. Emissions growth may have slowed over the past decade, but it has not fallen. To prevent the 2015 Paris Agreement's goals from being shattered – and to ensure that Earth system's tipping points are not breached – emissions must decrease by 5.5% annually from 2024 to keep warming below 2.0°C by 2030 and by 9.0% annually to stay below 1.5°C. As a comparison, global greenhouse gas (GHG) emissions fell by 4.7% from 2019 to 2020 during the COVID-19 pandemic, before bouncing back to even higher levels.[3]

Weather is becoming more extreme

Speeding up the pace of climate adaptation is critical. The past decade has featured the 10 warmest years on record,[4] with 2024 entering the record books as the first calendar year to exceed 1.5°C above pre-industrial levels. That makes last year the hottest since records began in 1850 – until this year, that is.[5]

The physical impacts of climate change are becoming increasingly evident and persistent,[6] pushing adaptation to centre stage. The World Economic Forum's Global Risks Report 2024 listed extreme weather as the most likely global risk to trigger a major crisis in the next decade.[7] Slow-onset events such as droughts and sea-level rise are worsening, while extreme weather events – wildfires, heatwaves, cold waves and floods – are occurring at unprecedented rates (see Figure 1). If current trends persist, the United Nations (UN)

FIGURE 1 **2024 saw an unprecedented number of climate-related disasters**



Note: Climate-related disasters include heatwaves, wildfires, droughts, extreme weather events, floods and landslides.

Source: Boston Consulting Group (BCG) analysis.

2024 was the first calendar year to exceed

1.5°C

above pre-industrial levels.

predicts that extreme weather events could exceed 560 per year – well over one per day – by 2030.[8]

Since 2000, reported costs of damage from extreme weather events linked to human-driven climate change have nearly tripled, rising from $149 billion between 2000 and 2004 to a projected $435 billion for 2020-2024.[9] In 2024 alone, storms and heavy rains caused flooding in Europe, UAE, Kenya and Brazil; heatwaves and wildfires ravaged North America and South America; while hurricanes and typhoons endangered millions of people across Asia and North America. These disasters have had devastating impacts on communities and businesses.[10]

Nearly every sector of the global economy faces physical risks from climate change and, in many cases, the risks are already reality. By 2050, in the >3.0°C scenario, companies in several industries – such as telecommunications, utilities, food and beverages and construction – could see their profits (EBITDA) plunge by between 5% and 25% annually (see Figure 2).[11]

FIGURE 2 **Physical risks could harm 5-25% of EBITDA under current trajectory** (by sector and region)

Average financial impact of physical risks by 2050

% yearly EBITDA at risk vs. today in a >3°C (current trajectory) vs. <2°C (Paris-target) scenario

	>3°C scenario								>2°C scenario							
	Communication services	Utilities	Construction & infrastructure	Materials	Food & beverages	Oil & gas	Healthcare	Industrials	Communication services	Utilities	Construction & infrastructure	Materials	Food & beverages	Oil & gas	Healthcare	Industrials
Europe	10-15%	10-15%	5-10%	5-10%	5-10%	<5%	<5%	<5%	5-10%	5-10%	<5%	<5%	<5%	<5%	<5%	<5%
North America	10-15%	10-15%	5-10%	5-10%	<5%	<5%	<5%	<5%	5-10%	5-10%	<5%	<5%	<5%	<5%	<5%	<5%
South America	15-20%	15-20%	10-15%	10-15%	5-10%	5-10%	5-10%	5-10%	5-10%	5-10%	<5%	<5%	<5%	<5%	<5%	<5%
Asia-Pacific	>25%	>25%	10-15%	10-15%	5-10%	5-10%	5-10%	5-10%	10-15%	5-10%	5-10%	<5%	<5%	<5%	<5%	<5%
Africa & Middle East	>25%	>25%	10-15%	10-15%	5-10%	5-10%	5-10%	5-10%	5-10%	5-10%	5-10%	<5%	<5%	<5%	<5%	<5%
Sectoral average	20-25%	15-20%	10-15%	10-15%	5-10%	5-10%	5-10%	5-10%	5-10%	5-10%	<5%	<5%	<5%	<5%	<5%	<5%

Notes: Estimates include economic impact from asset damage and business interruption from wildfire, heat, coastal flooding, fluvial flooding, cyclones, water stress and droughts vs. historical baseline normalized to today.

>3°C scenario is based on SSP3.7-0, which is a moderate- to high-emissions scenario projecting temperature increases of 1.7-2.6°C by 2050 and 2.8-4.6°C by 2100.

Translation of impact from % of asset value to EBITDA margin is carried out using sector benchmarks on median fixed asset turnover ratios (FAT) and EBITDA margins assuming sector and regional composition in 2050 is identical to current levels.

Individual company impact estimates can vary vs. sector estimates shown here depending on differences in e.g. share of fixed assets and EBITDA margins vs. benchmarks.

See Appendix for methodology and sources.

Source: World Economic Forum. (2024). The Cost of Inaction: A CEO Guide to Navigating Climate Risk.[12]

Investing in adaptation reduces the cost of climate impact

Despite imminent and growing risks, business leaders have failed to invest adequately in tackling climate change. They have responded to stakeholders' pressure to report climate risks by using frameworks such as the Task Force on Climate-related Financial Disclosures (TCFD) or the Corporate Sustainability Reporting Directive (CSRD) for companies operating in the EU. However leaders remain hesitant about shouldering the upfront costs of mitigation and adaptation.

There are links between mitigation measures, which seek to reduce the damage from climate change by trying to shift the world to a lower temperature path, and adaptation efforts, which strengthen society's resilience against the effects of climate change. Both efforts can reduce the costs of the climate crisis, but even if optimum measures are in place, some economic damage is inevitable.

The net cost of inaction can be expressed as the difference between the projected costs of climate change before and after implementing mitigation and adaptation measures, minus the investments made. In other words, it represents the potential savings generated by taking climate action. The current 3.0°C-plus pathway is projected to lead to total economic losses of between 16% and 22% of cumulative GDP by 2100, but these figures are likely to be underestimated, as systemic or unquantifiable impacts such as social costs and the lagged impacts of climate shocks on economic output are not considered.[13]

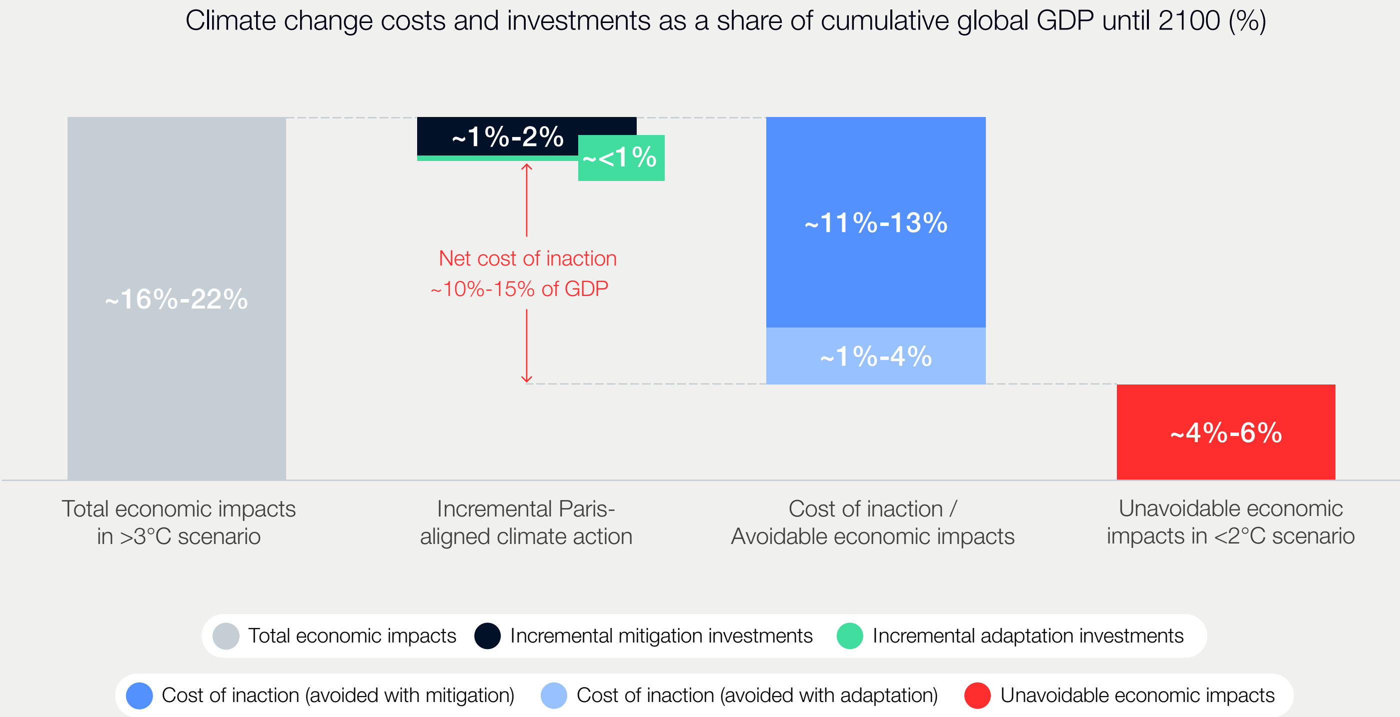
However, investing around 2% of the world's cumulative GDP in additional mitigation efforts could keep the temperature increase below 2.0°C. In this scenario, economic losses of 11% to 13% of cumulative GDP by 2100 could be avoided. By additionally investing a relatively small share of cumulative GDP – less than 1% – in adaptation, it may be possible to reduce these losses by an additional 4% of cumulative GDP by 2100 (see Figure 3).

The net cost of inaction is thus estimated to range between 10% to 15% of global GDP by 2100. However, if leaders take necessary mitigation and adaptation actions now, these costs could be significantly reduced.[14]

Resilience across the value chain will unlock greater value for all

Adaptation must be at the core of every organization's climate strategy, but it cannot stop there. Vulnerability to climate change is not just about a company's own exposure – it is also tied to the resilience of the entire value chain (see Figure 4). Most adaptation strategies are narrowly focused on individual organizations or regions, yet the ripple effects of climate change extend far further.

FIGURE 3 **The economic case for taking climate action now**



Source: BCG. (2024). Why Investing in Climate Action Makes Good Economic Sense.[15]

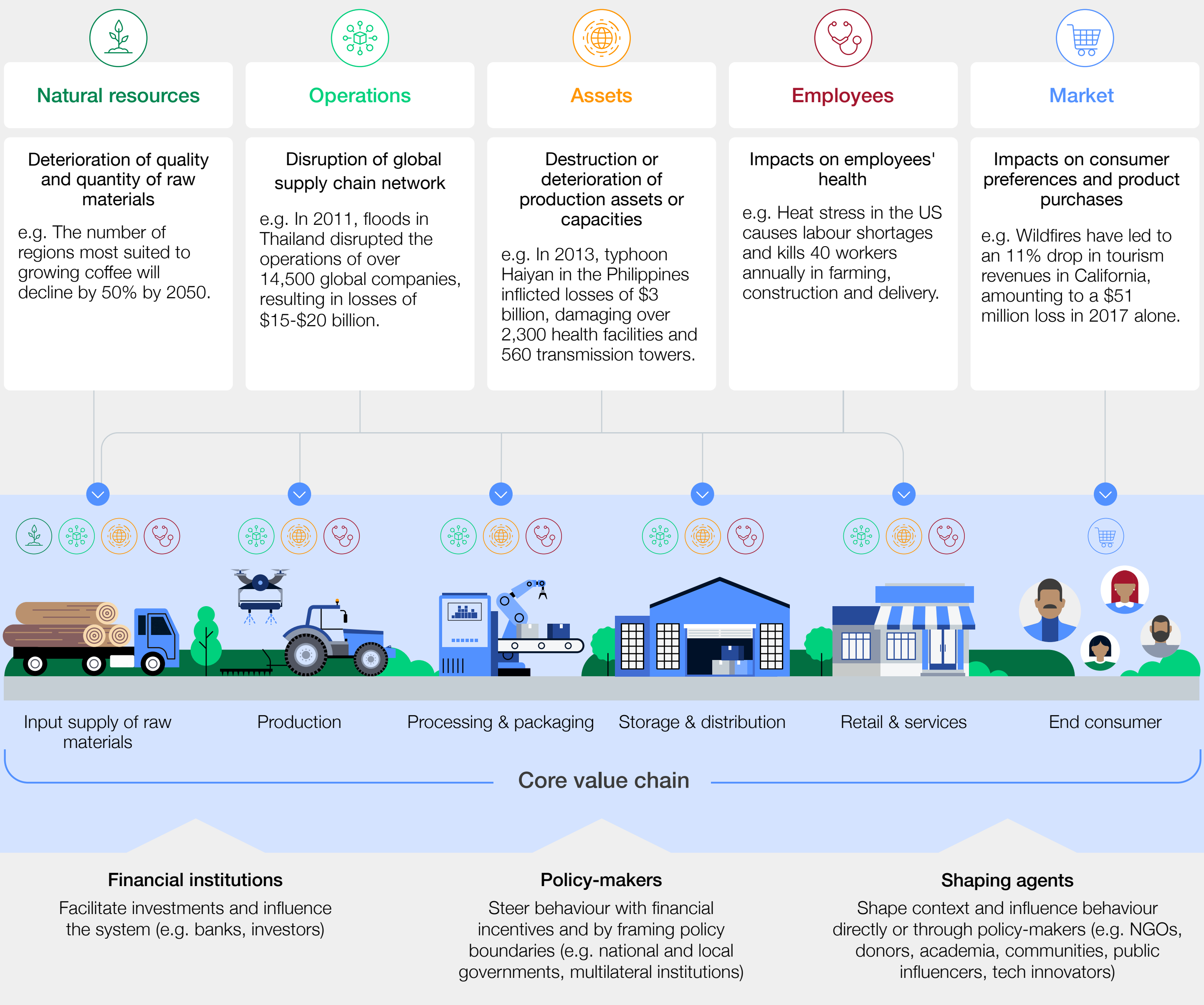
Climate risks can impact value chains in many ways, such as a decline in raw material quality or quantity, supply chain disruption, destruction of production capacity, shifting consumer preferences, weakened community support systems and harm to employees' health. Each of these causes financial impacts from increased operating costs and lower revenues to unforeseen asset damage and escalating insurance premiums.[16]

Collaboration is therefore vital. If one part of the value chain fails – for example, a raw material supplier goes out of business due to a hurricane – the repercussions will reverberate all along the chain. Companies have to adopt a systemic approach to climate risks.

Collaboration unlocks several benefits, including:

1. Increased resilience to climate change impacts for companies and their value chain partners, safeguarding operations and long-term growth.
2. Improved financial returns by pooling adaptation investments, reducing costs and unlocking collaborative value creation.
3. Streamlined regulatory compliance through unified adaptation standards and metrics across the value chain.
4. Accelerated research and innovation for adaptation by combining the expertise of value chain players and technology providers.
5. Greater positive impacts on communities, ecosystems and local businesses through more equitable access to technology and data.

FIGURE 4 **Physical climate risks threaten value chains in five dimensions**



Sources: BCG-GRP-USAID, Grüter, Trachsel, Laube & Jaisli, BBC, Government of the Philippines, Asian Development Bank, Time Magazine, Visit California.[17]

By working together, companies can make adaptation more effective. Constanza Gómez, CEO of C-Minds, explains: "There is a higher probability of sustained success and thus sustained economic growth for larger corporations if the complete chain, including the smaller companies, are aligned with practices that will make them resilient to changes and aligned with new regulations. Economic stability depends on ensuring that sources of input are resilient to climate effects and comply with growing ESG measures." Building resilience along a value chain does require investment, but when an organization and its stakeholders jointly deploy adaptation measures, their costs fall while everyone's benefits increase.

> **Geographical diversification doesn't mean climate diversification. Extreme weather events in one region, such as Australia, can have far-reaching impacts on supply chains in the EU and US. This is the butterfly effect.**
>
> Himanshu Gupta, Chief Executive Officer, ClimateAI

Mobilize all stakeholders to maximize the impact of adaptation

Collaboration is needed at every level. For example, a port authority aiming to safeguard its infrastructure from rising sea-levels must coordinate with local governments, shipping companies, financial investors and adaptation solution providers, transcending individual value chains. In planning and executing adaptation strategies, organizations must engage all stakeholders within their ecosystem. This coordination is especially critical in areas facing localized physical risks.

Financial institutions, such as banks, insurers and investors facilitate investments and influence the system. Policy-makers, from national and local governments to multilateral institutions, provide financial incentives and set regulatory boundaries. Shaping agents, including NGOs, academia, public influencers and tech innovators help drive the transformation agenda by influencing behaviour. Local communities, including employees, citizens and Indigenous groups, must also be involved, as their insights are crucial to find a just and inclusive path forward, nourished by local wisdom and ancestral knowledge.

> **It's crucial to map priority value chains onto regions most vulnerable to climate change – areas that face the highest risks, like rising sea levels, fires and floods. These regions become 'hubs of vulnerability', where multiple value chains converge, requiring concentrated adaptation efforts to mitigate widespread impact across industries.**
>
> Gail Whiteman, Hoffmann Impact Professor for Accelerating Action on Nature & Climate, University of Exeter

Follow the adaptation cycle using technology

Frontier technologies, such as AI, help organizations adapt to climate risks in more ways than one, through anticipating impacts, responding swiftly and building long-term resilience. If used simultaneously, these technologies amplify each others' impact and allow smart executive decision-making by enabling standardized communications, risk measurement and data sharing.

As described in the World Economic Forum's January 2024 publication, *Innovation and Adaptation in the Climate Crisis: Technology for the New Normal*,[18] technology has become central to building resilience, propelling innovation and creating new capabilities for leaders and communities. Advanced technologies, such as the internet of things (IoT), drones and satellites, all equipped with AI, have emerged as critical tools for climate adaptation. They can be used independently or together and provide companies with capabilities that extend from predictive decision-making to modifying behaviour.

Business leaders can leverage these technological capabilities to address the three stages of the adaptation cycle:

- **Comprehending risks and opportunities.** AI, Earth observation (EO), IoT and drones have transformed how leaders gather, process and analyse information. These technologies provide intelligence on how the Earth is changing at the planetary level and how companies and communities will feel the impacts.

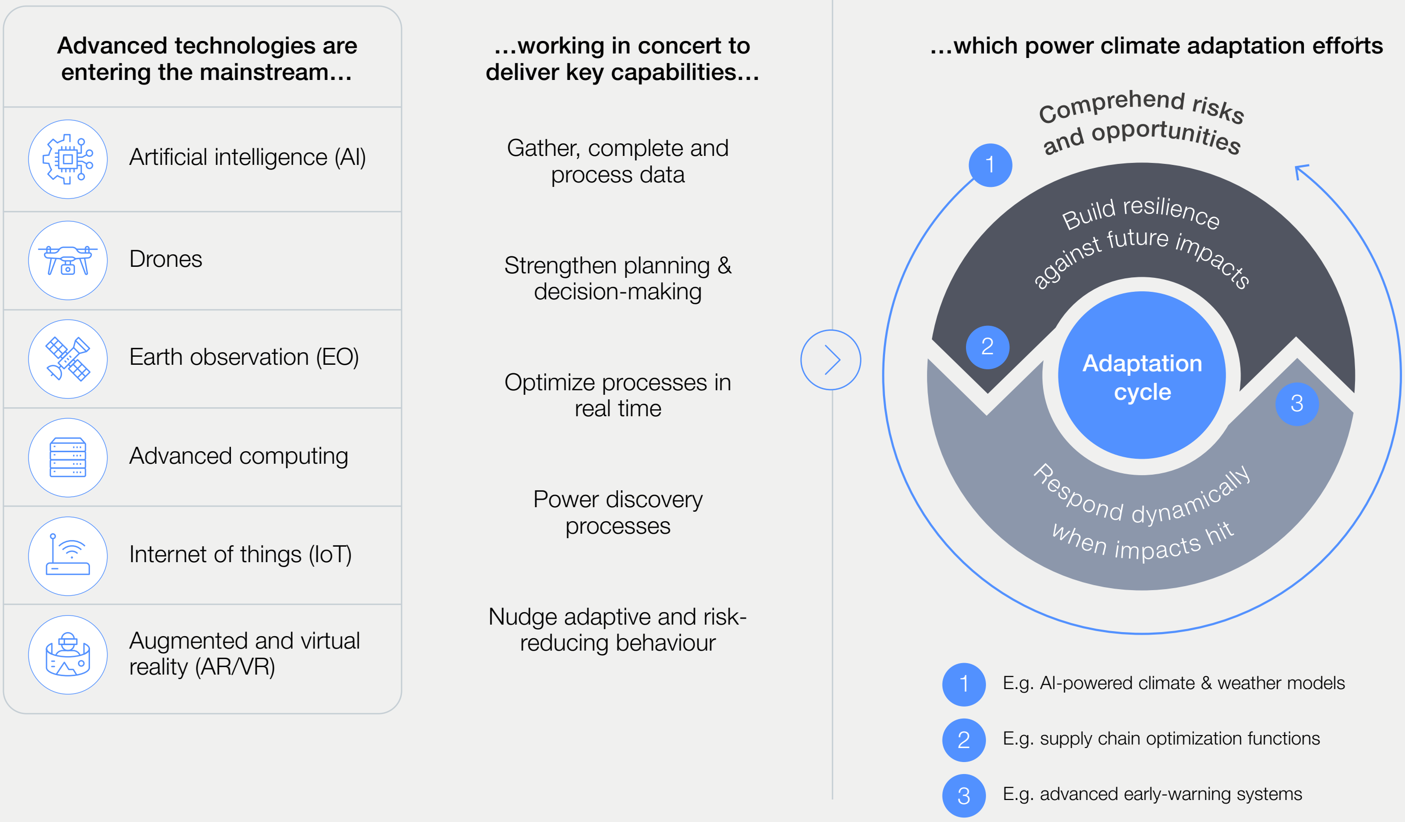
- **Building resilience against future impacts.** AI has built resilience into critical infrastructure, such as flood management systems, through optimization and real time maintenance. EO and IoT have brought a new degree of precision to resilience tools such as early-warning systems.

- **Responding when climate impacts hit.** EO, along with drones, can provide a view of hard-to-reach areas in the aftermath of an extreme event. Drones can be used to make deliveries of emergency aid as well as support search and rescue operations, especially since their AI capabilities improve situational awareness.

Data-driven insights are the foundation of successful climate adaptation strategies. Better access to climate and value chain data ensures more efficient planning, targeted resilience efforts and faster adaptation when risks materialize. Leaders must collaborate to ensure data and technology accessibility and then act on it to drive meaningful change.

> **Adaptation is first an information problem, because leaders have to understand the forces of change to design solutions.**
>
> Andrew Zolli, Planet Labs

FIGURE 5 **Frontier technologies are powering climate adaptation efforts**



Source: World Economic Forum. (2024). *Innovation and Adaptation in the Climate Crisis: Technology for the New Normal*.

1 Boosting value chain resilience through technology and collaboration

How to embed adaptation to climate change across value chains in three vulnerable systems – food, energy and manufacturing.

Frontier technologies enable companies to adapt their value chains to climate change-related risks on their natural resources, assets, operations, employees and market dynamics. These factors are characteristic, to some degree, of all value chains. This chapter focuses on three key industries: food, energy and manufacturing, where the first three factors – natural resources, assets and operations – are most critical, as they present the highest cost implications and immediate, tangible opportunities for action:

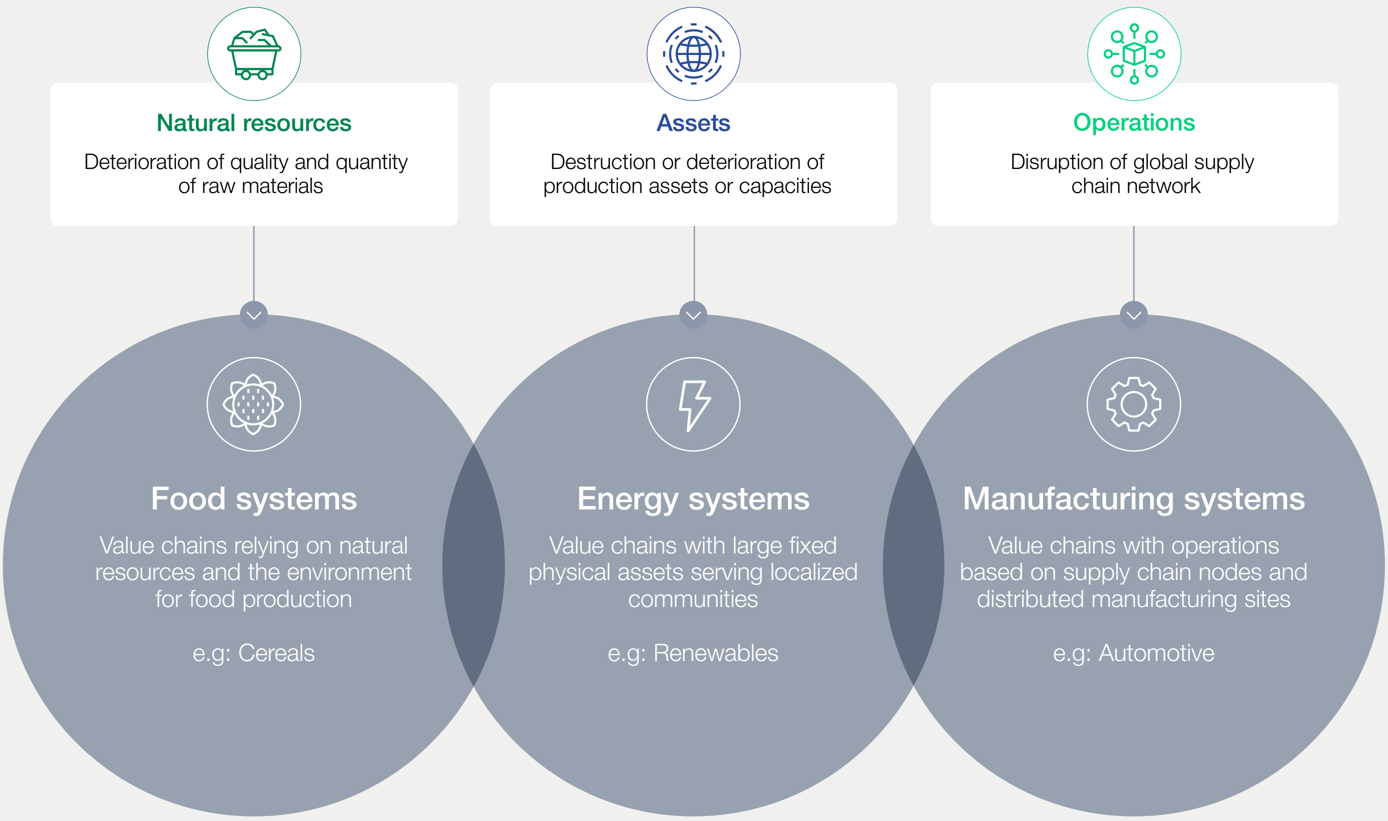
– **Food systems value chains depend on natural resources:** these systems (e.g. cereals value chain) are particularly vulnerable to environmental changes such as water scarcity and shifting weather patterns.

– **Energy systems value chains feature large, immovable assets:** these systems face significant risks from extreme weather events that can damage infrastructure and disrupt essential services like healthcare.

– **Manufacturing systems value chains have complex global distribution networks and operations:** these systems (e.g. automotive sector) are susceptible to climate-related disruptions at multiple stages of their supply chain.

Each value chain requires tailored adaptation strategies to address its unique challenges. Looking at these three key industry systems, the following sections provide examples of how collaboration can play a critical role in overcoming the barriers to tech-driven adaptation and how this might be extended to other value chains.

FIGURE 6 **Focus on climate impacts in three key value chains**



Source: World Economic Forum and BCG analysis.

1.1 Food systems

Under the current warming trajectory, rice, maize and soybean yields could fall

24%

by 2030, while wheat yields may rise by 17%.

Weather extremes are a major driver of food insecurity.[19] According to the Food and Agriculture Organization of the United Nations (FAO), 28.9% of the global population – 2.33 billion people – experienced moderate or severe food insecurity in 2023, across both developing and developed countries.[20] Beyond nutrition and health, food insecurity affects social equity, causes political instability and hampers economic development.

Food systems and climate change share a paradoxical relationship. From one perspective, the food value chain is responsible for about one third of greenhouse gas emissions.[21] The sector consumes around 70% of the world's freshwater and uses 50% of all habitable land, often at the expense of forests and native grasslands, further exacerbating climate change.[22]

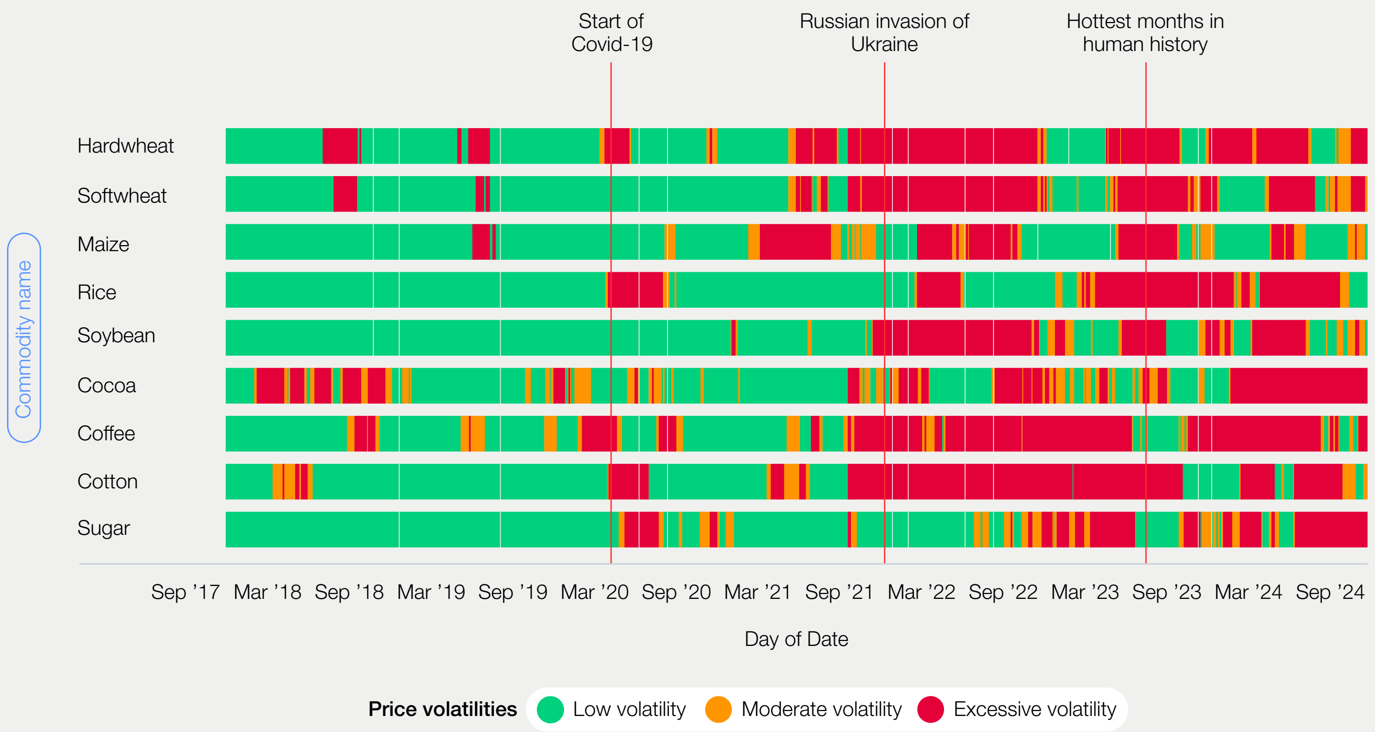
From another perspective, food systems are extremely vulnerable to climatic factors such as rainfall, temperature, pollinator health, sunlight and soil conditions. Under the current warming trajectory, rice, maize and soybean yields could fall 24% by 2030, while wheat yields may rise by 17%.[23] Soil erosion could also lead to a 10% loss in crop production by 2050,[24] reducing the amount of arable land, while global crop yields could be reduced by 20%-40% annually due to plant pests and diseases.[25]

Extreme weather events drive up food prices

Extreme weather events have already taken a toll on agricultural production. In early 2024, droughts slashed olive production in Spain by 40%, driving olive oil prices up by 27% over the past year.[26] Similarly, after extreme weather hit cocoa farms in Ghana and Côte d'Ivoire, chocolate producers faced a 400% surge in cocoa prices.[27]

These extreme events also trigger short-term crises that erode communities' and countries' food security, with cascading impacts on regional stability. Consider the global wheat market in 2022, after Russia invaded Ukraine. Both are major suppliers of wheat, but the war limited their ability to export the commodity. India, France and Argentina were expected to bridge the gap but a heatwave in India shrank wheat production there, leading the government to temporarily ban exports. Then, a heatwave in France and a drought in Argentina further reduced global wheat supplies. Panic ensued, with wheat prices shooting up by nearly 110% over 18 months.[28]

FIGURE 7 **Food prices have seen excessive volatility since 2020**



Source: FAO.[29]

Food and beverage companies report a perceived benefit-to-cost ratio of 19:1 from adaptation investments, with some reaching as high as

43:1

Climate change is expected to increase cereal prices by a median of 7.6% by 2050, increasing food prices and the risk of food insecurity and hunger.[30] The most vulnerable, particularly in low-income countries, will be disproportionately affected. Agriculture, food and beverage companies have started paying the costs of inaction, reporting a median 6% yearly profit impact by 2050 due to physical climate risks – a figure likely underestimated, with sectoral estimates ranging from 8%-12%.[31]

When food companies adapt to minimize the impact of climate change, they achieve significant results – generating economic returns, reducing costs and benefitting stakeholders along the value chain. Food and beverage companies report a perceived benefit-to-cost ratio of 19:1 from adaptation investments, with some reaching as high as 43:1.[32] This underlines the opportunity for food companies to quickly adopt advanced technologies, such as AI, drones, IoT or Earth observation, strengthening resilience while creating efficient, productive operations that reduce the climate footprint of agriculture and promote sustainable practices.

Embedding adaptation technologies into food networks

One of the key characteristics of a food system is that it operates as a social network. Each network node (e.g. port, warehouse, retail store) faces specific climate risks, so its adaptation capacity depends on the role it plays and its ability to access resources, data and technologies. Specifically,

- **Upstream, input-providers**, such as seed and fertilizer companies, have to learn to adapt to climate crisis-induced changes in crop yields and pestilence.
- **Farmers**, at the frontlines of climate change, must take on extreme weather events such as droughts and floods, which threaten agricultural productivity and livelihoods.
- **At the processing and distribution stages**, climate risks disrupt the movement and supply of raw materials, amplifying the vulnerability of the global food trade.
- **Downstream retailers and consumers** must manage major fluctuations in food supplies, which will lead to price volatility and food insecurity.

Building on the network-like nature of food systems, integrating data and advanced technologies can significantly improve resilience, efficiency and sustainability across all stages. Six key tech-driven adaptation use cases show how food systems can adapt to climate-related disruptions (see Figure 8). Some – such as precision farming, digital agricultural platforms and food supply chain tech – help the value chain to better understand climate risks and opportunities. Others – such as regenerative agriculture, agri-biotech and novel farming systems – focus on building resilience against climate impacts.

One thread that runs through all of them is the need for collaboration, facilitating the sharing of resources, data and technologies that single entities cannot access alone. Adopting a system-wide approach magnifies the benefits of adaptation, driving transformation at larger scale.

> **We learned through our collaboration with institutions that it's essential to clearly define the use cases for collective adaptation, to ensure that collaboration between the public and private sectors is focused, goal-oriented and yields measurable results. Commitment from leadership is also required to prioritize and invest in climate-related projects.**
>
> Hatice Yildirim, Koç Holding

FIGURE 8 | **Six tech-driven use cases show how food systems can adapt to climate-related disruptions**

1 Precision farming

Model weather and climate impact optimize inputs and productivity with data from aerial imagery & sensors.

Ground sensing uses integrated system of mounted sensors for tillage planning and fertigation.
Aerial sensing uses drone or Earth observation, along with AI-models to map precise field conditions. Monitor impact on surrounding ecosystems.
Smart irrigation uses data from sensors to manage water, nutrient, and pesticide application.

2 Digital Agri platforms

Empowers farmers with integrated digital services.

Agri-Business platforms provide farmers with access to agronomic advice, financing and input procurement.
Marketplace services facilitates direct online transactions between farmers and consumers (B2C) or businesses (B2B).

3 Food Supply Chain Tech

Tech-enabled solutions for improving food safety & traceability and logistics efficiency.

Agri-Tech supply chain improve logistics, reduce losses, ensure field to fork traceability, enhanced food storage.

4 Regenerative agriculture

Resilient farming methods that regenerate soil health and capture carbon in the soil.

Regenerative agriculture practices aimed at improving biodiversity, soil health, and carbon sequestration.
Synecoculture develops a mixed high-density polyculture based on regenerative agriculture and self-organization of ecosystems augmented by ICT-supported monitoring and management systems.

5 Agri Biotech

Gene editing and biologics enhance yields, nutrients and resilience.

Gene editing methods allow targeted traits.
Biofertilizers utilizes microbiomes to increase nutrients in the soil for a crop.
Biopesticides are pesticides that are naturally-derived, or with added genetic material.

6 Novel farming systems

New tech-enabled farming methods including vertical hydroponics, aquaponics, and vertical farming.

Vertical and hydroponic farming grows crops indoors in stacked layers with controlled environments using a water-based nutrient solution rather than soil.

Value chain stakeholders involved

Upstream input providers | Farmers | Processing & distribution | Retailers & consumers

Source: World Economic Forum and BCG analysis.

TABLE 1 | **Tech and data needs, to enable adaptation across food systems value chain**

Adaptation use case	Tech needs	Shared data needs	Illustration
Comprehend risks & opportunities			
1 Precision farming	– IoT sensors (for soil moisture, temperature, etc.) – Drones and Earth observation for aerial imagery – AI and machine learning models for predictive analytics – Smart irrigation systems – Ground sensing technologies	– Weather and climate data from meteorological agencies – Soil data (composition, moisture, nutrient levels) from agricultural research institutions – Crop yield data from farmers and agronomists – Historical performance data from previous crop seasons – Data on pest and disease prevalence from agricultural extension services	**CropX** (ground sensors tech solution) deploys sensors to collect soil data (e.g. salt concentration, fertilizer movements) with ~30% savings in input costs, ~10% yield improvement and ~30% water savings for farmers.
2 Digital agri platforms	– Online marketplaces for direct farmer-consumer sales – Mobile apps for advisory services, improved by AI – Blockchain for transaction transparency	– Market demand data from retailers and consumers – Financial data for farmers (costs, revenue, profits) – Agronomic advice based on soil and crop health data – Consumer preferences and behaviour data	**Twiga Foods** in Kenya serves 5,000 Kenyan outlets daily and works with 13,000 farmers to improve supply chain efficiency and reduce food waste.
3 Food supply chain	– Blockchain for traceability and transparency – Supply chain management software, powered by AI for optimization of routes, supply or distribution – IoT devices for real-time tracking of food products – Cloud-based storage for data sharing among stakeholders	– Logistics data (transportation, warehousing, distribution) – Food safety compliance data from regulatory bodies – Inventory levels from suppliers and retailers – Consumer feedback on product quality and availability	**OpenSC** is helping coffee producers track the sustainability and ethical sourcing of their coffee by using blockchain technology, providing real-time traceability from farm to consumer while reducing inefficiencies across the supply chain.
Build resilience against future impacts			
4 Regenerative agriculture	– Soil health monitoring tools – Biodiversity tracking and exploration software – Carbon sequestration measurement tools – AI powered decision-support systems for sustainable practices	– Data on soil carbon levels from environmental agencies – Biodiversity and biotic interaction data from ecological research organizations – Crop association, rotation and cover crop performance data from agronomists – Data on ecosystem functions and services provided by introduced and naturally occurring species (pollination, water filtration)	In Burkina Faso, **Synecoculture** has boosted productivity by 50-200 times compared to traditional farming, generating an income of €1,000/month/500m². This method cultivates over 200 edible plant species without plowing, fertilizers, or agrochemicals, promoting biodiversity and supporting sustainable livelihoods while enhancing the ecosystem.
5 Agri biotech	– CRISPR and other AI-powered gene-editing technologies – Bioinformatics tools for genetic analysis – Microbial inoculants for soil health – Precision agriculture tools for targeted application of inputs	– Genetic data from plant breeding programs – Soil nutrient data from agronomic studies – Performance data from genetically modified crops – Regulatory compliance data for biotech products	Companies like **Corteva** have used CRISPR technology to develop drought-resistant crops, reducing the impacts of water scarcity on farming.
6 Novel farming systems	– Hydroponic and aquaponic systems – Vertical farming technology (LEDs, climate control) – Automated nutrient delivery systems – Data management software for environmental controls	– Market data on consumer demand for fresh produce – Performance data on yield per square foot from existing systems – Water usage and recycling data – Energy consumption data for sustainability assessments	**AeroFarms**, a vertical farming company, produces 390 times more yield per square foot compared to traditional farming while using 95% less water.

Sources: AGBI, BCG, Corteva, CropX, OpenSC, Sony CSL.[33]

CASE STUDY 1

Building tech-driven resilience in cereal value chains

OCP Group, a global leader in plant nutrition solutions from Morocco, aspires to transform soil health, enhance carbon sequestration and boost farmers' long-term productivity by driving a just agricultural transition through the development of sustainably produced, customized fertilizer solutions and smart farming practices.

Challenge: Climate change threatens cereal yields amid rising demand

Cereals, such as wheat, rice, soybean and maize, are the mainstay of human consumption but are increasingly vulnerable to climate change. By 2050, cereal production could fall by 11%, with strong geographic disparities, due to rising temperatures, erratic rainfall patterns, extreme weather events and the loss of suitable agricultural lands, which together create a double impact on yield and the availability of land. Meanwhile, the demand for cereals will grow by up to 60% due to population growth and biofuel development, exerting greater pressure on the world's food systems. To address this dual threat, food systems need to shift rapidly to agricultural practices that boost productivity while helping farmers adapt to a hostile climate.

Action: Tech-driven, collaborative ecosystem for sustainable agriculture

Against this backdrop, OCP launched a programme aimed at helping small farmers to combat the impacts of climate change. The objective is to secure food supplies by promoting sustainable farming through advanced technology and agronomic expertise:

- **Precision farming:** OCP's Tourba platform provides smallholder farmers access to expert advice by integrating satellite imagery, weather data and soil analysis. It monitors carbon sequestration in soils and develops recommendations for fertilizer usage and irrigation, helping farmers optimize their yields while maintaining soil health. OCP also deploys mobile laboratories to test soil fertility and provide farmers with tailored recommendations for plant nutrition. The process not only reduces costs but also minimizes environmental impacts such as soil degradation and water contamination.

- **Digital agri platforms:** OCP's Pocket Agronomist, an AI-driven chatbot, provides farmers with 24/7 access to customized agronomic advice based on soil, crop and local climate data. The Agribooster programme allows farmers to connect with input suppliers, financial services and market intermediaries. OCP has also helped accelerate the use of climate-smart practices such as conservation tillage and drip irrigation, which helps farmers adapt to increasingly erratic weather patterns.

Results

OCP's success is rooted in its collaborative approach. Backed by an extensive network of partners, such as UM6P (Mohammed VI Polytechnic University), the World Food Programme and local governments, OCP integrates the latest agronomy and climate resilience science while promoting access to resources and markets for smallholder farmers.

Since 2018, OCP's initiatives have reached 2.5 million smallholder farmers and aim to support 4 million in 2024 across Africa and Brazil, boosting both productivity and sustainability. For example, farmers have reported yield increases of up to 21% in three years, while fertilizer-use efficiency has improved by over 20%, reducing cereal farming's environmental footprint. That translated into a 23%-34% rise in farmers' net profit margins.

The next phase will focus on scaling digital advisory platforms by integrating AI-driven crop monitoring systems, offering predictive analytics of climate risks and deploying blockchain technology to enhance supply chain transparency and traceability. By developing collaboration platforms, OCP aims to ensure that smallholder farmers not only survive but also thrive despite the climate crisis.

Sources: OCP Group, FAO, IFPRI, World Economic Forum, BCG analysis.[34]

1.2 Energy systems

By 2050, solar and wind are projected to account for

60%

of global electricity generation – a significant increase from just 13% in 2023.

Energy companies report perceived benefit-to-cost ratios ranging from 2:1 to

14:1

on their adaptation investments.

Energy systems power nearly every essential service in our modern societies. As with food systems, they are vulnerable to physical climate risks (extreme heat, cold, precipitation and wind) due to their reliance on immoveable, heavy assets and infrastructure such as power plants, grids and pipelines.

Conventional energy sources will continue to play a part in electricity generation in the near future, but by 2050, solar and wind are projected to account for 60% of global electricity generation – a significant increase from just 13% in 2023. Electricity demand will continue to rise because of economic development, population growth and expanding electrification. According to the International Energy Agency (IEA), electricity demand surged by 6% in 2021, the largest increase in over a decade[36] and is projected to nearly double by 2050. To meet this additional demand, electricity generation will need to increase by up to 92% by mid-century, driven largely by renewable energy sources such as solar and wind.[37]

Financial toll of climate change on energy systems

In 2023, extreme weather events caused significant disruption to energy infrastructure. For example, the cost of meeting rising global demand for cooling systems during heatwaves climbed from $10 billion per annum in the 1990s to nearly $30 billion. At the same time, the output of hydropower has declined globally due to changing precipitation patterns and physical damage from extreme weather, costing around $18 billion annually to compensate for lost generation.[38] Between 2000 and 2021, about 83% of the power outages reported in the US were attributed to weather-related events.[39] For instance, during the winter storm in Texas in February 2010, nearly 10 million people lost power when the traditional energy infrastructure was unable to handle freezing temperatures. Despite efforts from utility companies and government agencies, restoring power took weeks, resulting in over $10 billion in insured losses and an estimated $80 to $130 billion in total economic impact.[40]

By 2050, physical climate risks could put up to 16% of yearly annual profits (EBITDA) at risk in the energy sector under a 3.0°C scenario.[41] As climate impacts intensify, energy assets will face faster depreciation and loss of value, leading to supply disruptions, increased prices and added strain on global supply chains. As a result, the energy sector's physical assets are estimated to be overvalued by 3-10% due to insufficient consideration of climate risks.[42]

In the US, annual costs from extreme weather-related power outages are projected to escalate, requiring a total of $500 billion in utility investments by 2050 to build resilience and mitigate potential disruption.[43]

Moreover, societal costs will rise significantly unless energy companies proactively address climate risks. Energy supply disruptions have cascading effects on essential services such as healthcare, emergency responses, transportation, communication and computing. Power outages put lives at risk, particularly for vulnerable populations such as the elderly or the ill. In US rural areas, where energy costs can account for up to 15% of household incomes,[44] climate-driven increase of energy costs disproportionally burdens low-income families.

Adaptation as a guardrail for energy systems

On the other hand, the benefits of adaptation are substantial. Investments in climate-resilient infrastructure help energy companies withstand climate impacts, minimize disruptions, lower maintenance costs and ensure that energy systems work during crises. As a result, energy companies report perceived benefit-to-cost ratios ranging from 2:1 to 14:1 on their adaptation investments.[45]

Despite the clear financial and operational benefits of adaptation, the ability to implement these strategies varies significantly across the energy value chain. Many companies lack access to the data and capabilities required to deploy advanced technologies and enable efficient adaptation approaches. Without data to inform decision-making and optimize operations, even well-funded energy companies will struggle to deploy adaptation systems.

Small energy companies, such as local utilities, face bigger challenges. These operators, essential to maintaining grid stability in rural and underserved areas, lack both the financial capacity and access to cutting-edge technologies, thus remaining vulnerable to climate risks.

Technology to anchor adaptation in energy companies

Energy systems are built on a complex network of public-private collaborations, involving stakeholders from resource providers and energy producers to distributors, storage managers and consumers.

Investments across the energy value chain are crucial for sustaining resilience and driving innovation. However, each part of the system is exposed to specific climate risks, requiring targeted adaptation technologies to ensure resilience of the whole system:

- **Upstream input providers** supply materials such as copper, lithium, oil, gas and biofuels. Climate risks (e.g. droughts, floods, water scarcity) disrupt mining, fossil fuel extraction and biofuel production, threatening essential resources for energy systems.

- **Energy producers** convert inputs into electricity, heat, fuels and industrial by-products such as steam. Climate impacts (e.g. extreme heat, droughts, floods) reduce renewable energy output and damage refineries, nuclear plants and bioenergy facilities.

- **Distributors and storage systems**, including pipelines, fuel transport, the electric grid and batteries are vulnerable to climate risks (e.g. flooding, freezing, extreme heat, storms). This can damage infrastructure, disrupt energy delivery and reduce the efficiency of energy storage systems.

- **Consumers**, such as households, businesses and critical services, are directly impacted by power outages and supply disruptions. These interruptions lead to heating and cooling failures, production halts and strain on essential services like healthcare, endangering both lives and livelihoods.

As climate-related disruptions become more frequent and severe, the transformation of energy systems becomes more urgent.

While energy companies' adoption of advanced technologies is inconsistent, successful applications are increasingly bridging the technology gaps.

Four key technology-driven use cases are enabling energy systems to adapt and thrive under increasing climate pressures: climate impact modelling, real-time energy management, energy emergency response and energy early warning systems (see Figure 9). By highlighting the need to share relevant data and technologies across stakeholders, these use cases clearly demonstrate that collaboration is vital for scaling adaptation.

FIGURE 9 | Four tech-driven use cases to help energy systems adapt to climate-related disruptions

1

Climate impact modelling

AI and digital twins simulate systems for real-time monitoring and help operators preemptively manage extreme weather impacts on energy infrastructure.

Asset monitoring: AI & digital twins monitor and predict maintenance needs for key assets (e.g., turbines, dams, offshore wind farms), reducing costs and extending asset lifespans.
Grid modelling:AI & digital twins model vulnerabilities across the grid, helping operators fortify weak points like substations and transmission lines before failures occur, as well as fluctuations in energy supply and demand based on weather and climate event scenarios.

2

Real-time energy management

AI and real-time data optimize energy use and storage, ensuring grid stability by balancing supply, demand, and renewable integration.

Peak demand and grid stabilization: AI reduces energy consumption during peak times and leverages energy storage to supply power, preventing overloads and maintaining stability during high demand.
Failure avoidance and waste reduction: Predictive AI identifies potential failures early, allowing for proactive maintenance and reducing energy waste by balancing supply with demand, improving grid efficiency.

3

Energy early warning systems

Earth Observation and IoT sensors detect environmental risks such as wildfires or storms, allowing operators to take preventive action before grid infrastructure is compromised.

Extreme weather event monitoring: Real-time data from Earth Observation detect storms and other extreme weather events.
Wildfire risk monitoring: Sensors track environmental conditions to detect wildfire risks, avoiding outages and damage.
Flood detection and prevention: IoT sensors monitor flood-prone areas, providing early alerts that allow operators to reroute power and take preventive measures to avoid damage to the grid.

4

Energy emergency response

Microgrids and energy storage systems ensure critical facilities maintain power during disasters, allowing them to operate independently from the main grid.

Power continuity in disasters: Microgrids maintain power to essential services like hospitals during extreme weather.
Smart battery and storage management: Smart storage systems efficiently manage energy supply, providing backup power during outages and supporting the grid during high-demand periods.

Value chain stakeholders involved

Upstream input providers | Energy producers | Distributors and storage systems | Consumers

Source: World Economic Forum and BCG analysis.

TABLE 2 | **Tech and data needs, to enable adaptation across energy systems value chain**

Adaptation use case	Tech needs	Shared data needs	Illustration
Comprehend risks and opportunities			
1 Climate impact modelling	– AI and real-time data analytics for energy infrastructure resilience modelling – Monitoring tools for key assets – Digital twin modelling for energy system simulation	– Historical performance data for grid stability and energy consumption – Real-time data from turbines and energy assets – Vulnerability assessments across the grid – Historical maintenance and failure data	**Siemens Gamesa** uses digital twin models of wind turbines to optimize maintenance schedules, reducing turbine maintenance costs by 30% and extending their operational lifespan, ensuring reliable energy production even in extreme weather conditions.
Build resilience against future impacts			
2 Real-time energy management	– Real-time data analytics tools for energy balancing – AI models for grid and energy use optimization	– Energy consumption data during peak times – Supply and demand metrics for energy – Predictive analytics for identifying potential failures – Historical performance data for grid stability	By using AI, **NESO** reduced downtime by over 20% during critical weather events. The system anticipates grid stresses and reroutes energy flows, ensuring grid stability during peak demand.
3 Energy early warning systems	– IoT sensors for environmental monitoring – Data analytics tools for risk assessment – AI for short-term weather modelling	– Real-time data on environmental conditions (including Earth observation) – Historical data on natural disasters and their impacts – Alerts for flood-prone areas and other risks	**PG&E** uses IoT sensors to monitor environmental conditions, identifying wildfire risks early. This system prevents major infrastructure damage and blackouts by enabling operators to take early action before fires escalate, ensuring continued service during high-risk seasons.
Respond dynamically when impact hits			
4 Energy emergency response	– Microgrid technology for independent operation – Energy storage systems for backup power – Smart battery management systems	– Data on critical facility energy requirements – Environmental data for disaster preparedness – Historical data on emergency responses and outages – Metrics on energy supply during high-demand periods	After Hurricane Maria, **CERI** deployed solar-powered microgrids with battery storage to three key facilities in Puerto Rico. These microgrids provided reliable power to hospitals and essential services, ensuring continued operation during extreme weather events while reducing energy costs by 20%.

Note: NESO = National Energy System Operator (formerly UK's National Grid ESO); PG&E = Pacific Gas & Electric; CERI = Center for Economics, Resources, and Innovation, University of California, Berkeley.

Sources: Siemens, National Grid ESO, Power Grid International, Enel North America, BCG analysis.[46]

CASE STUDY 2

Enhancing resilient energy systems through smart technology

Schneider Electric, a global leader in energy management and automation, has pioneered innovative solutions that combine real-time data and advanced technology to enhance energy system resilience. By partnering with Manchester Metropolitan University (MMU) and Salix Finance, Schneider Electric implemented a comprehensive climate adaptation strategy using the EcoStruxure platform.

Challenge: Avoiding grid failures due to climate events

Climate change is placing increasing strain on energy systems, with rising temperatures and extreme weather events leading to more frequent and severe disruptions. Power outages driven by heatwaves, storms or grid failures not only compromise the resilience of essential services but also increase energy costs and greenhouse gas emissions.

Action: Tech-driven, collaborative platform for energy systems resilience

To address these challenges, Schneider Electric partnered with MMU and Salix Finance to deploy a climate adaptation strategy centred on its EcoStruxure platform, which integrates real-time energy monitoring, smart infrastructure and data-driven decisionmaking. This allowed MMU to gain continuous visibility over its energy consumption and adjust dynamically during extreme weather conditions, reducing the risk of power outages.

The initiative involved modernizing MMU's energy infrastructure, by consolidating IT services into a resilient, energy-efficient data centre designed to withstand extreme conditions including high winds and flooding. For example, providers such as Tonaquint developed data centres capable of withstanding tornado-force winds up to 310 mph. The design also incorporated redundant power systems, advanced cooling technologies and floodresistant infrastructure, ensuring continued operation during climate-induced disruptions.

Deployment included:

- Elevating structures above flood levels and installing flood barriers.
- Deploying back-up power systems and robust defences to protect infrastructure.
- Distributing sites geographically to build redundancy and mitigate localized failures.

Results

Rémi Paccou, Director of Sustainability Research at the Schneider Electric Research Institute, describes the results: "Manchester Metropolitan University's investment in a resilient, energy-efficient data centre showcases the critical role of infrastructure modernization in climate adaptation strategies for higher education institutions. By implementing Schneider Electric's modular architecture, the university has not only enhanced its IT service reliability but also fortified its operations against future climate-related challenges, setting a benchmark for sustainable and adaptable technological infrastructure in the industry."

This partnership achieved significant outcomes in both climate adaptation and operational efficiency. MMU successfully enhanced its energy resilience by reducing its vulnerability to power outages during extreme weather events, while cutting energy costs by 30%. The project is expected to reduce MMU's carbon footprint by 15,600 tonnes, translating to annual savings of £3.8 million and showcasing how investments in energy resilience can also deliver financial and sustainability benefits.

Furthermore, the initiative embraced sustainable energy models, reducing reliance on fossil fuels and implementing AI-driven energy management systems that optimize energy use and enable predictive maintenance as climate impacts intensify.

Looking ahead, Schneider Electric plans to scale-up its efforts by fostering greater cross-institutional collaboration, enhancing data interoperability and integrating AI-driven energy analytics to further optimize energy performance and climate adaptation across its value chains.

Sources: Schneider Electric, TechTarget, Green City Times, Elea Data Centers, Foster Fuels.[47]

1.3 Manufacturing systems

Frequent droughts at the Panama Canal, which handles up to

6%

of global trade, have reduced traffic from 40 to 24 vessels per day.

Over time, manufacturing has become extremely global in nature, relying on intricate supply chains that span several continents to integrate raw material supplies, production, assembly and distribution, making them extremely vulnerable to disruptions. As the aftermath of the Covid-19 pandemic demonstrated, manufacturing systems nowadays are prone to ripple effects where small, seemingly insignificant events in one part of a value chain can lead to large, unpredictable consequences across all other nodes in the chain.

When a butterfly flaps her wings, a breeze goes around the world

Climate change exposes global manufacturing to even more risk. Water scarcity, in particular, is a growing concern for manufacturing. For example, frequent droughts at the Panama Canal, which handles up to 6% of global trade, have reduced traffic from 40 to 24 vessels per day.[48] This has delayed the movement of raw materials and finished goods in sectors such as electronics, automotive and consumer goods, driving up costs across these value chains. Taiwan, producing over 60% of the world's semiconductors, is dealing with prolonged droughts that have forced chip production cuts and worsened the global semiconductor shortage, affecting several other sectors – a scenario that is likely to persist because of climate risks.[49]

Compounding the climate chaos is the rising frequency of extreme weather events. In 2024, severe flooding at a key aluminium supplier forced Porsche to slash its revenue forecast from €40-42 billion to €39-40 billion and its anticipated profit margins by two percentage points.[50] Extreme weather events can disrupt supply chains and damage corporate bottom lines if climate risks are not addressed.[51]

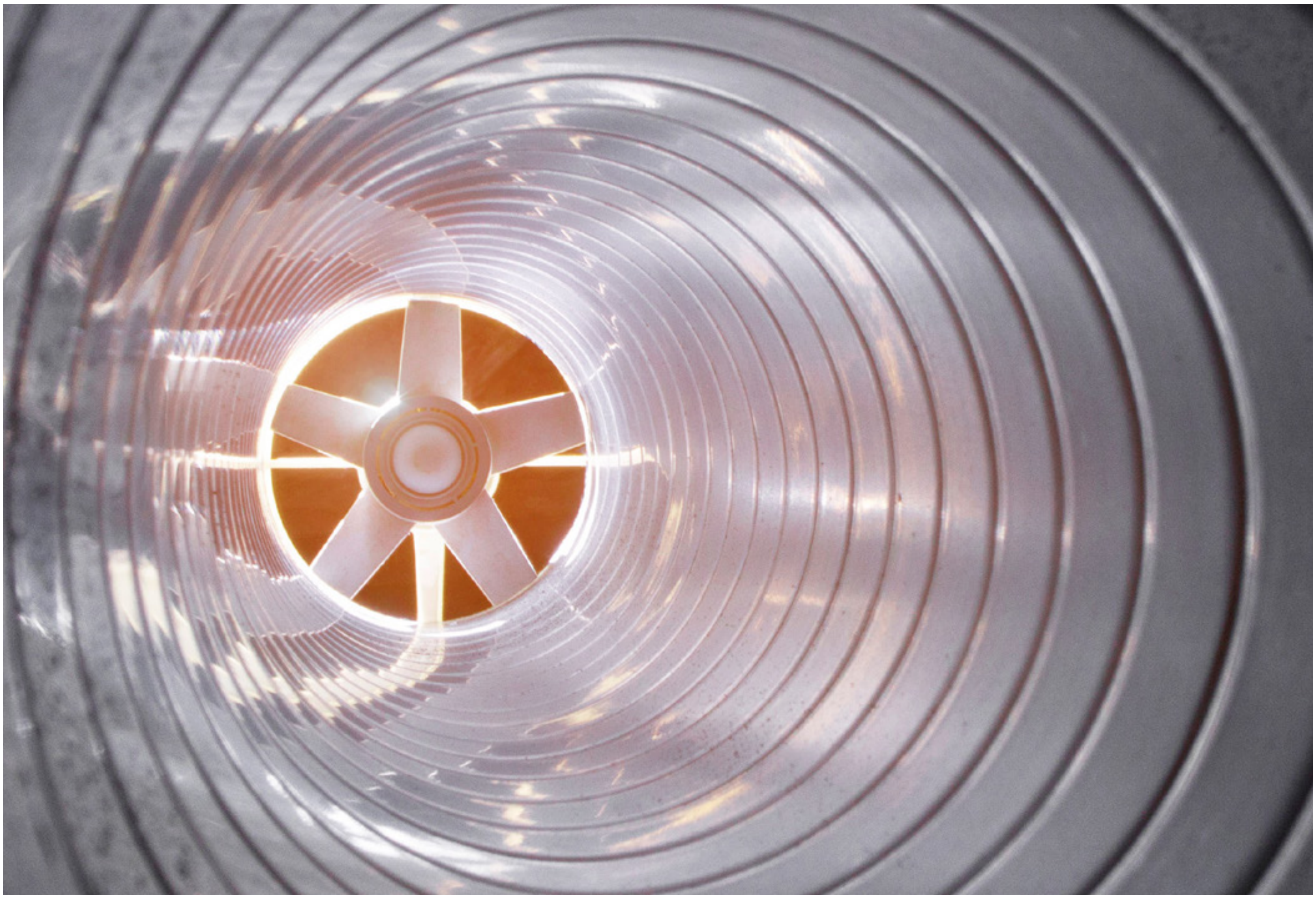
The societal impacts of climate-induced problems are far-reaching. Shortages of critical products such as electronics, pharmaceuticals and food drive up prices, disproportionately affecting vulnerable communities, especially in low-income countries. By 2025, it is estimated that unmanaged climate-related supply chain disruptions could cause losses of $3.75 trillion to $24.7 trillion annually, depending on carbon emission levels.[52] In the 3.0°C warming scenario, physical climate risks could threaten 4%- 8% of manufacturing companies' annual profits (EBITDA),[53] with impacts rippling across interconnected economies worldwide.

Flexible supply chains make resilient industries

Fortunately, some manufacturers are using adaptation strategies to reduce climate-related risks. Dual sourcing and higher inventory levels, which allowed them to offset supply chain disruptions during the COVID-19 pandemic, are now being repurposed to manage extreme weather events. As a result, companies that have diversified their supplier bases are experiencing fewer disruptions compared to those relying on single suppliers.[54]

Building buffers is a key adaptation strategy. Recognizing their vulnerability to climate impacts, companies that adhere to just-in-time (JIT) philosophies have adopted a novel hybrid approach. Many have shifted to a just-in-case (JIC) methodology, creating buffer stocks and developing multiple sources of supply. This allows companies to benefit from JIT's efficiency while improving their ability to adapt when disruptions occur.[55]

Many companies using adaptation strategies generate higher economic returns, incur lower costs and benefit all stakeholders in the value chain. Perceived benefit-to-cost ratios ranging from 2:1 to 20:1 have been reported.[56]



Building climate resilience across manufacturing networks

Manufacturing systems are part of complex, multi-layered networks, involving numerous public and private stakeholders, from raw material extraction to large-scale production, distribution and consumption. With global interdependencies and reliance on both private enterprises and public infrastructure, manufacturing is especially vulnerable to climate risks. Each part of the system is exposed to specific climate risks, requiring targeted adaptation technologies to ensure resilience of the whole system:

- **Raw material suppliers and component manufacturers** rely on materials such as metals, plastics, chemicals and textiles. Climate risks can disrupt mining, chemical production and the global supply of essential materials, leading to shortages, rising costs and delays.

- **Factories and production facilities** convert raw materials into finished goods. Climate impacts can damage facilities, interrupt production lines, or impact temperature-sensitive processes and employees' health.

- **The logistics networks** responsible for moving and storing manufactured goods depend on functioning transport routes and infrastructure. Climate-related events can disrupt these networks, delaying shipments and damaging goods in storage.

- **End users** rely on a steady flow of manufactured products. Disruptions in manufacturing and distribution due to climate impacts can lead to product shortages, price fluctuations and economic losses.

To successfully fight the climate crisis, manufacturers have to connect and scale-up tech-driven adaptation applications along their value chains rather than using them in isolation. Four use cases will make a difference: digital supply chain platforms, advanced predictive maintenance, advanced cooling and heating systems, and automatic protection systems (see Figure 10).

However, manufacturers still face challenges in implementing such adaptation solutions. Limited data access and lack of shared systems between value chain participants make it difficult to monitor risks and respond quickly to disruptions. To bridge these gaps, more public-private collaboration and stronger leadership are needed to catalyse financing, optimize operations and mitigate risks.[57]

FIGURE 10 **Four tech-driven use cases to help manufacturing systems adapt to climate-related disruptions**

1

Digital supply chain platforms

Adjust supply chains in real time to avoid climate-related disruptions, ensuring timely deliveries and uninterrupted production.

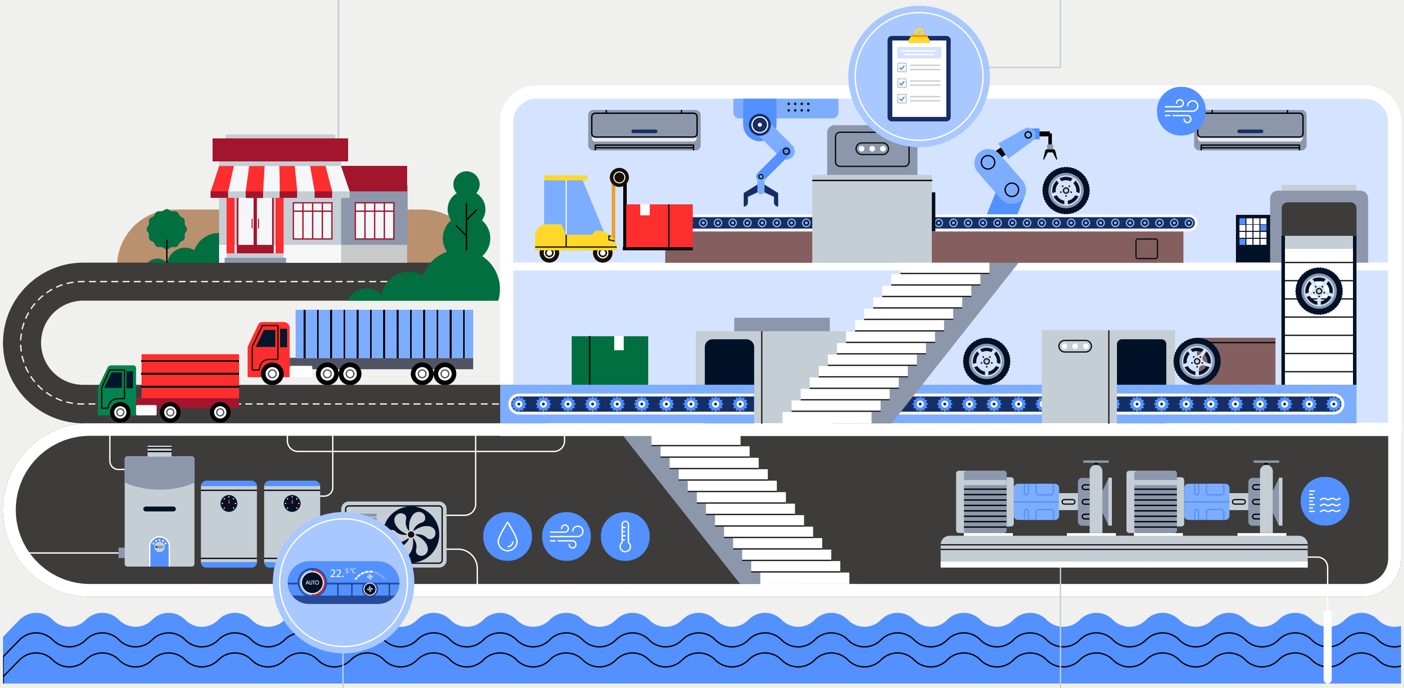
Real-time supply chain optimization uses AI to detect disruptions and adjust sourcing and routing.
Supplier risk assessment identifies suppliers vulnerable to climate impacts.
Climate-driven demand forecasting predicts shifts in demand based on climate patterns.

2

Advanced predictive maintenance

Predict climate-induced equipment failures, enabling timely maintenance to prevent breakdowns caused by heat, moisture and wear.

Real-time climate impact monitoring analyses machine data to detect overheating or moisture-related failures.
AI-powered predictive maintenance monitors machine data to predict climate-induced wear, schedule repairs and enable remote diagnostics to prevent equipment failures.
Energy optimization uses AI algorithms to balance energy loads during peak demand and store surplus energy to ensure continuous operation during grid outages.



3

Advanced cooling & heating systems

Advanced HVAC systems dynamically adjust temperature, maintaining safe working conditions during heatwaves or cold spells while minimizing energy use.

Dynamic HVAC systems use AI to adjusts cooling/heating based on real-time climate data.
Heatwave response systems activate cooling systems during heatwaves, preventing overheating of equipment.
Energy-efficient climate control ensures factories stay operational during extreme temperatures with minimized energy use.

4

Automatic protection systems

Flood barriers and storm protection systems automatically secure factories and equipment during climate-induced disasters.

Automated flood barriers use AI systems to raise barriers preventing flooding.
Automated equipment relocation use robotic systems to move vulnerable equipment to higher ground.
Real-time environmental monitoring uses IoT sensors to issue alerts when environmental thresholds (e.g. temperature, flooding) are exceeded.

Value chain stakeholders involved

Upstream input providers
Production facilities
Logistics networks
End users

Note: HVAC = heating, ventilation and air conditioning.

Source: World Economic Forum and BCG analysis.

TABLE 3 | Tech and data needs, to enable adaptation across manufacturing systems value chain

Adaptation use case	Tech needs	Shared data needs	Illustration
Comprehend risks and opportunities			
1 Digital supply chain platforms	– AI-powered supply chain management software – Supplier risk assessment systems – AI-driven demand forecasting systems	– Real-time supply chain data (sourcing, routing) – Supplier risk data based on climate impacts – Climate patterns & demand trend data	**IBM Watson's Supply Chain Platform** helps manufacturers adapt to climate-related disruptions, such as hurricanes, by using real-time weather data and AI to adjust operations. **CEVA Logistics** achieved a 90% increase in data processing speed, ensuring zero downtime during peak periods and mitigating supply chain delays caused by extreme weather like storms.
Build resilience against future impacts			
2 Advanced predictive maintenance	– AI algorithms for predictive maintenance – Smart energy load balancing systems – Remote diagnostics systems	– Real-time machine data (temperature, moisture) – Equipment wear and tear data – Energy load and demand data – Physical teams and equipment movement, and operational conditions during climate disruptions	**Siemens' Senseye** predictive maintenance system reduced unplanned machine downtime by 20% in an East Icelandic aluminium manufacturing plant.
3 Advanced cooling & heating systems	– AI-powered HVAC systems – Heatwave response systems – Energy-efficient climate control systems	– Real-time climate and temperature data – Factory operational data during extreme weather – Energy usage and efficiency metrics	**Koç Holding**, through its subsidiary Tofaş, implemented a central heating system that optimizes energy usage in production workshops by leveraging outdoor temperature data and historical heating patterns. A machine learning algorithm predicts the necessary heating levels one hour in advance, ensuring precise control, energy savings and reduced harmful gas emissions.
Respond dynamically when impact hits			
4 Automatic protection systems	– AI-powered flood barriers – Automated equipment relocation systems – IoT sensors for environmental monitoring – AI-driven energy storage and distribution management	– Environmental data (temperature, humidity, flood levels) – Equipment location and vulnerability assessments – Weather forecast data – Grid outage and energy demand data	**FloodBreak's** flood barriers at Cummins' Engine Plant in Indiana provide automatic flood protection without human intervention, ensuring continuous operation during extreme weather.

Sources: Supply Chain Digital, Siemens, Koç Holding, Floodbreak, BCG analysis.[58]

CASE STUDY 3

Scaling-up adaptation tech platform for manufacturing systems

Plattform Industrie 4.0 is a network led by the German Federal Ministry for Economic Affairs and Climate Action aimed at securing and expanding Germany's position in the manufacturing sector. It brings together stakeholders from politics, business, academia, trade unions and associations to facilitate pre-competitive exchange and advance climate adaptation strategies for industrial players.

Challenge: Pressures on Germany's industry underscore the need for digital & environmental transformation

Germany's manufacturing sector, the largest in Europe, contributed 28% of the country's GDP in 2023 and supports 15 million jobs in Germany. It consists mainly of small and medium-sized enterprises operating in capital-intensive industries such as automotive, chemicals and heavy machinery.

Despite being the backbone of Germany's economy, manufacturing has been repeatedly plunged into crisis in recent years, due to the Covid-19 pandemic, Russia's invasion of Ukraine and escalating climate impacts. In 2020, droughts lowered water levels in the country's major rivers, disrupting transportation routes, increasing costs and delaying manufacturing production. In 2021, severe floods in North Rhine Westphalia and Rhineland Palatinate halted production at automotive and chemical plants. Meanwhile, the rising frequency of heatwaves has strained the power grid, disrupting energy-intensive industries such as steel and aluminium, while driving up energy costs.

Action: Tech-driven, collaborative platform for manufacturing systems resilience

To build climate resilience in German manufacturers and reduce emissions, the German Federal Ministry for Economic Affairs and Climate Action launched Plattform Industrie 4.0, the country's main network for advancing the digital transformation of manufacturing. It brings together over 350 actors from more than 150 organizations, including government, business, science, trade unions and other associations. They share ideas and best practice on climate adaptation and the circular economy.

The Manufacturing-X initiative was also launched to build data and tech-driven resilience into Germany's industrial companies, with three objectives:

– **Resilience:** reorganize value chains in manufacturing, enabling quicker reactions.

– **Sustainability:** design new business models, a circular economy and increase efficiency.

– **Competitiveness:** develop innovations that ensure German companies' global leadership.

To achieve these objectives, the initiative has taken three major steps:

– **Data space:** Manufacturing-X has created a shared, secure platform that contains data on flagship projects and use cases, allowing German manufacturers to exchange data in real time. This helps, for instance, the early detection of extreme weather events and triggers efforts to reduce their impact before they arrive.

– **Knowledge transfer:** small and medium-sized enterprises will be integrated into the data space with the help of supporting transformation hubs, supporting them in adopting adaptation strategies.

– **Community building:** Manufacturing-X is internationalizing its broad-based community by implementing global standards for a comprehensive data economy.

Results

Manufacturing-X promotes standards such as the Asset Administration Shell standard (AAS), a digital representation of an asset (component, machine or plant), which ensures the interoperability of components in its systems. It also developed a digital governance system with Gaia-X, applicable to any cloud or edge technology, to ensure transparency, controllability, portability and interoperability across data and services. With Catena-X, one of the world's first open data spaces for the automotive industry, it boosts business processes using data-driven value chains. Thus, Manufacturing-X serves as a hub, facilitating cross-domain dialogue and tackling technical, legal and administrative challenges.

Manufacturing-X is improving the resilience, stability and sustainability of Germany's industrial supply chains in the face of climate change. In the future, it will expand to more industries and scale-up technologies such as blockchain to enhance traceability and cybersecurity in supply chains. Manufacturing-X showcases the enormous potential of collaborative, technology-driven ecosystems to drive climate adaptation.

Sources: Manufacturing-X; Plattform Industrie 4.0.[59]

2 Shaping collaboration platforms for value chain adaptation

Setting up collaboration platforms will enhance resilience across value chains and unlock greater benefits for all.

The previous analysis of three key value chains shows that business leaders are beginning to recognize the benefits of developing and implementing adaptation strategies and the need to accelerate the deployment of adaptation systems. However, despite this growing awareness, three main challenges remain:

– **Demonstrating the value of adaptation investments** to investors and other stakeholders to attract greater financial support. Companies need to better comprehend and articulate the risks posed by climate hazards, the costs avoided through adaptation and the opportunities these projects create, in order to secure backing from both private and public entities. Since risks and rewards are often unevenly distributed across the value chain, it is essential to value and distribute costs and benefits fairly to incentivize all stakeholders.

– **Navigating the lack of standardized metrics**, frameworks and regulation around adaptation. Organizations need to keep evolving to comply with current and future climate-related regulations as they adapt to climate change. Developing standardized approaches early on will help them avoid potential penalties, strengthen stakeholder relations and establish themselves as sustainability leaders.

– **Accessing data, technologies and capabilities** to roll out adaptation strategies at speed and at scale. Limited or costly access to relevant and comprehensive climate and value chain data restrains effective value chain-wide predictive modelling and data-driven decision-making. Max Gulde, CEO of constellr, explains: "Traditional Earth observation models provide discrete images, where a single image is only encapsulating 2% of the data that is useful, while you still have to pay for the entire image". Unequal access to advanced technologies, such as analytical tools and affordable computing resources, coupled with gaps in internal expertise and capabilities limit companies' (especially SMEs') ability to analyse data, model scenarios and execute adaptation strategies.

To overcome these challenges, global leaders can start by rethinking their approach to innovation in adaptation and asking the question: Am I better off adapting alone or collaborating with others in the value chain?

2.1 Framing objectives and roles of collaboration platforms

In this context, it may be worth drawing on James Moore's idea of a business ecosystem, wherein a company, along with its partners, co-evolves novel capabilities around an innovation. The ecosystem's partners work cooperatively to support the new product, meet common objectives and, eventually, develop the next innovation. Relevant in the context of climate change, Moore likened companies to species in a biological ecosystem, where they co-evolve, cooperate and compete, influencing each other's survival.[60]

In the same way, value chain-wide adaptation can be accelerated through collaboration platforms – technology-driven environments in which stakeholders, along a value chain or within a region, share data, tools and resources to drive innovation and scale-up climate adaptation solutions.

Collaboration platforms – objectives

Collaboration platforms serve three main objectives: to scale-up, innovate and protect.

1. **Scale-up**

Collaboration on adaptation projects should aim to maximize impact by pooling investments, sharing costs and reducing individual risk. Expanding project reach can generate collective benefits and have a positive influence on nature and communities beyond the immediate value chain, laying the groundwork for long-term protection. Adaptation applications will become more economical as their use expands along the value chain.

2. **Innovate**

Research and innovation in adaptation must accelerate by fostering breakthrough technologies and solutions that are specific to the value chain. Leveraging start-ups and open-source platforms will enhance the adoption of new technologies, driving sustained progress.

3. **Protect**

Ultimately, value chains must safeguard themselves against future hazards by implementing technology-driven solutions, such as early warning systems.[61] Ensuring compliance with unified regulations and standards on adaptation will further secure long-term sustainability.

Collaboration platforms – roles

To collectively address adaptation challenges along value chains, collaboration platforms will play three roles: unlock and share data, integrate and develop technologies and support implementation with shared experience and insights.

1. **Unlock and share data**

Oversee the collection, aggregation and maintenance of climate and value chain data from diverse public and private sources, such as data commons, Earth observation systems and academic or scientific research. To ensure data is usable, up-to-date and securely handled, the platform will need to clean and process it, ensuring compliance with privacy standards and regulations. Value chain participants should select relevant data for adaptation and agree on secure data-sharing protocols, pre-empting competition concerns and ensuring stakeholders' interests are protected. Participants must recognize that sharing climate data is critical for effective adaptation.

2. **Integrate and develop technologies**

Accelerate research and innovation in adaptation by creating public-private partnerships to develop and share technologies and capabilities, such as AI foundation models, data analytics engines and open-source applications, allowing customization. It must provide secured digital public infrastructure (DPI) to support the ecosystem with cloud storage and computing power (e.g. next-gen computing systems). The power of sharing technological innovations collaboratively and responsibly has already been proven in different areas: Linux, which is freely available to all, has evolved into one of the most robust operating systems in the world, while the new wave of Generative AI systems, such as ChatGPT, would not have emerged without openly available information on the internet.[62]

3. **Support implementation with shared experience and insights**

Ensure standardization, transparency and interoperability of data and insights between stakeholders, by integrating existing use cases in the value chain. It will seek to create opportunities along the value chain to connect stakeholders with technology providers and accelerate use cases deployment. By sharing best practices and experience, participants can also facilitate the development of new applications and enhance the scalability of adaptation efforts across multiple sectors.

> **Climate data should have a label on it: if this is an asset that should be shared across government or made public, it must become a public good. But it must be treated as a long-term asset, much like physical infrastructure. Currently, the failure to maintain and update risk data after its initial use leads to significant failures in project planning and increases future costs. Data investments should be provided with maintenance budgets for the lifetime of the infrastructure they support and with training plans for those that should provide updates to datasets.**
>
> Edward Anderson, World Bank

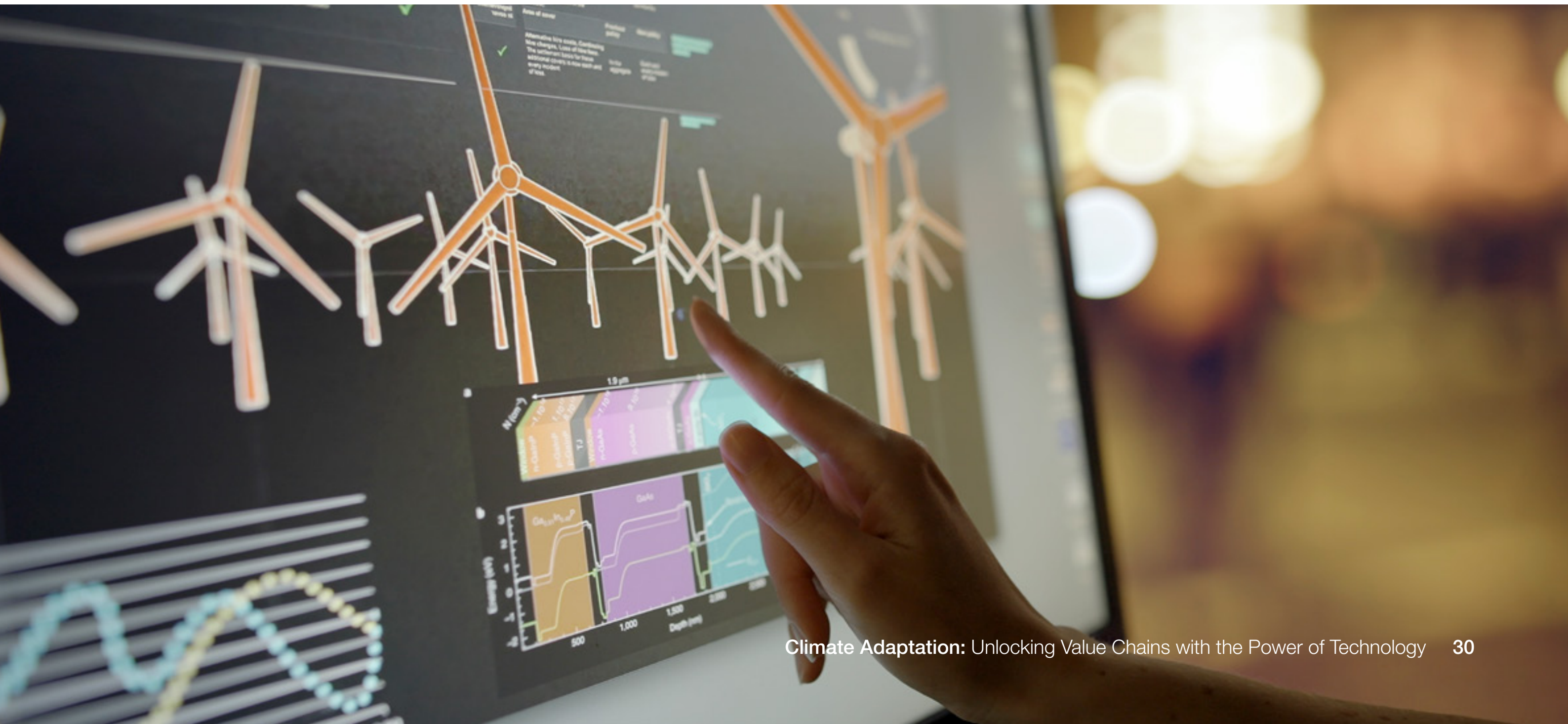
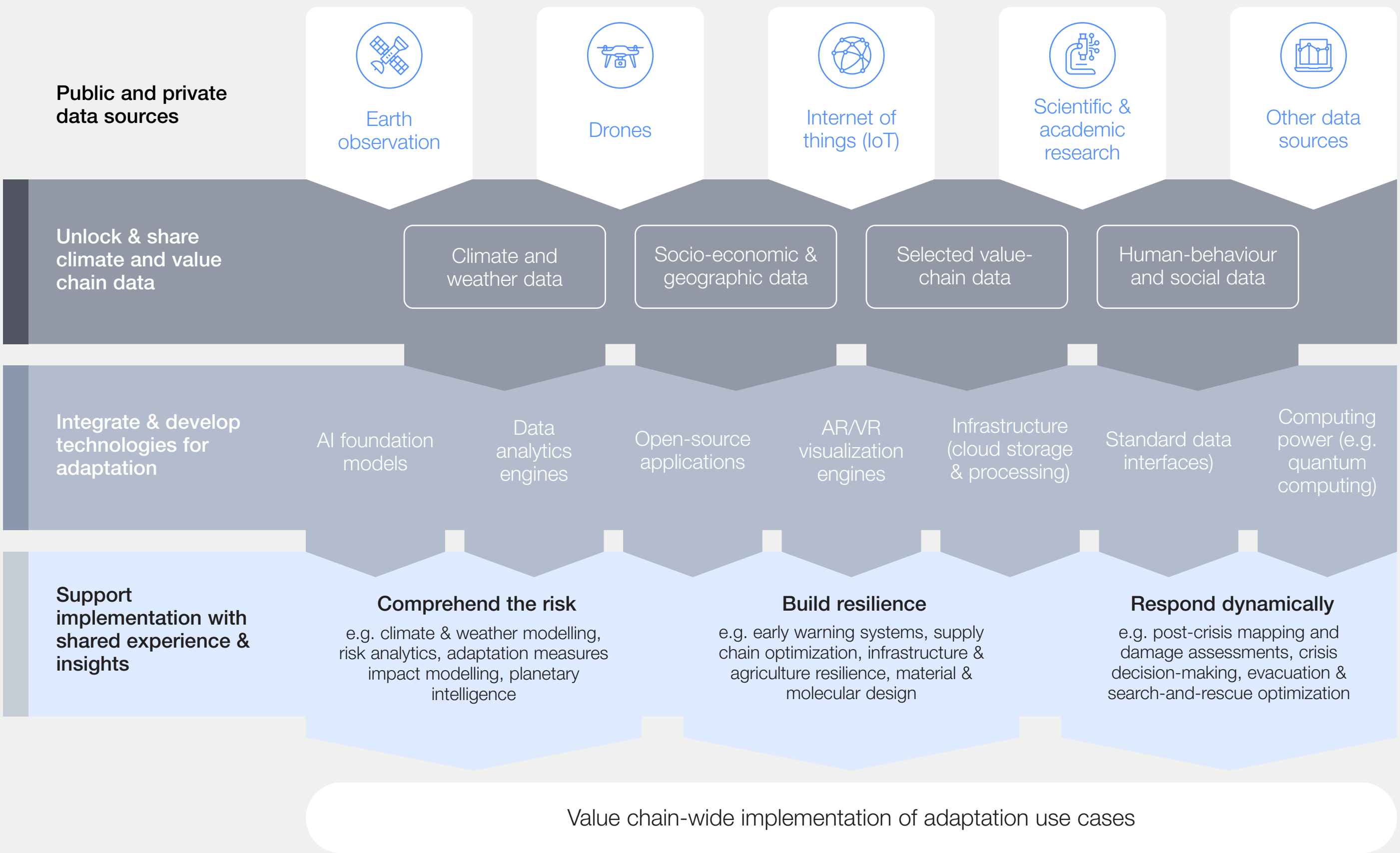


FIGURE 11 **Collaboration platforms provide data, tech and insights to accelerate adaptation**



Source: World Economic Forum and BCG analysis.

BOX 1 **NASA, BCG and Universities Space Research Association developing geospatial AI foundation model**

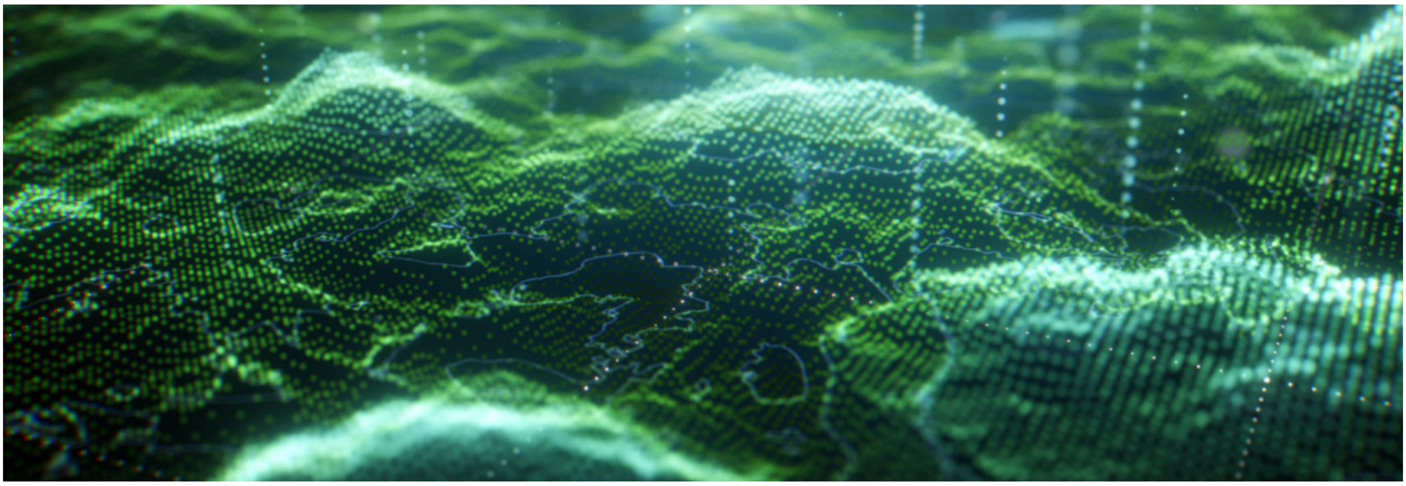
A key example of a collaboration platform comes from NASA, in partnership with BCG and the Universities Space Research Association (USRA). Together, they are developing a geospatial AI foundation model aimed at addressing critical climate adaptation challenges. This initiative high-lights how collaboration across public, private and academic sectors can drive innovation and tackle complex global issues.

The system uses data from NASA's GOES satellite constellation, which has been collecting atmos-pheric, oceanic and climate data since 1975. This data, including top-of-atmosphere thermal brightness (a measure of the infrared radiation, or heat, leaving the Earth's atmosphere), is pro-cessed by AI to provide insight into the Earth's energy balance and climate conditions. Trained on over 5 trillion data points gathered every 30 minutes from 18 locations over the last 15 years, the model predicts extreme weather events and real-time insights into climate risks.

This model is designed to benefit many value chains by incorporating other datasets including wind speeds and precipitation, making it fit across industries such as aviation safety, where it can optimize flight routes and reduce contrail-induced climate impacts.

NASA's geospatial AI foundation model demonstrates how collaboration platforms can democratize cutting-edge technologies and stimulate better climate adaptation strategies across multiple sectors. Through such partnerships, businesses can leverage AI-powered insights to enhance resilience, protect value chains and contribute to global sustainability efforts.

Sources: NASA, BCG analysis.[63]



2.2 Building a collaboration platform model and rules of engagement

Value chains can create platforms by establishing guidelines that foster effective collaboration from the very outset. Participants must clearly define which aspects of the value chain require alignment and which remain flexible, based on the value chain's unique needs. Each collaboration platform needs to align on three core features: governance, funding and rules of engagement.

1 Governance

First, the community must establish a governance model that facilitates collaboration, structured around either a private entity with a sustainability-focused mission or an organization formed through a public-private partnership (PPP). The platform can be led by an independent body composed of representatives from both the public and private sectors, including key value chain participants, government agencies and civil society organizations to ensure balanced decision-making, transparency and viability. This entity would lead the design of collective adaptation strategies that benefit the entire value chain. The community must define a clear process for decision-making, dispute resolution and stakeholder engagement to ensure commitment and accountability between participants.

2 Funding

Second, participants must align on a funding model combining private and/or public funding that ensures financial sustainability. Contributions from participants would support operations, infrastructure and assistance to value chain participants in deploying adaptation use cases. Participation incentives could include membership-based access to value chain and climate-related data, assets and insights that advance both collective and individual adaptation efforts.

3 Rules of engagement

Third, the platform should define clear rules of engagement, including standards and protocols for data sharing, technology use and interoperability. Trust and transparency must be guaranteed to safeguard data ownership, privacy and intellectual property (IP), ensuring fair competition and the ethical use of algorithms. Membership should be open to all stakeholders in the value chain as long as they commit to maintaining integrity and meeting agreed-upon goals.

By participating in these ecosystems, global leaders will play a role that goes beyond protecting their own assets and operations. Building system-wide resilience and innovation, they will lay the foundations for thriving in an uncertain future.

> **GenAI and AI agents enable collaboration through data sharing without revealing sensitive information because they aggregate data and provide insights without exposing the underlying sources. This allows companies to cooperate while safeguarding proprietary or competitive information.**
>
> Vijay Karunamurthy, Scale AI

TABLE 4 | **Successful collaboration platforms implemented across value chains**

Collaboration platform	Model implemented
Carbon Disclosure Project (CDP)	CDP is a non-profit charity that offers a standardized platform for climate data reporting, allowing companies, cities and regions to report on environmental impacts and benchmark performance. Governance is managed by an independent board of trustees and the platform adheres to global reporting standards such as the Greenhouse Gas Protocol (GHG-P), Global Reporting Initiative (GRI) and Task Force for Climate-Related Financial Disclosures (TCFD).
Science Based Targets initiative (SBTi)	SBTi is an NGO-led coalition of organizations including CDP, the UN Global Compact and WWF, helping companies align with the Paris Agreement's climate targets. Governance is handled by a steering committee representing partner organizations and SBTi provides an online portal for tracking and reporting climate target progress.
Taskforce on Scaling Voluntary Carbon Markets (TSVCM)	TSVCM operates as a hybrid platform involving NGOs and private entities such as the Institute of International Finance (IIF) to improve the integrity, scalability and transparency of voluntary carbon markets. It aims to support the Paris Agreement by developing frameworks for carbon credits and market infrastructure, enhancing market credibility and enabling compliance navigation.
Unilever & Google	Unilever partnered with Google to monitor the deforestation-free sourcing of palm oil using data analytics and Earth observation. This collaboration improves supply chain traceability and compliance with the forthcoming EU Deforestation Regulation (EUDR), creating a scalable blueprint for responsible supply chain practices.
AgroDataCube	AgroDataCube is a Dutch open data platform led by Wageningen University and Research (WUR), offering harmonized agricultural data at the parcel level. The platform adheres to FAIR principles, providing both public and commercial API-access. It facilitates better decision-making for farm-scale analytics, supporting applications such as crop monitoring and yield forecasting.

Sources: CDP, SBTi, IIF, Unilever, Earthinformatics, BCG analysis.[64]

3 Call to action

By acting now to collaborate across value chains, global leaders can more fully harvest the benefits of technology for adaptation.

The challenges of climate change are no longer conceptual. The immediate and cascading impacts of extreme weather events and the economic and supply chain disruptions they cause are tangible threats. The question before business leaders is no longer whether climate change will disrupt their organizations, but how best to anticipate and prepare for the climate crisis that is occurring now and will only worsen. To enable a resilient future, business leaders must take the following steps to set up collaboration platforms for adaptation in their value chain (see Figure 12).

Six actions to set up value chain-wide collaboration platforms

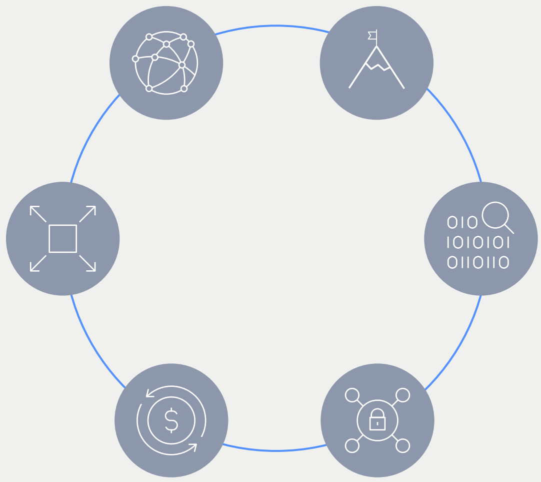
FIGURE 12 **Six actions to set up value chain-wide collaboration platforms**

1 Come together

Engage on climate adaptation by creating or joining a forum within your value chain.

2 Align under a common North Star

Define value at stake to create a shared purpose for adaptation between value chain stakeholders.



3 Set clear standards

Standardize adaptation with a common language and metrics shared across the value chain.

4 Unlock and share data

Align on a secure data-exchange protocol with your value chain.

5 Invest in tech foundations

Invest in innovation and infrastructure to develop and host data insights and open technologies.

6 Deploy locally and scale-up

Involve local communities and stakeholders to scale-up adaptation solutions.

Source: BCG analysis.

1 Come together

- Engage on climate adaptation by creating or joining a forum within your value chain.
- Create a new forum or initiative within your value chain to address climate adaptation or actively participate in existing initiatives to scale-up your adaptation efforts.
- Encourage collaboration by engaging other companies, governments and innovators across your value chain to join and co-develop scalable adaptation solutions.
- Hold meaningful conversations about the nuance behind design of these systems, including who benefits, who may be excluded and potential intended and unintended consequences.

2 Align under a common North Star

- Define value at stake to create a shared purpose for adaptation between value chain stakeholders.
- Measure your exposure to climate risks under various temperature scenarios and their impact on your assets, employees, operations and supply chain.
- Inspire collective action by uniting all stakeholders – governments, business and communities – around shared climate goals to drive investment, responsibility and lasting impact.
- Position your organization as a climate frontrunner, leading by example and charting the path for others to follow, while strengthening your brand and attracting purpose-driven talent.

3 Set clear standards

- Standardize adaptation with a common language and metrics shared across the value chain.
- Shape standards for adaptation data usage, structure and privacy while ensuring interoperability and security along the value chain.
- Leverage existing best practice from other value chains to design adaptation metrics and reporting and inspire future regulations.
- Establish clear governance among value chain stakeholders to create trust, transparency and commitment in the ecosystem.

4 Unlock and share data

- Align on a secure data-exchange protocol with your value chain.
- Unlock access to selected climate and value chain data necessary for collective resilience initiatives upstream and downstream.
- Benchmark against peers and the rest of the ecosystem.
- Label certain climate data as public goods, democratizing access for underserved communities and local initiatives to ensure equitable and widespread adaptation.

5 Invest in tech foundations

- Invest in innovation and infrastructure to develop and host data insights and open technologies.
- Invest in advanced technologies, such as open climate AI models, and in digital public infrastructure (DPI) to accelerate adoption of adaptation technologies.
- Pool resources to reduce financial burdens and enable large-scale climate solutions.
- Share access to computing power, cloud storage or AI model training.
- Facilitate the development of open-source analytical tools and shared expertise with cross-sector partnerships, connecting cutting-edge tech providers and academic researchers with end users.

6 Deploy locally and scale-up

- Involve local stakeholders to fast-track adaptation solutions design and deployment.
- Bring onboard academia, start-ups, local businesses and communities to your value chain collaboration platform by offering them opportunities to co-design, experiment and implement local adaptation solutions.
- Support them to build local expertise and promote innovation at the community level.
- Advocate for equitable climate adaptation, benefiting local communities and natural ecosystems, hence contributing to long-term sustainable development.

Ultimately, organizations that fail to adapt to the climate crisis risk falling behind, both in terms of operational efficiency as well as stakeholder expectations. Business leaders can position themselves as sustainability leaders only if they understand that the secret of adaptation lies in understanding that the cost of action is too high when adapting individually and is far outweighed by the benefits of adapting collectively.

This is not only a risk management technique, but an opportunity to gain a competitive edge. Organizations that invest early in adaptation technologies will be better positioned to manage climate issues, maintain operational continuity and respond to regulatory changes. In that sense, climate adaptation is not just an operational necessity but has become a driver of competitive differentiation in today's turbulent world.

> “ The secret of adaptation lies in understanding that the cost of action is too high when adapting individually and is far outweighed by the benefits of adapting collectively.

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Endnotes

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