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REPORT

We're doomed, now what?

Finding the way through climate change adaptation technologies in an uncertain future

BLUE SHIFT
BY ARTHUR D. LITTLE

“Mankind was born on Earth. It was never meant to die here.”

— Cooper, *Interstellar*

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The collective Making Tomorrow gathers experts in foresight, anthropologists, economists, but also makers, designers, and science fiction authors. It is a pioneer in foresight and design fiction approaches." http://making-tomorrow.mkrs.fr/

Thinker-in-residence

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CONTENT

Executive summary

No matter how successful the world is at mitigating global warming, many of the impacts of climate change are already underway and will greatly affect the future of humanity, society, and business. There is an unavoidable need to adapt to climate change, alongside efforts to reduce emissions and achieve net zero targets. For businesses, this implies a requirement to consider adaptation as part of any forward-looking strategy. Adaptation forms part of a broader set of sustainability goals, alongside mitigation of impacts and improvement of resilience. Indeed, there are many overlaps between them; for example, improving resource-use efficiency is an adaptation measure that also mitigates impacts. Protecting assets against climate impacts contributes to adaptation by bolstering resilience. Our chosen focus on adaptation in this Report does not imply that it should be prioritized ahead of mitigation or building resilience, but rather that it should be part of the overall response.

Deciding where to focus investment and development efforts for adaptation is difficult. The technologies to address adaptation needs are, for the most part, specific, numerous, and fragmented. Adaptation solutions are diverse across different industries and are often driven by local circumstances, making scalability hard to achieve. At the same time, funding for adaptation tech remains low — it is estimated that less than 10% of all climate technology funding went to adaptation in 2020–2021. Furthermore, the suitability and viability of adaptation solutions in the future will be greatly affected by a range of uncertainties, such as market dynamics, regulation, and consumer behavior. This complexity often leads to decision paralysis or, at least, an extended "wait and see" philosophy.

In this Report, we aim to provide a way through the complexity for executives, responding to the key question, "How can decision makers harness technology to help their businesses adapt to the diverse, multivariate, and ambiguous impacts of climate change?" The Report is based on a four-month study by Arthur D. Little's (ADL's) Blue Shift, incorporating the results of more than 40 interviews with corporate executives, climate adaptation experts, venture capitalists (VCs), and start-ups, along with two surveys covering 70 respondents. We were pleased to collaborate with the United Nations's (UN's) World Intellectual Property Organization (WIPO), which has established the "Green Technology Book" and a solutions database comprising some 140,000 entries, as well as design fiction agency Making Tomorrow on future projections.

Our approach was first to understand the adaptation challenges businesses face and then to set the scene by providing a clear summary of the relevant geophysical and biological impacts of a "+3°C by 2100" climate change, based on projections by the Intergovernmental Panel on Climate Change (IPCC). We took these impacts as a "given." Next, we explored the implications of adaptation for a range of possible futures by considering specific combinations of critical economic and behavioral variables. This enabled us to develop a series of plausible future projections, which we fleshed out in terms of their impacts using design fiction approaches. We then analyzed how each future projection would give rise to a set of functional expectations and technology needs for adaptation. Finally, we identified a series of "no regret" adaptation solutions, as well as enabling technologies and capabilities that are relevant for businesses irrespective of future uncertainties, and developed guidance on how to embark on the adaptation journey.

The challenges ahead

In Chapter 2, we discuss the four generic business challenges that companies must address to adapt to climate change. These include:

1. **Source — securing the availability and supply chain of critical raw materials and resources.** Sub-challenges include water scarcity, declining crop production, access to critical materials, and disrupted supply routes.
2. **Make — adapting manufacturing and other industrial processes to a changing climate.** Sub-challenges include securing energy and water supplies, productivity improvements, and maintaining viable working conditions.
3. **Protect — safeguarding industrial sites and assets from climate change impacts.** Sub-challenges include detection and alerting (of unforeseen weather events), shielding of assets, resilient design, remediation after disruption, and relocation of sites.
4. **Sell — marketing competitive and differentiated goods and services to meet the needs of consumers in a changing climate.** Sub-challenges include developing new innovative products and services and adapting to new consumption patterns and changing sales channels.

Companies must consider how these four types of challenges could affect their business operations as they consider their options.

Modeling uncertain outcomes

Chapter 3 addresses some of the factors shaping the future environment for adaptation, split across geophysical, biological, behavioral/demographic, and economic categories. Modeling these critical factors suggests five future projections that companies should consider in developing their adaptation responses.

We identified a total of 11 shaping factors that affect climate change adaptation. In the Report, we describe five geophysical and biological factors and characterize their likely impacts, such as extreme climate events, freshwater availability, sea level rise, biodiversity loss, and increased pests. These results are based on an assumed "+3°C by 2100" trajectory, which falls within the confidence interval for the IPCC's Representative Concentration Pathway (RCP) 6.0. The geophysical and biological impacts of this trajectory are widespread and large-scale.

In the behavioral/demographic and economic categories, which together we call "human shaping factors," we identify six factors, of which four are the most critical because they have both high potential impact and high uncertainty. These critical factors are regulations, consumer behavior shift, competitive pressure, and availability of finance. By considering each "on/off" combination of these four factors, we generated 24 future projections, of which five are the most plausible, differentiating, and technologically relevant:

1. **Green Communities** — strong consumer behavior shifts but limited finance. This is a resource-scarce world in which grassroots adaptation initiatives flourish, without large-scale projects.
2. **Lonely at the Top** — no consumer behavior shift but high competitive pressure. Adaptation is driven by global market leaders targeting affluent customers in a highly unequal, two-speed society.
3. **Wild Green West** — strong finance but little regulation. This is characterized as creative chaos in which adaptation initiatives sprout everywhere, fueled by private capital but lacking any regulatory backbone.
4. **Don't Look Up** — limited finance and no consumer behavior shift. This is a pessimistic future in which neither customers nor financial institutions have adjusted to the new climate reality.
5. **Adaptation Surge** — all variables favor adaptation. This is a relative utopia in which adaptation is the norm, resetting expectations and creating new markets and new needs.

These projections don't seek to describe a full world but rather illustrate a range of futures that may partly coexist. To deliver a deeper understanding of their consequences, we used a design fiction approach, creating artifacts from each possible future. These help better identify the technological options that will flourish in particular projections.

Responding with technology

The most relevant technologies for each future projection can be mapped and ranked by maturity and impact, as well as across the four challenges discussed in Chapter 2. Overall, value lies more in adjusting already-existing technologies to specific and local problems rather than cutting-edge breakthroughs. In Chapter 4, we identify a short list of no-regret solutions, enabling technological bricks, and key capabilities that companies should consider.

Each future projection implies a partly different set of functional needs and priorities, for which particular technological solutions are relevant. In Chapter 4, we identify 89 of the most relevant technology families, mapped across the four challenges and ranked by maturity and impact. We also indicate specific technology examples and representative providers.

Overall, there is a wide range of technologies to consider due to the highly local, multivariate, and multidisciplinary nature of adaptation. The value that adaptation technologies bring lies less in cutting-edge performance or breakthroughs and more in applying existing technologies to solve very specific and local problems at an acceptable financial, environmental, and social cost for all stakeholders involved. This is the key area for innovation. Many technologies that were not developed for adaptation nevertheless play a key role in this space, from advanced consumer sentiment analysis to digital twinning. There is no single best approach to solving adaptation challenges. Instead, a nuanced consideration of a business's ecosystem on its operations, and vice versa, is needed. Adaptation strategy is therefore best approached as an integral part of company strategy.

No-regret moves that will be relevant regardless of the projection, or the industry concerned, include:

- **Solutions** — early warning systems, thermal comfort systems, geographic information systems (GIS) for site location, aerial drones for imaging, robots for maintenance and automation of production, and water efficiency and recycling systems
- **Key technological bricks** — sensing technologies, including Internet of Things (IoT) and remote sensing (including light detection and ranging, or LiDAR); digital twins and generative AI (GenAI) for simulation; and neural networks (notably graph neural networks [GNNs]) for prediction
- **Underlying capabilities** — data science, complex systems modeling, design for scarcity, responsive risk assessment, and strong local partnerships

Ultimately, climate is a complex system, which means it exhibits hard-to-predict, emergent effects. While the likely scale of climate change impacts is well evidenced, generally the sequence and speed of development of individual events are hard to predict. The capability to model complex systems and their impacts at a local scale will be key to developing comprehensive and nuanced approaches to successful adaptation.

Taking action

A survey conducted as part of the study confirmed that a lack of knowledge of the best course of action is the biggest hurdle to business adaptation. As described in Chapter 5, to move forward, companies should focus on understanding their climate change issues and risks, putting suitable governance in place, establishing means of financing, and developing local partner ecosystems.

A lack of knowledge on the best course of action is followed by resistance to change, lack of funds, and technology limitations as the biggest hurdles to business adaptation. To move forward with adaptation strategies, companies must consider four key questions:

1. **How to predict?** Decision makers should begin by creating their own global warming trajectory assumptions and identifying the shaping factors most critical for their industry and global footprint. They need to conduct site-by-site assessments of potential risks, both acute and chronic, and pilot improved risk-monitoring and modeling approaches, leveraging digital technologies, such as digital twinning and AI.

2. **How to decide?** Businesses will need a suitable governance approach to oversee the adaptation agenda, which often stretches across several functions. New metrics are likely to be required. Approaches such as heat maps can help allocate priorities. Abilities to "think global, act local" and enhance customer listening are key.

3. **How to finance?** Mobilizing funding for adaptation requires updating financial metrics, including pricing climate-risk vulnerabilities in terms of damage to assets, production loss, and possible reputational effects. It may also involve the complex task of pricing positive externalities (productivity gains, employee retention) and potential market opportunities from adaptation (market share gains, or new product-market fit). It also requires working with longer timelines (>15 years) than is customary for most corporate decision-making. Blended finance solutions, which combine concessional public funds with private capital, can be leveraged when corporate adaptation investments impact communities.

4. **How to build?** Because adaptation problems require local solutions, it will be essential for businesses to develop local ecosystems of partners. As with any collaborative innovation effort, it is important to set clear ground rules for intellectual property (IP). Finally, companies will have to accept longer timescales for adaptation investments.

Conclusion

Ultimately, the effectiveness of adaptation to climate change will be a function of how governments, businesses, local communities, and individuals can collaborate to meet local, national, and global challenges.

Beyond the no-regret solutions, technological bricks, and capabilities outlined in the Report, there is no single best approach to solve adaptation challenges. What is needed is a nuanced consideration of the impact of a business's ecosystem on its operations, and vice versa, to identify the most relevant solutions. Climate change will become an increasingly consequential constraint on business strategy and forward planning. By 2040 and beyond, we may already be in a situation where "adaptation strategy" has become almost inseparable from "business strategy."

While this study focuses on the technological dimension of adaptation, technology alone will not solve adaptation challenges. As our future projections illustrate, the effectiveness of adaptation responses will be the result of how governments, businesses, societies, and individuals interact and behave. In particular, it is both very uncertain and very consequential whether consumers change habits, regulation is enacted, financial mechanisms are developed and funds unlocked, and large companies assume leadership in adaptation. Adaptation tends to require localized solutions, yet focusing only on local perspectives, following self-interest, and applying single metrics will fail to address the system-level global challenges. It will also increase the risk of "maladaptation" solutions where the remedy is worse than the cure. Behaviors toward adaptation are prone to the prisoner's dilemma: is it better to postpone costly adaptation investments and maintain competitive advantage, or invest now and rely on others to do the same for mutual benefit?

Solving the dilemma requires a new type of collaboration — between governments, local communities, businesses, and individuals — that combines local, national, and global system-level interests and challenges. Such collaboration is extremely challenging to achieve and will involve painful trade-offs. Nevertheless, change does come from necessity. Businesses play a key role in shaping a future that ensures that "wait-and-see" does not result in much worse damage.

Preamble

I am in the process of reaching the 2,507-meter apex of Pic d'Anie, a summit of the Pyrénées-Atlantiques, Randonnée skis equipped with seal skins on my feet, ice axe in hand. Sweat is dripping from my forehead, stinging my eyes. Yet I am only wearing shorts and a tank top. I think to myself, "This would be a great illustration for our Report on adaptation to climate change." I also recall what the president of a large sports equipment company confided in me a few weeks ago: "We are going to leave the ski industry...."

Just a small average global temperature increase — such as +3°C by 2100 versus the preindustrial era — has an enormous impact of which most of us are unaware.

Why leave the ski industry when the market is continuing to grow? On the one hand, because climate change has already severely impacted the operational costs of ski resorts and their opening periods (as an example, about 87% of American ski resorts are dependent on artificial snow production[1]). This market is therefore not sustainable in the long term. On the other hand, it's a matter of image: the company's brand cannot continue to be associated with what is becoming an unnatural exploitation of the mountains.

As I cautiously embark on the descent, these thoughts lead me to maladaptation, referring to adaptation initiatives that increase climate change risk and vulnerability, like turning up the air-conditioning in a heat wave. A lazy and cynical approach to adaptation. An adaptation about resignation.

We wrote this Report for those businesses that don't plan on resigning from the fight against climate change. In it, we summarize the study we conducted that involved about 40 international experts. This journey has allowed us to forge certain convictions, some of which are very alarming.

As an example, regardless of our decisions and actions today, the world is likely to be heading toward a warming of +3°C by 2100. And this reality comes with cascading consequences: from rising sea levels to increasingly extreme weather events to massive migratory flows.

For businesses, this raises four major challenges: sourcing critical materials, maintaining manufacturing productivity (making), protecting assets, and selling new products and services for the new normal. The unavoidable conclusion? While continuing our efforts to mitigate our impact on global warming, companies must begin to adapt today. Climate change adaptation is an existential question.

I wish I could say that I am an expert on climate change. I am not. However, during this study, my team and I interacted with more than 40 leading experts across the globe. I would like to share three key insights with you that I found surprising, alarming, and yet still hopeful:

1. Just a small average global temperature increase — such as +3˚C by 2100 versus the preindustrial era — has an enormous impact of which most of us are unaware.
2. The most complicated problems (understanding what is going on and proposing solutions) turned out to be relatively simple, while the simple problems (deciding and acting) turned out to be the most complicated.
3. The climate change trajectory we are most likely already on will make it very tough for all of us; however, we can adapt. We will adapt. Technology is part of the solution, but only one part.

These three insights are detailed in Chapters 2-4 of this Report.

As an appetizer, I share two intriguing anagrams:

"climate change"

is the anagram of

"technical game"

Illustrating the fact that technology, indeed, is part of the solution to this major challenge that we are collectively facing.

Maybe more obscurely,

"climate change"

also transforms into

"teaching camel"

Which reminds us that besides technologies, nature can teach us effective solutions — like the camel, perfectly adapted to its warm environment. This reminds us also that we should not fall completely into techno-solutionism.

— Albert Meige, PhD

CHAPTER 1

CONSIDERING AN ADAPTATION APPROACH

1 Considering an adaptation approach

No matter how hard we try to correct course now, climate change impacts are going to affect us. This means that businesses must consider adaptation as an important aspect of future strategy building.

Our focus on adaptation in no way suggests that it should be a substitute for mitigation efforts or is in any way a higher priority. However, it is important to understand the requirements and potential opportunities that adaptation brings, from both a business and technology perspective.

To frame this Report, we have based our thinking on a climate impact of +3˚C by 2100.[2] As Figure 1 shows, this will have dramatic impacts on agriculture, sea levels, disease, freshwater availability, biodiversity, and extreme weather events, such as wildfires.

A double focus: Businesses & technologies

Clearly, adaptation to climate change is a broad and complex topic. This Report focuses on just two aspects: (1) climate change adaptation from the perspective of businesses and (2) technologies enabling adaptation. This means that the Report addresses policies, infrastructure, and community-based initiatives only to the extent that they can be co-implemented by the private sector and include a technological component. We also do not address wider trends, such as geopolitical turmoil, which will also impact or potentially limit the abilities of businesses to adapt. This chosen scope reflects Blue Shift's focus on forward-looking technologies. It should not be interpreted to suggest that political, economic, and social changes are secondary to technological enablers.

Fig 1 — Likely climate impacts for a "+3°C by 2100" trajectory

Extreme climate events	Freshwater availability	Sea level rise	Biodiversity loss	Pests & diseases
Likelihood of wildfire events will **increase by nearly 30%** globally by 2040–2050	**1 in 4 people** may live in a country affected by chronic shortages of fresh water by 2050	Over **500 cities & 1 billion people** will be exposed to sea level rise by 2040–2050	**More than 90%** of live coral reefs could vanish by 2040	Pest damage to wheat, rice & maize production may rise by **10%-25% per degree of global warming**
1	2	3	4	5

Source: Arthur D. Little, IPCC

Adaptation: A subset of the climate change toolbox

As Figure 2 shows, the sustainability conversation is rich and broad and includes several overlapping but distinct goals, among them **mitigation, adaptation,** and **resilience.** Business adaptation overlaps partially with each of these goals in various ways, for example:

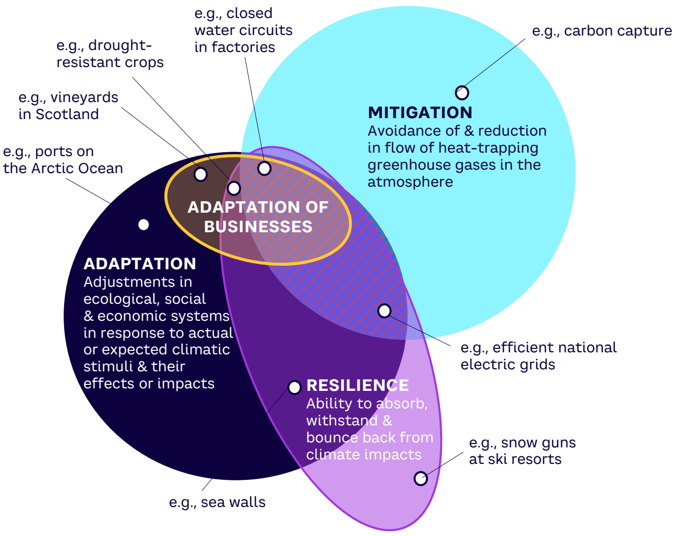
- **Mitigation-promoting adaptation** — mostly in the form of resource-use efficiency (e.g., adapting to lower water resources), while also preserving existing supplies
- **Opportunities borne out of adaptation** — the creation of new products and services to accompany the transition to a changing climate
- **Resilience** — protecting industrial assets, people, and processes against climate impacts

Adaptation: A plethora of solutions

While climate change mitigation focuses on the release of greenhouse gases (GHGs) into the atmosphere from a range of sources, adaptation is more concerned with addressing a multiplicity of impacts that all occur locally. For example, a community living in a single valley may need to address the drying up of its local river, the exposure of the village to heat waves, and landslides due to mountain slope erosion — using tools that may not be fully scalable or applicable to other locations or issues.

Essentially, this means that the value of adaptation solutions lies in the successful application of technologies to a particular problem at an acceptable cost. Therefore, the technologies to address adaptation needs are specific, numerous, and fragmented. At the same time, technological hype and funding for adaptation tech remain low. It is estimated that less than 10% of all climate funding went to adaptation in 2020–2021.[3]

Fig 2 — The climate change issue space



Source: Arthur D. Little, IPCC, Global Environment Facility (GEF)

To help identify green technologies, WIPO established the free, online WIPO GREEN Marketplace for Sustainable Technology platform in 2013, which catalogs around 150,000 technologies and patents for solutions to environmental or climate change challenges across seven large application domains (see Figure 3).

"Adaptation technologies are a highly diverse field of innovation, which to some degree live in the shadows of the more dominating mitigation technologies. One of the reasons for this is exactly this diversity, which may make it harder to recognize both what is needed where and when, and what could be the solution. Furthermore, many solutions for contributing to adaptation are already there and in use but will gain new importance, while others will be based on new technologies, some advanced, others more simple."

Peter Oksen, WIPO

Technology for climate change adaptation

In this Report, we aim to cut through the noise by responding to a simple problem statement: **how can decision makers harness technology to help their businesses face the diverse, multivariate, and ambiguous impacts of climate change?**

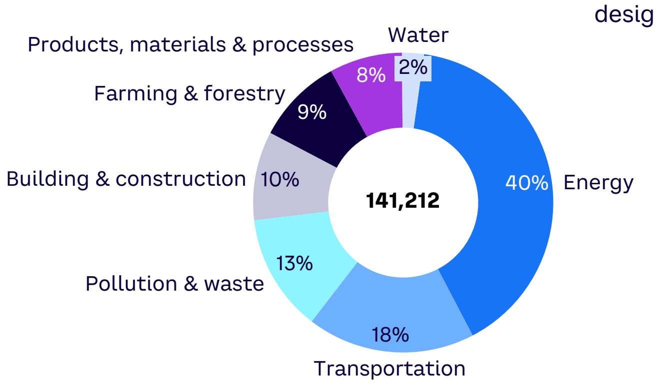
To answer this question, we followed a seven-step approach:

1. Outline the main **challenges** companies face in adapting to climate change.
2. Set the stage by **assuming a "+3°C by 2100" trajectory** in 2040.
3. Draw out **projections** combining possible human responses to climate change.
4. Use design fiction methods to amplify the **concrete impacts** of specific projections.
5. Detail **functional expectations** and **relevant technologies** for each projection and challenge.
6. Identify the **no-regret moves:** solutions, enabling technologies, and capabilities that should be developed now to be able to adapt.
7. Provide insights to help companies embark on their **adaptation journey:** how to predict, decide, and build capabilities.

The Report is based on a combination of sources, including:

- **Interviews** — more than 40 interviews with corporate executives, climate adaptation experts, VCs, and start-ups
- **Surveys** — two surveys, one with corporate executives and one with global academic experts, with a total of 70 respondents
- **Collaboration** with WIPO, covering the requirements for adaptation technologies
- **Documentary sources,** including the 2022 "WIPO Green Technology Book" ("Adaptation edition") and the IPCC's "AR6 Synthesis Report: Climate Change 2023," among others
- **Collaboration** with design agency Making Tomorrow, creating design fiction and artifacts for each selected projection

Fig 3 — WIPO GREEN database, technologies by application type



Source: Arthur D. Little, WIPO

CHAPTER 2

THE CHALLENGES AHEAD

2 The challenges ahead

The many adaptation challenges businesses face vary between locations and industries. However, it is useful to consider them in terms of four generic categories by function: source, make, protect, and sell.

Source

Securing the availability and supply chain of critical raw materials and resources includes sub-challenges, such as:

- **Water scarcity.** The availability of fresh water for irrigation is declining, especially in regions affected by droughts and flooding, while flooding and rising sea levels cause water salination, making the water unusable for agriculture.
- **Declining crop production.** Suboptimal weather conditions are decreasing agricultural yields, such as European heat waves that lead to crop failures. Additionally, climate effects are increasing the appearance of pests and invasive species, while changing growing conditions mean many traditional crops are now unviable.
- **Access to critical materials.** Due to climate effects like sea level rise, storms, and droughts, interruptions and/or significant slowdowns in supply chains are expected. This means critical materials will become increasingly expensive to procure, including rare earths or rare metals for the manufacturing of batteries.
- **Disrupted supply routes.** Interruptions and/or significant slowdowns to the transport and distribution of raw materials, resources, goods, and services are increasing due to severe climate events. For example, due to droughts, the Panama Canal functioned at reduced capacity during the winter of 2024, with a major impact on global supply chains.

Critical materials will become increasingly expensive to procure.

Example: Wine industry requires resilient crops

Since grapes grow in narrow temperature zones, with average growing season temperatures between 12°C-22°C (56°F-72°F), increasing heat and more severe climate events such as longer heat waves are reducing winemakers' productivity. For example, in 2022, France saw its smallest harvest since 1957 due to increased heat waves and rain, costing the industry around US $2 billion in sales. Vineyards near Madrid, Spain, can no longer make wine below 16%-17% alcohol, which falls outside mainstream consumer tastes. Producers that have started moving to regenerative agriculture have suffered invasions of ants that have eaten their vines. Water scarcity is also a key issue for vineyards in countries such as Chile. Adaptation technologies are needed, and companies are experimenting with new techniques that enable modifications to vines to increase their resilience against diseases and climate events.

Make

Manufacturing and other industrial processes also must adapt to a changing climate, including sub-challenges, such as:

- **Energy and water supply.** The instability of traditional electricity grids and water shortages caused by extreme climate events impact reliable access to energy and water. As a result, companies are looking to reduce inefficiency and install water recycling systems.
- **Productivity improvements.** Despite challenges around raw material availability, companies need to preserve product quality to ensure customer satisfaction, while maintaining their manufacturing processes against a backdrop of extreme temperature variations. To offset these factors as well as supply chain and business interruptions, companies are looking to potentially increase the pace of production, reduce labor and inventory costs, and/or rationalize manufacturing processes to optimize costs and meet changing consumer needs.
- **Working conditions.** Companies must maintain viable working temperatures in factories and offices despite frequent heat waves, while implementing remote working plans to mitigate more frequent epidemic risks.

The instability of traditional electricity grids and water shortages impact reliable access to energy and water.

Example: Securing a reliable energy supply

Due to cheap labor costs, India is home to many textile, electronics, and automotive factories. Today, according to experts we interviewed, the Indian electricity grid is 70% coal-powered and 15% hydroelectric, with the remainder coming from nuclear and solar sources. However, the country imports coal from Indonesia and Australia, and lower Indian rainfall due to climate change means that hydroelectric and nuclear power plants are not as efficient as they once were. This makes the Indian grid highly unstable, with two-thirds of rural and two-fifths of urban households reporting that they face at least daily outages, also interrupting factory production. Adaptation technologies could help improve energy supply (e.g., through smart grid and stabilization systems).

Protect

Industrial sites and assets (including extraction, manufacturing, and logistics) must be protected from climate change impacts, such as rising temperatures/sea levels and extreme climate events. This includes sub-challenges such as:

- **Detection and alert.** With the increase of unforeseen climate events, such as flooding and storms, governments and companies must ensure they have better capabilities to both predict and warn people of such dangers.
- **Shielding.** In the event of sea level rise, floods, and storms, companies must better protect their assets and infrastructure from damage, using natural or man-made solutions.
- **Resilient design.** With more severe climate events, companies also must consider new ways of designing and building resilient assets, such as solar panels that can easily be removed before a storm hits.
- **Remediation.** Companies face increased damage or loss of their machinery/production sites due to extreme adverse climate events. To limit downtime and productivity losses, they must be more efficient and quicker to restart production after such interruptions.
- **Relocation.** Some key business locations will be vulnerable to sea level rise/flooding (e.g., China, Vietnam, and Bangladesh) and droughts/heat waves (e.g., Sub-Saharan Africa, India, and Southeast Asia), forcing companies to find more resilient locations for their industrial sites and assets. For example, in China, the headquarters of Alibaba in Hangzhou, the Suzhou Industrial Park (Panasonic's country headquarters) and Tesla's Shanghai Gigafactory are all located in at-risk areas.

Companies must consider new ways of designing and building resilient assets.

Example: Military bases on the US East Coast

Sea level rise and more severe storms and flooding are increasingly affecting businesses on the US East Coast, with studies showing that flood frequency is predicted to triple in the coming years, reaching up to 85 flood days a year by 2050. At the same time, assets and real estate continue to be built in high-risk locations. The US military's East Coast bases are impacted by this trend. In 2018, for example, a hurricane and floods ripped through a naval base, causing about $4.7 billion in damage, while affecting its ability to conduct and support operations in the Atlantic. The US Department of Defense estimates that there are more than 1,700 US military installations in coastal areas worldwide that may be affected by sea level rise. Consequently, the US military has begun to pilot adaptation measures. For example, it is building sea walls at its Norfolk, Virginia, naval base, and, in the Hampton Roads area, the US Navy has updated its building criteria to ensure more resilient infrastructure.

Sell

Companies must ensure goods and services are competitive and differentiated amid a changing climate while adapting to new consumer behaviors, including new use cases and changing customer demands. This includes sub-challenges such as:

- **New products and services.** Companies must design new innovative products and services in response to emerging needs driven by climate change (e.g., heat-resistant fabrics).
- **New usage patterns.** Companies must better understand and anticipate future consumer expectations and patterns of consumption, adapting their business models to remain competitive (e.g., embracing recycled, reusable, and modular products).
- **Changing sales channels.** In the event of climate-driven supply chain disruption, companies must still be able to deliver products to consumers. They also need to transform sales channels to mitigate against changing consumer behaviors.

Companies must adapt their business models to remain competitive.

Example: Modular products in the automotive industry

New car prices are rising due to increasing material costs. This is driving consumers to look for cheaper options with lower environmental impacts, such as buying used cars (2023 sales were up 5% on 2022), leasing vehicles (with this market expected to reach approximately $5.4 billion by 2030 in Europe, from $3.25 billion today, assuming a constant euro-dollar exchange rate), or car-sharing to reduce costs. To remain competitive, automotive manufacturers must look to reduce the customer's cost of ownership. One way to do this is to develop modular products, which allow users to easily customize their vehicle. By having fewer, more standardized and interchangeable parts, and incorporating fasteners to eliminate the need for screws and bolts, each modular component is designed to be cheaper and easier to assemble/disassemble, while extending the overall product lifecycle. Demonstrating the impact, rather than paying around $1,080 to replace an entire seat with one with lumbar adjustment, in a modular seat all that would be needed is to change and upgrade part of the backrest, at a cost of approximately $108 to the customer.

"We used to look up at the sky and wonder at our place in the stars. Now we just look down and worry about our place in the dirt."

– Cooper, *Interstellar*

INTERLUDE
We need you to take charge

Born in 1973, Cédric Villani is a French mathematician very active in public debate. His research in mathematical physics, at the crosspoint between probability, analysis, and geometry, and particularly on the equations of gases and plasmas, won him the prestigious Fields Medal (the "Nobel of Mathematics") in 2010. A passionate advocate of science for all, he gained the attention of millions of people through his lectures, books, and broad-audience writings about science. A specialist in the interaction between science and society, he sat in the French Parliament for five years, presiding over the Scientific Parliamentary Office, and is a regular participant in society debates. He is the current president of the Fondation de l'Ecologie Politique.

Some problems seem simple and turn out to be complicated; others seem complicated and turn out to be simple. As scientists, we live with that uncertainty. For example, a research project that I believed could be solved in a few weeks (as a warmup for further work) turned out to be a deep monster. My main collaborator and I finally solved the problem after more than two years of work, hundreds of mistakes and wanderings, and a 200-page proof, eventually earning me the Fields Medal (an award granted for outstanding contributions in mathematics by young scientists).

As for the climate change issue, the monster problem for the international scientific community 30 years ago was the technical analysis of natural phenomena at work. What an outstanding challenge to analyze the trends of temperatures, humidity, winds, and so on, behind the complexity, variability, and multifactoriality of weather! What seemed much simpler and understandable was the actions humans would need to take when the technical analysis was over.

It turned out to be precisely the contrary.

A fantastic international coalition of thousands of scientists harnessed an amazing amount of facts, measurements, and papers to establish conclusions that can all be summarized in a few sentences that even a child can understand: **Climate is warming up, and weather is becoming more unstable; this is certain. It can be measured, and it is happening fast. It (almost) all depends on carbon dioxide and methane. And it's totally — not partially — due to our human activities.**

This is a truly remarkable achievement in its simplicity, despite the amazing technical difficulties. All resources of natural science have been summoned. Data collection, climate sciences, physics, chemistry, biology, geology, statistics, computer science, numerical simulations ... I have witnessed many participants in this outstanding collective project, one of the scientific adventures of our time.

This coalition has also recommended some remedies, at least to mitigate climate warming. And it has provided some tools and directions to address the more complex issue of human adaptation. Dozens of plans have been put forth, with many ingredients, quantitative recipes, and so forth, using current tools and ideas. There's no need to wait for hypothetical recipes, and certainly no time.

So we have the diagnosis, and we have part of the cure. The math is clear. Change is occurring very fast and can be conjured. It's up to all of us to change the behavior of society. It's for citizens and governments and infrastructures and companies and banks, private and public sectors alike. Not in 10 years but now. The message seems clear. Scientists have provided a whole bunch of figures and predictions about potential catastrophes and the need for fast decisions and actions to mitigate and adapt.

But then, the real difficulties started, to a level that hardly anyone expected. And it was for the part that seemed simple: convince the whole world to act in the face of such a dire situation. Next came an array of political games, lobbying campaigns, smoke curtains, disinformation, billions of dollars to prevent action, and cognitive mechanisms for society to not act. The social sciences, including Naomi Oreskes and her collaborators, have made tremendous progress in analyzing these obstacles, but action has hardly started.

Taking part in the United Nations Framework Convention on Climate Change was an amazing experience. When the session was organized by scientists, it was marked with energy and determination to act as fast and efficiently as possible. In contrast, roundtables organized by politicians seem to act as slowly and inefficiently as possible. Science always gets things done; political actions can be stuck forever until the most important force comes into play: the will.

When I lecture about society transition, I like to enumerate seven key ingredients: diagnostic, plans, motivation, investment, governance, workforce, and control. The first two are what scientists can do. The rest are for society as a whole, particularly politicians, financiers, professional organizations, and unions, to work out.

Companies have a key role to play in this transition. First, because there is just not enough public money, investment, and workforce, by a long shot, to handle all the changes. Second, because change is easier to implement at the company level than at the government level, which is always subject to more pressure and tension.

So your company is also in charge. The good news is that there are plenty of diagnostic tools, examples, and recipes that your company can use to adapt. In the worst case, if your business model depends on the amount of greenhouse gas that you produce, then it's time to change your business. But in most cases, it will be about changing habits, replacing products, and finding new ways to continue the actions of your company.

Science has done its job; it's the part that you could never have done. Now it's your time to be in charge.

— Cédric Villani, President of the Fondation de l'Écologie Politique

"We have exactly six months, ten days, two hours, 11 minutes and 41 seconds, until a comet twice the size of Chicxulub tears through our atmosphere and extincts all life on Earth."

— Kate Dibiasky, *Don't Look Up*

CHAPTER

3

MODELLING UNCERTAIN OUTCOMES

3 Modeling uncertain outcomes

Based on our research and corroborated by our surveys and expert interviews, we have identified 11 shaping factors that affect climate change adaptation, grouped into geophysical, biological, behavioral/demographic, and economic categories (see Figure 4).

Shaping factors for climate change adaptation

Geophysical

1. **Extreme climate events** — phenomena outside the normal range of weather patterns characterized by their severity, duration, or frequency (e.g., heat waves, droughts, storms, wildfires, landslides, and flooding)
2. **Freshwater availability** — a decrease in the amount of clean and usable water accessible for human use and consumption
3. **Sea level rise** — an increase in the average level of the ocean's surface over time, due to melting glaciers and thermal expansion of seawater, leading to the erosion and submersion of coastlines

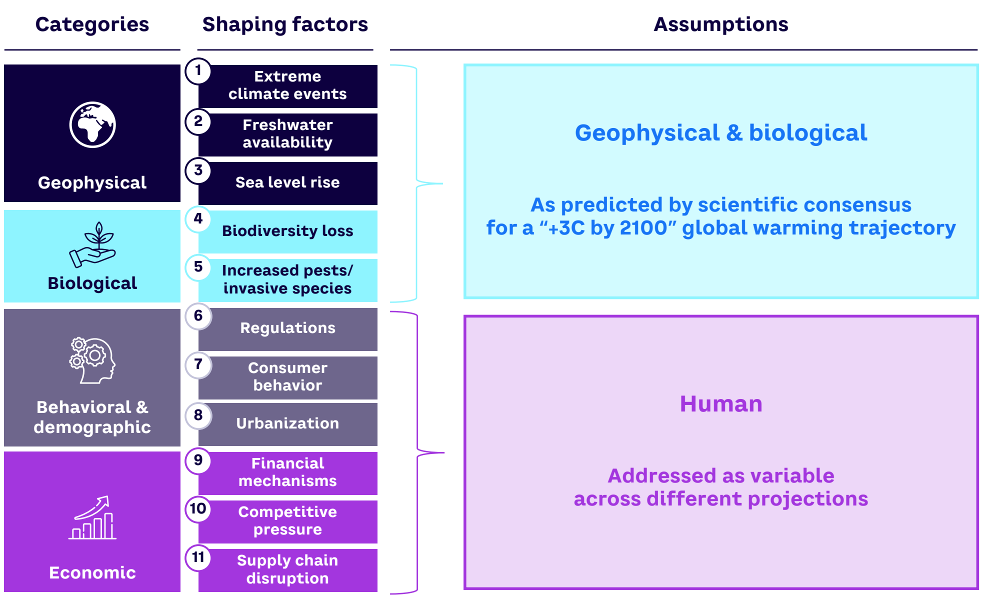
Biological

1. **Biodiversity loss** — a severe decline in yield from key crops and livestock, as well as mass vegetal and animal species extinctions
2. **Increased pests/invasive species** — an increase in the activity of destructive insects and animals, leading to damage to ecosystems and possible transmission of diseases to humans

Behavioral & demographic

1. **Regulations** — legislation and practices put in place by governments and local authorities to promote or impose adaptation to climate change
2. **Consumer behavior** — patterns of individual purchasing decisions that reflect adaptation to climate change
3. **Urbanization** — an expansion of cities and towns as populations migrate due to extreme weather, moving from rural to urban areas

Fig 4 — Shaping factors for climate change adaptation



Source: Arthur D. Little

Economic

1. **Financial mechanisms** — an ecosystem of polices, investors, and financial instruments that mandate or promote adaptation investment
2. **Competitive pressure** — major players in the value chain assuming climate adaptation leadership, driving a dynamic market and forcing behavior change onto competitors and suppliers
3. **Supply chain disruption** — interruptions or significant slowdowns in the transportation and distribution of raw materials, resources, goods, and services

During our analysis, we assumed that factors within the geophysical and biological categories will behave in line with the "+3°C by 2100" global warming trajectory (see sidebar "The '+3°C by 2100' trajectory"). However, the impact and scope of the behavioral/ demographic and economic categories will vary between the different projections outlined later in this chapter.

The impact and scope of the behavioral/ demographic and economic categories will vary between the different projections.

Impacts by category

Geophysical

The impacts of geophysical factors will be widespread and large-scale, as evidenced by projections[4] and estimates from a variety of sources. For example:

- **Heat waves** are likely to be longer and more intense over the coming decades, with minimum temperatures rising by at least +3°C, and an accentuation of up to +8°C at the poles, according to the IPCC. Additionally, the combination of high temperature and high humidity is likely to become more prevalent, increasing the "wet bulb effect," which limits the human body's ability to cool down from evaporation or sweat.

The "+3°C by 2100" trajectory

The "+3°C by 2100" trajectory falls within the confidence interval for the IPCC's RCP 6.0, which predicts a temperature increase of ~+2.8°C versus preindustrial levels, with a possible range between +2.0° and +3.7°C. This trajectory considers the likely target gap in 2030 based on current delays in policy and climate action at large. It therefore allows for a cautiously pessimistic outlook, which puts the challenges of adaptation for companies into sharper focus.

Global GHG emissions

A +3°C global increase by the end of the century is forecast to bring temperatures beyond +3°C above preindustrial levels in the second half of the century, as it is assumed temperature will peak before mitigation measures allow it to plateau and decrease. Treating the geophysical and ecosystemic/biological ramifications of global warming as givens helps make impacts concrete and solutions pragmatic. We purposely do not integrate the Shared Socioeconomic Pathways (SSPs) approach into our baseline temperature for projections, as we treat patterns of human development as uncertainties.

The share of the global land area and population affected by agricultural, ecological, and hydrological droughts is projected to increase substantially.

- Conditions will be more favorable for the formation of **tropical cyclones,** particularly affecting areas in the Pacific Ocean. For example, by 2050, the annual likelihood of an intense tropical cyclone in Japan is likely to more than double from 4.6% in 2020 to nearly 14%.[5]
- By 2040–2050, the likelihood of **wildfire** events will increase by nearly 30% globally, according to the IPCC, particularly due to higher temperatures causing vegetation — including rainforests, permafrost, and peatland swamps that would not usually burn — to dry out and combust.
- By the late 21st century, the share of the global land area and population affected by agricultural, ecological, and hydrological **droughts** is projected to increase substantially — from around 15% to 20% at a moderate or severe drought, and from around 3% to nearly 10% in the extreme or exceptional drought.[6] Some areas are more exposed to droughts, particularly Africa, South America, and the Mediterranean coast, which will see drought hazard increase by 82%.[7,8]
- **Extreme precipitation events** will be accentuated by climate change, increasing the risk of flooding, particularly in Southeast Asia. This will also lead to **soil erosion** due to extreme rainfall, a trend increasing over 80%-85% of the global land surface.[9] By 2050, experts project an increase in the frequency or intensity of precipitation events, especially in North America and Europe. In New York, annual rainfall is expected to increase from 45.6 to about 49.7 inches in that timeline.[10]
- As of 2022, 2.2 billion people lacked access to safely managed **drinking water.**[11] Other sources project that demand for water will rise by a further 20 to 25% by 2050.[12]
- The consequences of **sea level rise** will be global, with local variations in risks and damages. Some regions are more vulnerable than others; for example, 17% of Bangladesh is predicted to be submerged by 2050, displacing over 20 million people.[13]

Taking action on extreme heat

Exposure to extreme heat results in more deaths than any other climate-related hazard, and the impacts are increasing. Rising global temperatures, primarily caused by climate change due to GHG emissions, are leading to more frequent and severe heat waves. Alongside the impact on human health, heat waves also affect economies and infrastructure and can compound other climate and non-climate risks, such as drought and wildfires. The threat of extreme heat will continue to increase, and by 2030, between 160 million and 200 million people in India could live in regions with a 5% average annual probability of experiencing a deadly heat wave that exceeds the "survivability threshold" for a healthy human being. Extreme heat's impacts on human health and the economy are unequal and vary depending on vulnerability and exposure. People with chronic diseases, older people and the very young, low-income individuals, underserved populations, people living alone, pregnant women, and unhoused people are most at risk to extreme heat. While extreme heat can occur in most populated areas, the intensity is accentuated in urban areas, with dense populations and economic activity. Moreover, extreme heat exposes populations to multiple negative outcomes, impacting health, the workforce, productivity, and transportation. Extreme heat can compound or even instigate other climate-related risk events. Creating resilience in economies and communities is a necessity, but it is also an opportunity. Heat resilience stands as a pivotal opportunity for global corporations and organizations of all sizes to innovate and help society adapt. Extreme heat mitigation and adaptation is a great chance for innovation that benefits society and brand image and should be prioritized by forward-looking chief risk, innovation, and finance officers. *(Read more from Climate Resilience Consulting's Joyce Coffee and Robert Macnee on extreme heat in the Appendix.)*

Whether regulation will ever drive adaptation with the same force as mitigation is very much open to question.

Biological

A variety of biological factors will impact ecosystems, farming, and the spread of infectious diseases, such as:

- **Crop and livestock productivity decline** and biodiversity loss attributed to climate change are already endangering the whole range of "ecosystem services." Maize yields, for example, are projected to decline further by 24% by the late 21st century, even as the global demand for cereal for animal feed and food alone is expected to increase by 50%-60% compared to 2000.[14]
- A global increase is predicted in **crop pest damage** to wheat, rice, and maize production of 10%-25% per degree of global warming.[15]
- The threat of **zoonotic disease** transmitted between vertebrates and humans is increasing dramatically due to the disruption of natural habitats by climate change (and other human factors like deforestation and urbanization). A greater probability of mosquito-borne West Nile Virus infection is expected in 2025, especially in eastern Croatia, northeastern Türkiye, and northwestern Türkiye, with further range expansion in 2050.[16]

Behavioral & demographic

The way humans react to climate change determines profound political, demographic, and societal trends:

- **Regulation** has so far been the major lever in climate change mitigation efforts. However, for adaptation, while there have been some regulations in place since 2008 (see Table 1), they are still sparse, limited to specific industries, and lacking in enforcement power. Whether regulation will ever drive adaptation with the same force as mitigation is very much open to question.
- While consumers in industrialized countries show some signs of **behavioral shifts** related to climate change adaptation, counter-adaptation behavior is also being seen. For example, in the US real estate market, homes near sea level rise areas are now sold for, on average, 7% less than comparable homes.[17] Yet at the same time, population growth is strong in the hottest, driest, and most vulnerable parts of the country. As an example, more than 800,000 people have moved from California to Phoenix, Arizona, since 2012.[18]
- **Urbanization rates** are expected to keep increasing, further boosted by the influx of refugees from affected areas, particularly in the Global South, where 70% of those displaced by climate change are moving to cities.[19]

We consider regulation and behavioral shifts in more detail in the next section.

Table 1 — Overview of selected climate-adaptation regulations

REGULATION	OBJECTIVES	YEAR	COUNTRY
Climate Change Act	• Binds UK to long-term emissions-reduction target • Includes provisions for adaptation: **risk assessment & adaption plan**	2008	UK
Monitoring Mechanism Regulation (MMR)	• Sets **EU internal reporting rules** in line with globally agreed obligations • First reporting took place in 2015, second in 2019	2014	EU
National Adaptation Plan	• **Reduce vulnerability** by building adaptive capacity & resilience • Integrate adaptation strategies **into policies & programs**	2015 *(Paris Agreement)*	
Energy Union Governance Regulation	• Expands on **MMR for adaptation reporting** • Sets **common rules** for planning, reporting & monitoring • Ensures **synchronization with ambitions** of the Paris Agreement	2019	EU
ISO 14090	• Provides **principles, requirements & guidelines** for climate adaptation • Offers **framework for organizations** to develop, implement & monitor policies, strategies & activities related to adaptation	2019	
Draft Climate Law	• Requires member states to **develop & implement adaptation strategies & plans,** including comprehensive risk management frameworks, & **progress assessments**	2020	EU
ISO 14091	• Gives guidelines for **assessing risks** related to potential impacts of climate change	2021	
ISO 14092	• Specifies requirements on **adaptation planning for local communities & governments** based on vulnerability, impacts & risk assessments	2020	
ISO 14093	• Establishes approach for **country-based mechanism** to **channel climate finance** to local governments • Uses **performance-based climate resilience grants** offering strong incentives for performance improvements	2022	
"Drone-swarm" farming	• FFA allows **fleets of drones** for **seeding & spraying crops** • Enables drones like Hylio AG-230 AgroDrone to cover ~**50 acres/hour**	2024	US

Source: Arthur D. Little, UN, Climate Change Committee (CCC), ISO

Economic

- Climate change will profoundly impact key economic drivers on a global scale, with tangible effects on businesses. **Financial mechanisms** for adaptation are in development, spearheaded by international development institutions, with insurance particularly active. However, while adaptation finance for climate change hit a record $63 billion in 2021/2022, increasing by 28%, it is still significantly below the $212 billion yearly need projected by 2030 for developing countries alone.[20]
- **Industry leaders** have transformed entire supply chains with their climate-mitigation efforts, pressuring customers and competitors to change. For example, Apple is demanding that its entire value chain reduce its impact on global warming.
- **Supply chains** are likely to be disrupted by rising sea levels and other factors, potentially leading to major changes in global economic structures. For example, severe droughts have limited transits through the Panama Canal to 25 per day (down from 36) since January 2024, causing significant supply chain delays and repercussions on costs.[21]
- **Commodity prices** are highly volatile due to market conditions, and future supply chain disruptions could significantly increase them. For example, cocoa market prices increased dramatically in 2023 due to heavy rainfalls in West Africa.

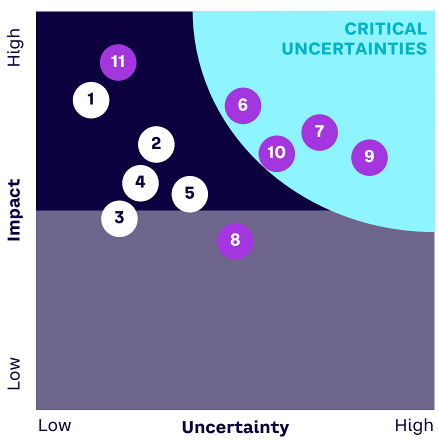
The impact of human shaping factors

In our analysis, we captured all the geophysical and biological factors (1-5 in Figure 4) as part of our underlying assumption of a "+3°C by 2100" trajectory, effectively taking these factors as a given. To explore plausible futures, we scored the "human shaping factors" (6-11 in Figure 4) according to their impact and degree of uncertainty, using the results of a survey polling 60 experts and corporate executives (see Figure 5). In the matrix:

- A maximum degree of **uncertainty** (scored 5 out of 5) refers to a 50/50 probability of a particular factor being realized. Conversely, a score of 1 out of 5 reflects near certainty.
- **Impact** is a qualitative appraisal of the intensity and range of consequences of a particular factor on societies, businesses, and humans. A score of 5 out of 5 reflects very high impact across the board, while 1 out of 5 reflects little or no impact.

The factors that gained the highest scores of uncertainty and impact, placing them in the top right-hand quarter of the matrix, constitute "critical uncertainties." These comprise **regulations, consumer behavior, financial mechanisms,** and **competitive pressure.** Supply chain disruption has relatively high certainty and major impact and was thus integrated as a given into all the future projections. Urbanization has relatively less impact than the other factors, so it was deprioritized in the analysis.

Fig 5 — Human shaping factor ranking and critical uncertainties



Geophysical & biological factors

1. Extreme climate events
2. Freshwater availability
3. Sea level rise
4. Biodiversity loss
5. Pests & diseases

Human factors

6. Regulations
7. Consumer behavior
8. Urbanization
9. Financial mechanisms
10. Competitive pressure
11. Supply chain disruption

Source: Arthur D. Little

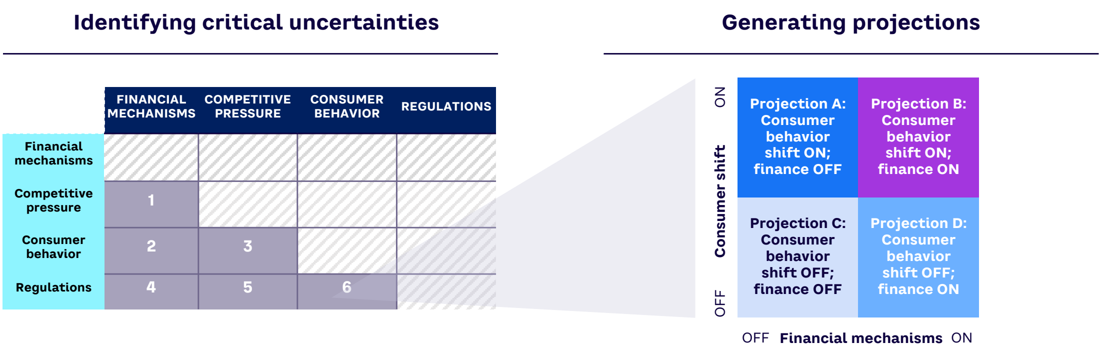
The projection methodology

To build our future projections, we followed a structured methodology (see Figure 6). The methodology comprised four steps:

1. Rank the four critical uncertainties listed in Figure 5.
2. Identify intersections between these uncertainties.
3. Generate on/off projections for the intersections between the four critical uncertainties.
4. Filter the resulting 24 projections down to five, considering:
   - **Plausibility.** Is this scenario internally consistent, or is it self-contradictory?
   - **Differentiation.** Is it sufficiently differentiated from others to tell us something new?
   - **Technological relevance.** Does this scenario enable us to predict which technologies will be useful for adaptation?

This approach yields projections not strictly exclusive of each other, as each only highlights two aspects of the future. Projections may be compatible in a single world (e.g., there is a single possible world with high levels of regulation, high competitive pressure, low consumer behavior shift, and low financial resources available). However, our approach addresses this result in two separate projections. We believe this approach more closely mimics real-world decision-making than multivariate scenario-building, which often proves an intractable exercise, especially when each variable displays high degrees of uncertainty. Additionally, this approach allows for thoroughly exploring the tension that arises at the confluence between shaping factors, demonstrating clearly where contradictions, challenges, and opportunities arise.

Fig 6 — Identifying critical uncertainties and generating on/off projections



Source: Arthur D. Little

"The future cannot be predicted, but futures can be invented."

— Dennis Gabor

5 projections for the future

Through this process, we have identified five projections, chosen for their internal consistency, differentiation, and relevance for technology (see Table 2). With the help of our design fiction partner Making Tomorrow, in this section we share "artifacts from the future" based on the five projections.

Table 2. Five projections for the future

TITLE	VARIABLES	DESCRIPTION
Green Communities	Strong consumer behavior shift, limited financing	A resource-scarce world in which grassroots initiatives flourish, without large-scale projects; a pull toward greater decentralization, circularity & frugality
Lonely at the Top	No consumer behavior shift, high competitive pressure	Highly concentrated & competitive industries in which market leaders spearhead adaptation to build competitive advantage & keep satisfying customers' demands while operating under increased constraints
Wild Green West	Abundant financing, limited regulation	A creative chaos in which private adaptation initiatives sprout everywhere, fueled by private capital & hype, with no regulatory backbone to provide an overarching strategy or ensure consistency
Don't Look Up	Limited financing, no consumer behavior shift	A pessimistic future in which neither customers nor financial institutions have adjusted to the new climate reality, leaving nothing but quick fixes & crisis management
Adaptation Surge	Strong competitive pressure, strong regulation, abundant financing & massive customer behavior shift	A relative utopia in which adaptation is the norm & the new currency, resetting expectations, creating new markets & new needs for differentiation

Source: Arthur D. Little

basi 𝕏
@Low-Lantah, worldwide TV show
3rd edition of the worldwide crowdfunding game rewarding inventive citizens adapting to climate change.
#Back to basics #Citizens resilience #Low cost #High creativity

Low-Lantah 2042 @lowlantah2k42 · 06/12/2042 ...
We are just a few days away from the end of the competition, and Joao Santos, from Porto Alegre, Brazil, remains in the lead. He and his team have developed CeuBrisa ("breeze from the sky"), a fan mounted on a leisure drone that keeps its owner cool wherever they go – without need for cumbersome wearables. His crowdfunding campaign has made impressive strides thanks to the outstanding support of his community back home.
139 · 19 · 432

Tiago Souza @tiag264 · 06/12/2042 ...
Go Joao! 💪 The entire neighborhood of Belém Novo is behind you. You're our champion. I've convinced my boss to donate to your campaign 💵
23

Mariana Alves @mariBrazil · 06/12/2042 ...
Joao, you're the best 🫶 But watch out for Kyle from California. He has a very effective value proposition… But we believe in you.
13

Low-Lantah 2042 @lowlantah2k42 · 06/14/2042 ...
It's neck and neck between Joao, Kyle, and Elena. Elena is back in the race with her retrofitted Renault Dacia car-sharing exchange. Her team has bought up dozens of nearly wrecked cars, had them retrofitted, and created a fleet which she has used to set up a car-sharing exchange in her suburban town next to Sofia. Cars are fitted with cheap sensors and tracked on a mobile app. They can be used for short-distance commutes (30 minutes only). With the increasing price of mid- to lower-range cars these past two decades, suburban commuters are loving this economical and endearing vintage option. Things are going smoothly for the Bulgarian entrepreneur…
174 · 25 · 353

Igor @igorngt · 06/14/2042 ...
Elena is winning this one!👸 We've been practicing frugal entrepreneurship for a long time in Eastern Europe…
1 · 2 · 12

Josh @josh79_ref · 06/14/2042 ...
It's not over yet! Check out Kyle's wearable air purifier for dogs. Wildfire season here gets longer every year. Humans all wear mini-purifiers around their necks…it is high time their four-legged friends had one, too! The market is very hot: there are more dogs than children in San Francisco, and they are spoiled. 👊☀️
4

Ivanka @iv_ka · 06/14/2042 ...
My grandmother is a fan; she goes to the market with a Dacia and comes back with another 👵. Same for me with my commute to university. OEMs should be getting nervous – I see no point in purchasing a car ever again…
6

Low-Lantah 2042 @lowlantah2k42 · 06/19/2042 ...
Our 2042 edition is over, and the winner is…Elena! Our first-ever Bulgarian finalist! Joao relinquishes second place – at the last moment – to Kyle. Our contestants' creativity and grit never fail to amaze, and even tickle the incumbents in their respective markets. Whether they'll choose to copy, compete, or buy them out, Low_lantah has a bright future ahead
196 · 36 · 475

Projection 1: Green Communities

Individuals are stepping back into the spotlight to drive adaptation when large corporations and the traditional financial system struggle to address these issues. To spread their light, we imagined a TV show presenting local small entrepreneurs all over the world seeking to raise funds from the public. The show provides a platform for their initiatives to be recognized and supported. The fiction features an excerpt from the show's feed on social media BasiX.

How did we get here?

A heightened awareness of climate change has dawned on consumers globally following catastrophic climatic events and shortages. This has led them largely to adapt their purchasing habits and lifestyles to cope with current or impending climate impacts. However, the investment world has not evolved to take climate adaptation into account, due mainly to its lack of adequate short-term ROI. Insurers either require highly inflated premiums or else refuse to insure large swathes of climate hazards.

The international economy

Globalized flows of capital and goods are limited by geostrategic conflicts and supply chain disruptions. The North-South division of labor remains largely in place, while Southeast Asia's and Central America's hubs suffer greatly from climate impacts. A partial re-localization of supply chains takes place, and local means of production develop. The lack of financial mechanisms for adaptation means there are significant disruptions to production and consequent losses in productivity, primarily concentrated in the areas most vulnerable to severe climate events.

Society

Frustration grows at the lack of investment in what is perceived by most consumers and citizens as a critical strategic issue (adaptation), as well as at the ensuing interruptions in service delivery and production of everyday necessities.

Winners & losers

Businesses and industries that are very asset-light (first and foremost digital players) or whose assets are located in low-vulnerability zones gain a competitive advantage. Extraction industries (oil, mining), heavy industry (metals, chemistry), or manufacturing (automotive) — and to some degree, telecommunications delivered through overhead lines in vulnerable regions — are heavily hit, as moving assets is not always possible or economically viable, repairs are costly, and there are no funds for large-scale adaptation projects to shield infrastructure.

Cultural shift

The seeming inability of existing financial mechanisms to address climate adaptation drives a move to alternative models, including increasing levels of state intervention and radical approaches to ownership of the means of production. However, none of these are successful on a large scale.

Impact on the source/make/protect/sell model

- **Source.** Customers have adapted their demands to consume **more local, seasonal produce and less meat** in developed countries. **Recycling of manufactured goods,** especially electronics, is on the rise at a local level, partially relieving pressure on sourcing battery components and microchips. Unable to invest in adaptation due to a lack of finance, businesses must **substitute ingredients** (e.g., rice for wheat), **discontinue product lines or features** (e.g., natural vanilla extract disappears), or **alter the performance** of products.
- **Make.** Innovation in manufacturing is **frugal,** focusing on **design-to-cost** (as consumer expectations become more basic) and optimizing **productivity.** Major changes to manufacturing processes can't be financed, so any productivity improvements remain **marginal and piecemeal.** Any productivity gains are **threatened by losses from climate hazards,** especially for those industries that consume a lot of water (chemicals, nuclear) or whose processes are temperature- and humidity-sensitive (pharmaceuticals). At the same time, scrutiny from **climate-conscious customers** grows, imposing reputational constraints on operations.
- **Protect.** Many industrial assets remain **uninsured,** causing regular interruptions to production while they are fixed. **Advanced warning systems** are increasingly used, while businesses rely on **crisis management** measures to limit damage. Entire geographies, including former manufacturing hubs, become unattractive for the deployment of **new assets,** while **nature-based solutions** (e.g., planting mangroves to combat freshwater salination) become increasingly attractive due to their low cost.
- **Sell.** Scrappy ventures offering **lower-cost solutions** for "strategic adaptation," or damage mitigation thrive, such as companies providing inflatable solutions to keep inventory dry when warehouses flood. **Maintenance/repair** services flourish, occasionally supported by robots/drones that can operate in challenging weather conditions. **Recycling** is supported by consumers, partially solving material scarcity issues, but a lack of financing prevents fully fledged, large-scale circular economies from developing. The **wellness and healthcare** industries grow by helping humans prevent and treat conditions caused by climate change (e.g., heat stroke and new epidemic diseases). **Frugal innovation** finds inspiration in traditional/ancestral techniques (e.g., using adobe or cut stone for construction). The consumption of digital services has evolved, with **more efficient AI models** developed to reduce the energy costs of computing and storage.

Green Communities: Sowing sustainable seeds for success

It is 2040, and the food and beverage industry is one of the first sectors to be significantly impacted by climate change. Volatile crop pricing and performance, frequent shortages, and disrupted value chains are causing major challenges. Consumers have largely adapted to the new climate reality — partly by choice, partly due to price constraints — and are pulling through new product trends and climate-related requirements, in particular an increased focus on food miles or embodied carbon. Consumer preferences are driving a move away from carbon-inefficient uses of land, such as extensive cattle farming for beef and dairy. Meanwhile, moves to decouple food production from climate threats are stalling, as the large-scale funds necessary for technologies such as indoor farming remain limited.

How will the food and beverage industry survive this tension? At least four levers stand out: (1) partnerships along value chains, (2) climate-conscious product development, (3) synthetic biology (SynBio), and (4) increased responsiveness to fragmented consumer trends, including new ways of using land, crops, and animals (and how we value them).

Unlike the pharmaceutical industry, the food industry is not a monolith but a complex, global network of people and organizations. Lack of funds for large-scale solutions can be remedied, partially, by careful collaboration across players in agrifood value chains. These relationships, particularly between large processors and farmers, like the Cargill Regenerative Agriculture Program launched back in 2019, need to mature to ensure resilience in the face of climate change and are only possible where direct relationships between the producer and user have been cultivated. Data sharing and analysis along the supply chain plays a crucial role in allowing retailers and consumers to make climate-positive choices. By 2040, this means the free and open sharing of complete information on growing practices, processing steps, and shipping and transport history for all ingredients, based on automated systems at every stage in the supply chain.

Product development is also a key lever for adaptation to climate change. Companies must adjust their recipes to locally available ingredients, especially when customers request ingredients with low or zero "food miles."[1] Substitution may be achieved by identifying third-party manufacturers with similar formulations to safeguard against short-term ingredient shortages rather than changing existing recipes and lines. Regardless, such changes require a robust supply quality assurance system, which invokes further supply chain regionalization. Under this paradigm, increasing "air miles" to source ingredients that meet requirements (e.g., flying Kenyan green beans to Europe for freshness) is no longer an option. (For more on this topic, read the ADL Viewpoint "Strengthening Resilience in Food & Beverage Product Development".) Climate change–induced shortages brought about by droughts or extreme weather events (e.g., Californian almonds in 2022 or Canadian mustard seeds in 2023) demonstrate the need for food and beverage companies to be proactive in securing resilient supply chains. As droughts and storms become more intense and frequent, these shortages pose even greater challenges.

SynBio, currently used in the pharmaceutical industry, could trickle down to the food industry as costs decrease and scale increases. Gene editing could accelerate breeding, particularly for high-value crops like drought-resistant tomatoes. Biotechnology companies such as Pairwise, Tropic Biosciences, or AgBiome are at the forefront of such developments but face regulatory hurdles in the short term and funding challenges in the Green Communities projection. In a more fruitful turn of events, one could see the development of a "return to roots" with the reintroduction of heritage vegetable and fruit varieties, once outcompeted on productivity, price, homogeneity, or (occasionally) taste, but now hailed for their climate-resistant properties, such as the drought-tolerant Hopi corn in the Southwestern US.

1 "Food miles" refer to the distance over which food is transported before it reaches the customer (including ingredients of processed foods).

Although consumers are adapting to climate change, aggregate behavior is nuanced and seemingly contradictory in parts. While the trend toward reduced meat consumption is expected to continue well into the 2040s for environmental and economic reasons, it may bring less anticipated effects along with it. A continuation of the somewhat counterintuitive trend of "permissive indulgence" (where people consume more "pleasure foods" like chocolate biscuits and cookies) is to be expected. As meals get less interesting and people look elsewhere for delight, the demand for indulgent snacks grows, supporting the segment for packaged goods companies. To thrive in the indulgence-snacking world, however, producers must be up front about their climate impact and nudge consumers toward more choices that promote climate adaptation and mitigation, including "net zero ingredients."[2]

Given the demand for adaptive products, food producers up and down the value chain must evaluate their forward-looking capability set, ensuring their supply, operations, R&D, regulatory, supplier assurance, and quality teams are all up to the task of refactoring products and logistics to compete in the future landscape. ADL has supported businesses in the consumer package goods and specialty ingredient space to evaluate the critical build-make-buy decisions for future-proofing the business, with sustainability and decarbonization standing as core pillars of future strategies. Identifying key strategic partnerships and instituting innovation ecosystem approaches may be the most cost-effective approach to changing the system.

Simon Norman, Manager, Technology & Innovation Management Practice, ADL

Phil Webster, Partner, Technology & Innovation Management Practice, ADL

The food industry is not a monolith but a complex, global network of people and organizations.

2 "Net zero ingredients" are ingredients for which an overall balance is achieved between the GHGs they create and the emissions removed from the atmosphere (e.g., through the plantation of trees or other systems that sequester carbon from the air).

Twist in lawsuit against QuasiMed pursuant to adverse effects in CoolDowna drug

13 May 2037

A few weeks ago, we, patient defense group Patients International, announced that we were pressing charges against US pharmaceutical giant QuasiMed. The charges follow a number of adverse effect reports associated with its new drug CoolDowna, designed to alleviate the symptoms of heat stroke.

For the past decade, QuasiMed has emerged as a leader in immunization, anti-seizure medication, and consumer healthcare. Its competitive advantage has come from its cutting-edge use of synthetic biology to manufacture substitutes for natural ingredients that have become expensive or difficult to procure. In recent years, QuasiMed has outsourced the manufacturing of synthetically produced biological ingredients to specialty suppliers. This was a result of Quasimed's effort to rationalize its manufacturing footprint by closing off plants, thus freeing CAPEX for other projects. It also allowed the pharma giant to offload part of its compliance risk onto its suppliers.

Over the past year, our tireless team has collected compelling clinical evidence of significantly reduced efficacy and adverse side effects in QuasiMed's CoolDowna. The latest findings indicate that a synthetically produced ingredient of CoolDowna, manufactured by supplier Synthetixia, is at fault. Our investigation suggests a disruption of the cold chain may have caused the organic ingredient to degrade, significantly altering its properties. The causes of failure in Synthetixia's quality control remains obscure, but it has been alleged that the supplier's compliance teams lacked the capacity to adequately address the very long list of QuasiMed's requirements. QuasiMed is known to impose excessive contractual terms upon its suppliers, especially with regards to its new policies on supply chain resilience and sustainability. QuasiMed's bargaining power is such that its suppliers have little choice: either align by investing heavily to keep up with requirements or disappear.

For Synthetixia, ballooning costs in R&D, compliance and logistics proved too much. Unfortunately, as the biotechnology industry becomes increasingly consolidated and margins are under pressure everywhere, we expect to witness such lapses more and more frequently. Regardless, we at Patients International remain committed to protecting our members in this new era of biotechnology, shining a light on the facts, and holding those that are responsible accountable.

Projection 2: Lonely at the Top

A handful of leaders are investing heavily in adaptation, imposing drastic changes on their entire value chain, which often struggles to keep up. As a result, actors with fewer resources make compromises, cutting corners on quality or price. Ultimately, this affects the leaders themselves and their reputations. To explore this issue, we focused on a lawsuit against a giant in the SynBio industry and the revelations about the involvement of one of its suppliers.

How did we get here?

Forward-looking companies with cash reserves have prepared for the future, betting on a much broader societal and economic move toward adaptation. However, most consumers have not kept up with that trend, largely due to competing priorities, such as rising inequality and higher living costs.

The international economy

Globalized supply chains and the international division of labor continue, albeit disrupted by geopolitical conflicts and climate change impacts. Manufacturing hubs migrate to less vulnerable locations within countries, away from coasts and typhoon-prone regions. Some industrial relocation to developed countries takes place, aided by generous government subsidies.

Society

Regarding many social structures — such as labor, education, care, and family — a two-speed society emerges. Ecosystems organized around powerful, global supply chains transform fastest: large industrial hubs and cities are reengineered to limit heat, build shelters, and protect mobility. Working hours are adapted both for these urban employees and their children at school, who also receive preventative healthcare. At the same time, communities on the periphery of global trade, especially in rural areas, do not undergo significant change.

Winners & losers

There is major consolidation in pharmaceuticals, automotive, electronics, and consumer goods industries like fashion and personal care — as only those firms with the money to invest in adaptation survive. Leading companies reap the benefits of their adaptation investments and have locked in their suppliers, thus gaining a competitive advantage.

Cultural shift

In developed countries, there is a growing cultural polarization between those who embrace a shift in norms, lifestyle, and consumption habits and those who resist that shift — further feeding the "culture wars."

Impact on the source/make/protect/sell model

- **Source.** Customer demand for goods made from **rare raw materials** including critical metals (lithium, cobalt, tellerum), rare earths, and crops (bananas, cocoa) has remained high. In particular, the fruit, meat, and dairy industries have been compelled to maintain their product range despite rising pressures from climate change. Ingenious ways to procure these crops bloom, such as with **vertical farming.** There is a growing lobby for **SynBio** to be applied in agriculture to help grow resilient species while meeting the unchanging preferences of consumers.
- **Make.** Constraints on manufacturing operations and processes in many sectors (automotive, electronic goods, pharma, food and beverage) have increased. Manufacturers must develop **resilience** in the face of power cuts and resource/workforce shortages, as well as **challenging working conditions,** such as extreme heat. When it comes to products, manufacturers have to compromise on other metrics, including quality and price, leading to **brand reputation** issues. Other manufacturing sectors that are globally integrated, such as **construction and defense,** continue to prioritize productivity and profitability, while **services** (including personal care, education, hospitality, and transportation) provided locally are not subject to the same pressures and are therefore slower to adapt.
- **Protect.** Leading businesses have mandated that their partners' and suppliers' **assets be protected or insured** against the main climate risks. Those companies unable to comply are no longer in business, including many in previously manufacturing-heavy regions in South/Southeast Asia and Central America.
- **Sell.** Disconnects between companies' visions and customer preferences have led to **commercial failures,** such as Tesla's amphibious car, making firms wary of disruptive product innovation. In a world of fragmented demand, players benefit from serving strong **affinity niches,** such as red meat eaters. Solutions that can help sense contradictory demand signals in an accurate and timely manner therefore become extremely valuable.

Lonely at the Top: The promise of SynBio

In 2040, the leading global life sciences companies are "lonely at the top." They have invested earlier than others into R&D for SynBio, as well as for components not usually produced in a fermentation setting. As supply chain disruptions and extreme weather events endanger global supplies of natural drug ingredients and raise the costs of raw materials, they remain resilient to shocks, further enhancing their competitive advantage. Those impacted by the growing disruptions of climate change have no choice but to adapt, and one sustainable approach to doing so is by implementing SynBio. The ability of SynBio to provide substitutes for climate-vulnerable ingredients has been demonstrated since the early 2000s. Since its foundation in 2003, California biotechnology start-up Amyris has used SynBio to produce artemisinin, the active pharmaceutical ingredient in antimalarial drugs. Artemisinin is traditionally derived from the sweet wormwood plant, a wetland plant whose distribution area will be negatively impacted by rising global temperatures.[1] By engineering yeast to produce artemisinin, Amyris has been able to create a more stable and sustainable source of this critical drug component. In a world of flooding and warmer waters that drive increases in malaria cases (+5 million cases; i.e., +2% globally from 2021 to 2022[2]), SynBio helps address pandemic risk by providing climate-resilient alternatives for effective treatments.

In 2019, Roche partnered with Boston, Massachusetts-based Gingko Bioworks to develop a more sustainable production method for oseltamivir phosphate, the active ingredient in its antiviral drug Tamiflu, a critical and widely used drug for the treatment of Influenza A and B. Oseltamivir phosphate is currently derived from shikimic acid, which is extracted from the Chinese star anise plant. This plant is vulnerable to climate change, and its supply has been affected by extreme weather events, including the 2010 droughts in Guangxi and Yunnan. By engineering bacteria to produce shikimic acid, Ginkgo Bioworks aims to create a more reliable and sustainable source of this essential drug component, helping to ensure Tamiflu's continued availability.

Other life science giants have shown interest in SynBio research as well. In 2018, Bristol Myers Squibb entered into a research collaboration with the biotechnology company Synthorx to develop novel immunotherapies using Synthorx's SynBio platform. This platform, called the "Expanded Genetic Alphabet," allows for the incorporation of non-natural amino acids into proteins, which can potentially lead to the development of innovative therapeutics with improved properties. In 2020, Pfizer participated in a $300 million funding round for Zymergen, a company that uses machine learning (ML) and SynBio to engineer microorganisms for the production of various chemicals and materials.

Previous investments in SynBio biology pay dividends in shielding life science companies against future disruptions in supply and skyrocketing ingredient prices. They also hold much promise as a competitive edge in developing a wide range of new products with sought-after properties, sustainably and at an attractive cost. The SynBio market grew at 20% per annum to 2030 overall,[3] driven by sustainability concerns but also by healthcare needs, demands for manufacturing efficiency, and (on the supply side) increasing investment, low technology costs, and growing ecosystems.

The benefits and potential gains that SynBio offers are clear. However, companies must have a well-defined strategy in place to successfully implement it. Key considerations are investing in the right technologies for scale-up and cost-efficiency and ensuring sufficient production capacity. Given the diversity of SynBio, companies should carefully consider which specific fields are relevant for their business and conduct realistic market-based assessments. With an ever-increasing acceleration in technology developments, timing is a further key consideration. *(For more about SynBio, see the ADL Blue Shift Report "The Brave New World of Synthetic Biology.")*

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Dr. Franziska Thomas, Partner, Healthcare & Life Sciences Practice, ADL

1 Wang, Danyu, et al. "Global Assessment of the Distribution and Conservation Status of a Key Medicinal Plant (Artemisia Annua L.): The Roles of Climate and Anthropogenic Activities." *Science of The Total Environment*, Vol. 821, May 2022.
2 "World Malaria Report 2023." World Health Organization, 30 November 2023.
3 Meige, Albert, et al. "The Brave New World of Synthetic Biology." ADL Blue Shift Report, 2024.

“The Forest Spirit gives life and takes life away. Life and death are his alone.”

— Moro, *Princess Mononoke*

GREEN undercover
n°127 08/04/2047

Climatic nonsense (again)

In its relentless pursuit of saving the world from climate decline, humanity occasionally runs into dead ends. Green Undercover has infiltrated adaptation initiatives in Bangkok, Thailand – with surprising findings.

All started with good intentions, in what appeared to be a genuine attempt at harnessing both biology and technology to protect communities.

Let's rewind. In 2044, the low-lying Bangkok megalopolis is as vulnerable as ever to sea level rise. Bangkok was built on the delta of the Chao Phraya River. Rapid urban development in the 1990s and 2000s all but annihilated the mangroves that once covered the shoreline of the Upper Gulf of Thailand, leaving coastal settlements directly exposed to sea level rise.

As communities were evicted from their inhabitable homes, violent tensions simmered – reaching a breaking point in the infamous 2033 riots.

The municipality of Bangkok responded with an ambitious plan to revitalize the delta, including replanting mangroves on a large scale – mobilizing a large workforce and drones for seeding.

Ten years later, results were starting to show, with lower rates of coastal erosion and restored fauna and flora.

Unfortunately, this strategy is being derailed by… a grain of salt. Actually, a few tons of it.

In an effort to secure access to freshwater for irrigation, a group of peri-urban farms has built a desalination plant in a neighboring municipality at the eastern edge of the delta.

> **“ desalination plants produce freshwater, they also release brine ”**

Indeed, repeated droughts and lack of governance over groundwater extraction have severely depleted the freshwater supply, and desalination was perceived as a quick, albeit expensive, fix.

Yet, while desalination plants produce freshwater, they also release brine, a hyper-saline mixture of extracted salts and metal compounds which, little by little, spreads across the delta, throwing off the delicate balance of the ecosystem. Mangroves have started dying in droves.

With no constraining regulation in place and limited means for cross-jurisdictional adjudication, it’s anyone’s guess how the trade-off between freshwater and protection from the sea will be resolved.

In Bangkok and elsewhere, local adaptation governance appears critical to align stakeholders. Otherwise, we may just end up pouring salt on the wound… ■

JULIE ICRE,
GREEN UNDERCOVER

Projection 3: Wild Green West

In a world without regulations to ensure coordination and alignment, well-intentioned adaptation initiatives often collide and can become counterproductive, or worse. To illustrate this tension and highlight the potential consequences, we chose the format of investigative journalism. The fiction unveils a local scandal centered on a crucial issue: water management.

How did we get here?

Governments are still focusing on mitigation, with a fear of imposing further heavy costs on industries around adaptation. This has led to a lack of globally agreed-upon regulations/practices to promote or impose adaptation to climate change. We see a market-driven approach to climate change adaptation, with businesses voluntarily investing to remain competitive.

The international economy

Leading companies invest in advanced adaptation technologies to protect their businesses from disruption by extreme climate events. In contrast, poorer and more vulnerable regions (e.g., Southeast Asia) struggle to access investment, due to the lack of strong institutions with the necessary manpower, data, and know-how to structure bankable adaptation initiatives. Business investment in climate change adaptation shows benefits, but the lack of societal focus on equality and long-term planning results in a lack of coordination and negative externalities. Such costs not only burden communities but also impact private companies, hindering overall progress toward sustainable and inclusive growth.

Society

A growing split emerges between generations: one prioritizes innovative new ways of living, while the other strives to maintain traditional lifestyles. Reliance on international and national government support diminishes, with private sector companies, regions, and local communities taking more of the initiative.

Winners & losers

Due to a lack of regulation, sectors that are strategically important (e.g., agriculture, energy, and coastal real estate) or have higher economic returns receive more investment than others, leading to crucial areas like biodiversity and public safety being neglected.

Cultural shift

The overwhelming focus on creativity as a catalyst for technological progress, in the absence of robust regulation, has led to ethical dilemmas and debates over moral standards. The consequences of unchecked innovation could have devastating effects, reshaping cultural and political mentalities.

Impact on the source/make/protect/sell model

- **Source.** The race to secure resources drives innovation in supply chain management but also prompts concerns over **resource monopolization and environmental degradation.** Companies invest in **desalination infrastructure** to secure water availability as well as **local grids** to secure productivity. With support from **local funds,** larger agricultural businesses invest in adaptation technology, such as **precision irrigation, vertical farming, and sensors for monitoring.**
- **Make.** We see creative adaptations in manufacturing processes to enhance their **efficiency and productivity,** mainly within sectors with high raw material and/or electricity costs, such as **heavy industries, automotive, and metal/chemical production.** With higher raw material prices, manufacturing companies need to focus on **cost optimization** in their production lines (e.g., by reducing machine time, increasing standardization, and improving resource efficiency).
- **Protect.** Companies invest independently to protect their assets, leading to a **wide range of solutions** with varying degrees of effectiveness, such as **predictive weather tools** and the use of **advanced materials.** Nature-based solutions, where ROI is challenging to quantify, are less likely to be supported by traditional financial strategies.
- **Sell.** Industries directly engaged in adapting to climate impacts thrive and introduce **new goods and services.** For example, the construction industry specializes in **resilient building technology,** the water management industry focuses on **water conservation/recycling,** while agriculture develops **drought-resistant crops and precision farming techniques.**

Wild Green West: Integrating mobility into the energy ecosystem

By 2040, the individual mobility industry, driven by private investment and minimal regulation, has continued to innovate, achieving enhanced performance, fuel efficiency, and the development of new vehicles for alternative fuels. Zero-emission vehicles, primarily electric, then hydrogen, make up most of the market, comprising 50%-75% of sales. However, in regions where natural disasters and energy supply disruptions are increasingly common, fuel choices face heightened scrutiny. Alternative fuels present different trade-offs in terms of fuel access, fire risks, and vehicle-to-grid (V2G) power capabilities.

As weather emergencies become more frequent, access to fuel is crucial for maintaining daily mobility. Electric charging stations are expected to proliferate, forming dense networks in developed countries. However, events like Hurricane Sandy in 2012, which rendered 15% of electric charging infrastructure in affected areas of the Northeastern US inoperable due to outages and flooding, are becoming more frequent.

Electric vehicles (EVs) offer unique benefits in emergencies, such as powering local grids or hospital generators for a short period of time. During the 2019 California wildfires in the US, Pacific Gas & Electric (PG&E) used Tesla Powerwall batteries, on which the maximal-charging "Storm Watch" mode had been activated, to supply temporary power to affected communities.[1] Similarly, V2G charging helps deliver electricity in the event of weather-induced blackouts. The city of San Diego, California, is experimenting with a pilot program to enable bidirectional charging with school buses.[2] PG&E CEO Patricia Poppe has supported V2G charging to prevent blackouts, bolstering efforts by General Motors to add this capability on most of its vehicles, which it provided early on Ford's F-150 Lightning.[3]

Volatile weather events, including floods, extreme temperatures, and wildfires, present trade-offs for alternative fuel vehicles. Extreme temperatures can cause batteries to degrade more quickly and require energy for temperature regulation, reducing driving range and efficiency. And while EVs tend to be less fire-prone than their conventional or hybrid counterparts (the US National Transportation Safety Board reports that EVs have been involved in approximately 25 fires per 100,000 sold in the US compared to 1,530 gasoline-powered and 3,475 hybrid vehicles[4]), fires in EVs are more challenging to extinguish. High-voltage lithium-ion batteries are at risk of thermal runaway, leading to intense, prolonged fires with pollutants and reignition risks. Hydrogen cars are more resilient to fires, as hydrogen is lighter than air and burns at a lower radiant than gasoline, reducing sustained fires and secondary fire risks. However, hydrogen cars present a (low) risk of explosion at critical concentrations of air and hydrogen. Moreover, hydrogen flames tend to be harder to detect, complicating emergency response efforts.

As a result of these trade-offs, the most resilient fleets by 2040 will employ a mixed-vehicle strategy. Large public and private fleets were early to adopt this approach. For example, Los Angeles and San Francisco committed to greening their fleets with a mix of alternative fuel vehicles, including electric, hybrid, natural gas, and hydrogen. By 2040, the mix has become electric or hydrogen-only, due to California's zero-emission mandate. The US Army invested in hydrogen fuel cell technology, such as the Chevrolet Colorado ZH2, while the Navy has deployed EVs for on-base transportation and logistics. Amazon ordered 100,000 delivery vans from Rivian back in 2022 as well as testing Daimler Truck's Mercedes-Benz hydrogen fuel-cell trucks in Germany.

1 Lambert, Fred. "Tesla Activated 'Storm Watch' for 'Hundreds' of Powerwall Owners over California Fires." Electrek, 11 June 2019.
2 "Current V2G Projects." San Diego Gas & Electric (SDGE), accessed May 2024.
3 Melendez, Lyanne. "PG&E CEO Proposes Using Electric Cars to Send Power Back to Grid to Prevent Blackouts." ABC7 San Francisco, 8 August 2023.
4 Weil, Gina. "Data Shows EVs Are Less of a Fire Risk than Conventional Cars." Fairfax County, Virginia, Office of Environmental and Energy Coordination, 12 February 2024.

To build systemic resilience to climate impacts, deep collaboration between EV manufacturers and local grid providers is essential. In 2016, Nissan and Italian utility company Enel launched the first large-scale V2G project in Denmark, integrating EVs into the national grid. The project installed 10 V2G units at the Danish utility company Frederiksberg Forsyning's headquarters, allowing EV owners to connect their vehicles to the grid and sell excess energy during peak demand periods, stabilizing the grid while providing an additional revenue stream for EV owners. Meanwhile, V2G options in the US garner significant interest for commercial EVs.

To prepare for this (and other possible) futures, company leaders must maintain a broad perspective. This includes looking beyond short-term impacts and starting to prepare for the new world as structural changes begin to significantly reshape the business environment. It also implies looking beyond obvious trends and reassessing major areas of uncertainty and their implications. Decision makers will need to shape scenarios, make swift no-regret moves, and develop strategic insurance to mitigate unwanted scenarios. This requires embracing uncertainty and embedding it into decision-making: developing capabilities for scenario development and monitoring of trigger events, adjusting strategic and operational planning and related governance mechanisms, and shaping corporate culture so employees feel empowered to deal with uncertainty. Then, companies will be able to leverage digital technologies to improve intelligence and increase agility and responsiveness. *(For more information on navigating this increasingly uncertain environment, see the ADL publications "Embracing Uncertainty, Driving Growth," "Electrifying the Future," "Truck Electrification — Profit Booster or White Elephant?," "Driving Profitability in US Public EV Charging," and "The Relevance of EV Battery Swapping in Emerging Markets.")*

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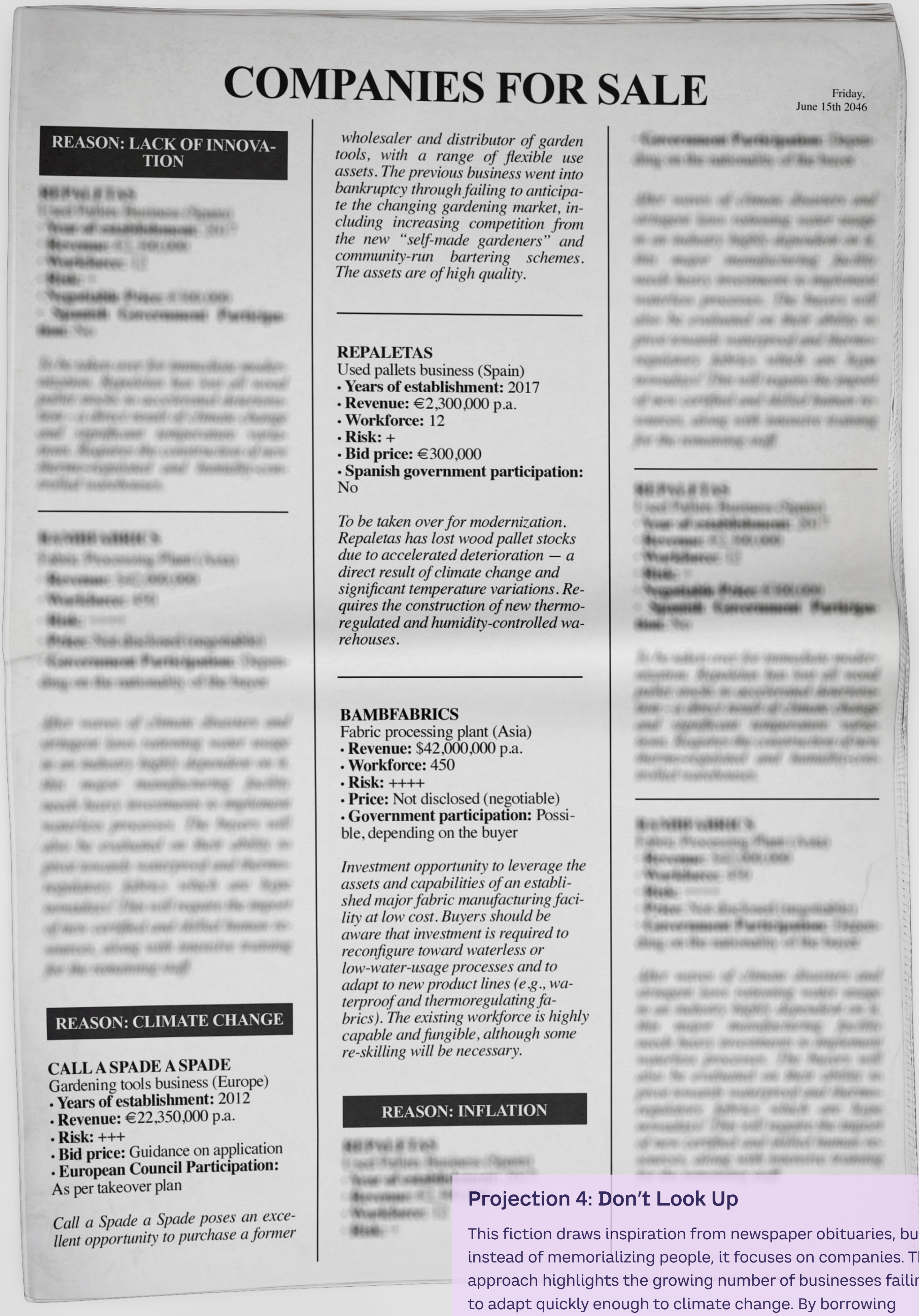
Marc Wiseman, Senior Advisor, Automotive Practice, ADL

As weather emergencies become more frequent, access to fuel is crucial for maintaining daily mobility.



COMPANIES FOR SALE

Friday,
June 15th 2046

REASON: LACK OF INNOVATION

wholesaler and distributor of garden tools, with a range of flexible use assets. The previous business went into bankruptcy through failing to anticipate the changing gardening market, including increasing competition from the new "self-made gardeners" and community-run bartering schemes. The assets are of high quality.

REPALETAS
Used pallets business (Spain)
- **Years of establishment:** 2017
- **Revenue:** €2,300,000 p.a.
- **Workforce:** 12
- **Risk:** +
- **Bid price:** €300,000
- **Spanish government participation:** No

To be taken over for modernization. Repaletas has lost wood pallet stocks due to accelerated deterioration — a direct result of climate change and significant temperature variations. Requires the construction of new thermoregulated and humidity-controlled warehouses.

BAMBFABRICS
Fabric processing plant (Asia)
- **Revenue:** $42,000,000 p.a.
- **Workforce:** 450
- **Risk:** ++++
- **Price:** Not disclosed (negotiable)
- **Government participation:** Possible, depending on the buyer

Investment opportunity to leverage the assets and capabilities of an established major fabric manufacturing facility at low cost. Buyers should be aware that investment is required to reconfigure toward waterless or low-water-usage processes and to adapt to new product lines (e.g., waterproof and thermoregulating fabrics). The existing workforce is highly capable and fungible, although some re-skilling will be necessary.

REASON: CLIMATE CHANGE

CALL A SPADE A SPADE
Gardening tools business (Europe)
- **Years of establishment:** 2012
- **Revenue:** €22,350,000 p.a.
- **Risk:** +++
- **Bid price:** Guidance on application
- **European Council Participation:** As per takeover plan

Call a Spade a Spade poses an excellent opportunity to purchase a former

REASON: INFLATION

Projection 4: Don't Look Up

This fiction draws inspiration from newspaper obituaries, but instead of memorializing people, it focuses on companies. This approach highlights the growing number of businesses failing to adapt quickly enough to climate change. By borrowing the solemn tone of obituaries, we underscore the urgency and severity of economic losses in a rapidly changing world, calling for swift and decisive action.

How did we get here?

Not all consumers are feeling the impact of climate change, meaning those who are not constrained to adapt simply do not. Insurance has not caught up with reality, and public funding for adaptation in developing countries remains limited, while private funding (including private equity) remains largely limited to projects that deliver short-term profits.

The international economy

Central banks struggle to curb inflation as the price of raw materials rises. The international division of labor remains in place, apart from a handful of critical materials (e.g., semiconductors) subject to state intervention. Local solutions are deployed in climate-vulnerable regions with access to capital (e.g., the Middle East), but do not spread elsewhere.

Society

Societies remain teetering on the brink of widespread change. Policies that promote both solidarity and climate adaptation have not been developed; hence, resistance to adaptation remains widespread, especially among groups most at risk, including farmers, hospitality workers, those in vulnerable industries or locations, and disenfranchised urban populations. Greater inequality gaps form between those who can afford price increases and those (still in the minority) who must radically change their lifestyles, such as living without a car, thus limiting their mobility. The disappearance of entire communities, towns, and landscapes due to fires, hurricanes, and rising sea levels creates large-scale trauma and challenging migration flows, both within and across countries.

Winners & losers

Asset-light companies in the digital space and companies whose manufacturing facilities are in low-risk areas reap benefits from being able to continuously produce goods, without interruptions from climate change effects. Companies that have already regionalized their production for regulatory reasons (e.g., life sciences) or due to transportation constraints (e.g., manufacturers of large car parts and construction materials) are more resilient. Manufacturers of commodity consumer goods (e.g., textiles and plastics) and smaller agricultural producers are immediately threatened.

Cultural shift

The public remains torn between adaptation to climate change and more pressing concerns, such as fighting rising costs due to inflation. Limited efforts by regulators and some industry leaders are insufficient to move the needle, feeding a sense of hopelessness and frustration.

Impact on the source/make/protect/sell model

- **Source.** Smaller agricultural producers not protected by insurance that lack the funds to invest in protection or optimization improvements face the prospect of **major consolidation. Shortages and delays** become a given — most companies focus on **managing disruptions,** as they cannot afford to limit them.
- **Make. Raw material** substitution is often needed, requiring machines that can function with a broader range of inputs. Only those manufacturers whose industrial processes are very vulnerable to increased climate events introduce new/innovative changes, albeit on a small scale.
- **Protect.** Unable to finance large-scale asset-protection projects, companies focus on **limiting/controlling damage** from the impacts of climate change. **Preventative maintenance** is also an area of focus to avoid infrastructure and machinery breaking under climate pressures. Greater focus is placed on **selecting the right site** when purchasing or building a new facility, according to multiple criteria. **Data centers,** in growing demand due to ongoing digitalization, take the prime spots. There is also increased demand for **connectivity,** with satellite links encouraged over terrestrial connections (fiber, cable) due to lower vulnerability.
- **Sell.** Remaining **affordable** is the primary concern of many industries producing mid-market products, especially in automotive. A lack of financing mechanisms causes lower readiness in key sectors, such as pharma R&D around the creation of vaccines/drugs addressing climate-borne illnesses.

Don't Look Up: Cooling for continuity

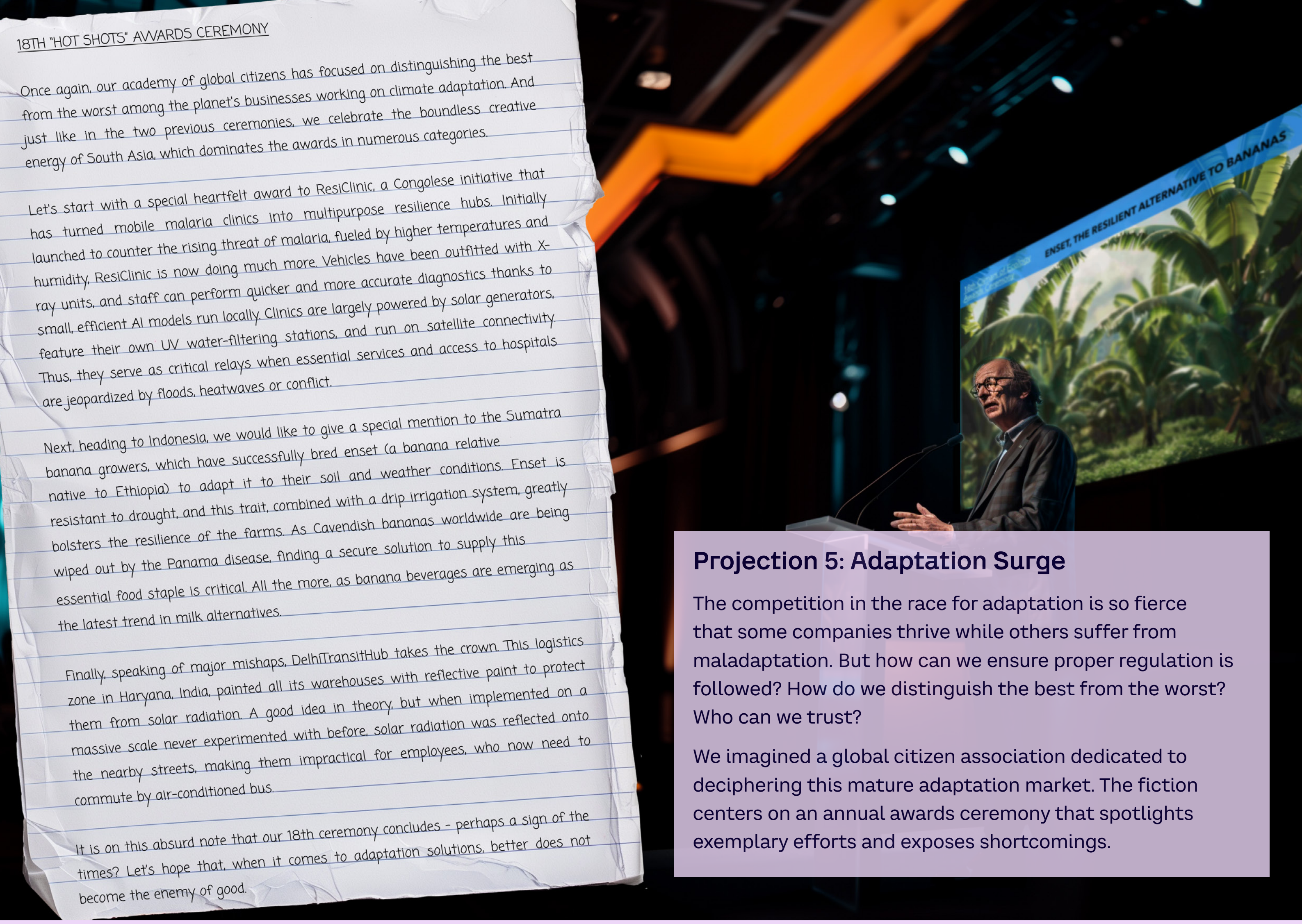
By 2040, manufacturing plants face regular production interruptions due to fluctuating energy supply, scarcer fresh water, and challenging labor conditions caused by frequent heat waves. Customer apathy and lack of investment in adaptation have slowed down systemic and large-scale changes, leaving manufacturers to cope and adjust under duress. As a result, production costs have risen significantly. Most costs have been passed on to the customer as "climate change inflation," making middle-of-the-range products like cars increasingly unaffordable for the median consumer, even in industrialized countries, and threatening entire markets. Concerns include:

- **Access to a stable, reliable energy source is critical.** In regions like India or Texas, disruptions to the electricity grid, already significant in 2024, are deeply problematic in 2040 due to damage from extreme weather and greater demands on the grid. These disruptions compel businesses to interrupt manufacturing operations for several days each year. For example, in France, in 2024, supply to industrial sites was interrupted for 10-15 days in January when residential consumption was at its highest. Manufacturers are forewarned and financially compensated by utility providers. By 2040, such arrangements have multiplied.
- **Local power generation helps compensate for variations in the grid supply.** Renewables such as wind and solar power, often implemented on-site, are largely insufficient for the needs of a manufacturing facility and intermittent by nature. Gas engine generators become more widespread. Small modular nuclear reactors, with capacities of up to 300 MWe, are considered for the largest, most demanding industries, such as chemicals. Additionally, there may be sporadic development of local energy communities to counterbalance the risk profiles of national grids, but the Don't Look Up world lacks the planning, investment, and coordination required (see the Adaptation Surge projection that follows).
- **Water is an equally critical resource.** Climate change has led to increased water scarcity and irregularities in water supply due to changing precipitation patterns and insufficient investment in water-harvesting infrastructure. This raises major concerns for critical processes, such as cooling in nuclear, metallurgical, and chemical plants. While desalination plants are an option in some coastal hubs, the release of brine restricts their installation in several areas. Maximizing efficiency in the use of available freshwater appears to be a safer bet. Water recycling technologies, such as membrane-aerated biofilm reactors, rainwater harvesting, greywater recycling, or closed-circuit reverse osmosis, which treat wastewater for reuse in manufacturing processes, are examples of innovations in this space.
- **The increased frequency and severity of heat waves worldwide, including those that are extremely humid, significantly impact working conditions.** Resulting changes in ways of working, such as shortening or moving **shifts** to cooler times, may lead to organizational issues, productivity losses, and increased labor costs. The automation and robotization of manufacturing tasks, usually implemented to streamline processes and improve productivity, also protect workers from high-temperature environments. However, automation has its limits, and not all tasks can be performed by robots. Additionally, most automated machinery relies on electronics that cannot withstand excessively hot environments (>25°C-30°C, or 77°F-86°F).
- **Investments in thermal comfort systems, hitherto considered too expensive, are likely to develop. Thermal comfort** implementations can be partial to control costs. For example, air-conditioning is installed in only the most heat-sensitive workshops, or factories are fitted with air-conditioned cabins like the Cabin Cool concept designed by Air Innovation, which directly cools air for machine-handling vehicle operators. Arguably, the most economical of thermal comfort solutions works symbiotically with heat-conscious design: improving airflow, managing exposure to the sun, and increasing the use of electric machines (e.g., electric presses) wherever relevant.
- **In 2040, reliable supplies of power and water will become leading criteria for the location of new manufacturing sites,** putting pressure on industrial hubs to secure these services for their tenants. In existing plants, companies are well advised to include adaptation in their comprehensive industrial strategy plans to ensure they can take on these challenges consistently and affordably when they arise — thus building lasting competitive advantage.

Arnaud Jouron, Managing Partner and Global Practice Leader, Performance Practice, ADL

“Some problems seem simple and turn out to be complicated, others seem complicated and turn out to be simple.”

— Cédric Villani, President of the Fondation de l’Écologie Politique



18TH "HOT SHOTS" AWARDS CEREMONY

Once again, our academy of global citizens has focused on distinguishing the best from the worst among the planet's businesses working on climate adaptation. And just like in the two previous ceremonies, we celebrate the boundless creative energy of South Asia, which dominates the awards in numerous categories.

Let's start with a special heartfelt award to ResiClinic, a Congolese initiative that has turned mobile malaria clinics into multipurpose resilience hubs. Initially launched to counter the rising threat of malaria, fueled by higher temperatures and humidity, ResiClinic is now doing much more. Vehicles have been outfitted with X-ray units, and staff can perform quicker and more accurate diagnostics thanks to small, efficient AI models run locally. Clinics are largely powered by solar generators, feature their own UV water-filtering stations, and run on satellite connectivity. Thus, they serve as critical relays when essential services and access to hospitals are jeopardized by floods, heatwaves or conflict.

Next, heading to Indonesia, we would like to give a special mention to the Sumatra banana growers, which have successfully bred enset (a banana relative native to Ethiopia) to adapt it to their soil and weather conditions. Enset is resistant to drought, and this trait, combined with a drip irrigation system, greatly bolsters the resilience of the farms. As Cavendish bananas worldwide are being wiped out by the Panama disease, finding a secure solution to supply this essential food staple is critical. All the more, as banana beverages are emerging as the latest trend in milk alternatives.

Finally, speaking of major mishaps, DelhiTransitHub takes the crown. This logistics zone in Haryana, India, painted all its warehouses with reflective paint to protect them from solar radiation. A good idea in theory, but when implemented on a massive scale never experimented with before, solar radiation was reflected onto the nearby streets, making them impractical for employees, who now need to commute by air-conditioned bus.

It is on this absurd note that our 18th ceremony concludes - perhaps a sign of the times? Let's hope that, when it comes to adaptation solutions, better does not become the enemy of good.

Projection 5: Adaptation Surge

The competition in the race for adaptation is so fierce that some companies thrive while others suffer from maladaptation. But how can we ensure proper regulation is followed? How do we distinguish the best from the worst? Who can we trust?

We imagined a global citizen association dedicated to deciphering this mature adaptation market. The fiction centers on an annual awards ceremony that spotlights exemplary efforts and exposes shortcomings.

How did we get here?

In response to recent climate catastrophes, governments worldwide enacted strict adaptation regulations, including prohibiting construction in vulnerable coastal areas, while consumers increasingly demanded action on adaptation measures. Some public sector funding was made available to support adaptation projects, but this is insufficient on its own, requiring additional finance from the private sector.

The international economy

International efforts are characterized by increased globalization in the form of cooperation on climate initiatives and technology exchange, combined with increased state intervention that focuses efforts and resources on climate adaptation. Disparities between the global North and South still exist, with unequal access to financial resources. However, with the global South being crucial to agriculture and electronics production, new ways to cooperate are developed and knowledge is shared, with large metropolises serving as the primary laboratories for adaptation.

Society

The relatively close alignment between business leaders and the public creates a catalyst for transformation, with change in daily life and basic needs. For example, food production relies on lab-grown meats and vertical farming to limit land use and water consumption, remote and digital collaboration is predominant, and electrification has spread among cars and trains.

Winners & losers

Success stories are found among risk-taking companies that rapidly develop climate adaptation technologies, particularly benefiting food and infrastructure industries, with some companies achieving near-monopoly status. As it is an extreme race, less innovative firms or those that move too slowly struggle. Industries are stuck in a pattern of "maladaptation" decline, leading entire regions to collapse, such as textiles in Bangladesh.

Cultural shift

When it comes to consumption, sobriety, localism, and resiliency are the key trends.

Impact on the source/make/protect/sell model

- **Source.** The sourcing of raw materials is affected by stricter environmental regulations and shifts in consumer behavior. Information and traceability technologies enable significant reductions in food waste. Farming practices adapt to biodiversity loss and water shortages by developing water management systems and lab-grown processes, while geo/climate-engineering techniques are developed to increase crop yields. Industries reliant on mineral extraction also face stricter regulations on their environmental impact, leading to limitations in raw material use.
- **Make.** Manufacturing processes are redesigned and now involve adaptation technologies like digital twins and predictive analytics, which require up-front investments but lead to long-term savings. Driven by consumer demand and greater regulation, the textile industry shifts to a closed-loop manufacturing process using the circular economy to minimize waste and water usage. Due to increased extreme heat waves, working hours have been adapted in exposed industries like construction. To limit operational interruptions and productivity losses, firms invest in technologies that secure their energy supply, including retractable solar panels.
- **Protect.** Insurers develop more sophisticated risk assessment models and push through incentives for climate-resilience infrastructure, leading firms to invest in measures to protect their assets. Public investments in major infrastructure (e.g., sea walls) increase to protect densely populated areas and industrial hubs. Businesses relocate their assets to areas less exposed to potential flooding or hurricanes, and any new plants and assets are built to be resilient to extreme climate events.
- **Sell.** During this extreme race for adaptation, the focus is on the speed of technology development. Market leaders invest heavily in talent and set the pace for innovation, forcing rivals to keep up or risk obsolescence. Firms must adapt to the shift in consumer preferences for "climate-appropriate" goods while ensuring product differentiation.

Adaptation Surge: Focusing on the local to drive adaptation

A key benefit of these communities is their ability to reduce exposure to the national grid, which can be vulnerable to disruptions from natural disasters and other events. By generating and consuming renewable energy locally, these communities can ensure a more reliable and resilient energy supply, even in the face of extreme weather events or other disruptions. For example, in the aftermath of Hurricane Sandy in New York, the Brooklyn Microgrid project was created to provide power to local residents and businesses even when the larger grid is offline.

Another benefit of local energy communities is their ability to use energy more efficiently through more granular demand forecasting. By analyzing local energy-usage patterns and predicting future demand, these communities can adapt and optimize their energy production and consumption to minimize waste and reduce storage costs. ML can be of considerable use in precisely forecasting demand, spotting issues, rerouting flows in the case of anomalies, and maintaining network security. This can lead to lower costs for consumers and a more sustainable energy system overall. For example, the Today Navarra Energy community in Northern Spain generates sustainable "0-mile" energy through solar panels installed on the roofs of municipal buildings, allowing approximately 5,000 homes and small businesses to save up to 25% on their energy bills.

In addition to these benefits, local energy communities also offer the ability to offload surplus energy onto the regional or national grid, further increasing the efficiency and sustainability of the wider energy system. By generating more energy than they consume during certain periods, these communities can sell excess energy back to the grid, reducing waste and increasing the overall supply of renewable energy. For example, in Germany, the sonnenCommunity project has created a network of local energy communities that can share surplus energy with each other and with the larger grid. Likewise, the El Rosario Solar Local Energy Community in Tenerife supplies the local industrial zone, households, and 20 EV charging points and can provide surplus energy to the commercial network.

Some challenges to consider when setting up a local energy community as a provider include identifying demand hot spots, designing a differentiated offering with collective benefits, and establishing the operating model. This involves defining the best times for offloading surplus-generated power and EV charging, price monitoring, and optimization — tasks for which dedicated tools can help.

Luis del Barrio, Partner, Energy, Utilities & Resources Practice, ADL

"It's people! Soylent Green is made out of people!"

— Heston, *Soylent Green*

CHAPTER

4

RESPONDING WITH TECHNOLOGY

4 Responding with technology

Common threads

In this chapter, we match technologies to the five projections described in Chapter 3 as well as identify no-regret technology choices that deliver benefits, whatever projection the future brings.

Adaptation is a highly local, multivariate, and multidisciplinary affair. Local contexts, such as weather systems, soil conditions, built-up areas and types, activities, natural resources, and geophysical conditions, vary enormously. Consequently, there are a wide range of adaptation solutions available. How they are configured and applied varies greatly between industries, regulatory environments, and geographies. (This study does not claim to be exhaustive when it comes to technology. We recommend exploring the "WIPO GREEN Database of Needs and Green Technologies" and the "WIPO Green Technology Book" to uncover the broadest possible set of technologies.)

Equally, many technologies that were not developed for adaptation nevertheless play a key role in this space. This is particularly true for the "sell" category. Here, technologies developed to capture ambiguous and fragmented demand trends and enable remote brand and shopping experiences will all serve adaptation needs. In the "make" category, solutions originally developed for visibility and resource efficiency in manufacturing are also well suited to meeting adaptation challenges.

Most adaptation technologies we surveyed are mature (technology readiness level [TRL] 7,8, or 9) — except for some analytical systems and new energy sources. Hence, lack of maturity is not a key barrier to implementation. Innovation will, however, be important for enabling the application of these technologies to specific, local adaptation needs at acceptable financial, environmental, and social costs.

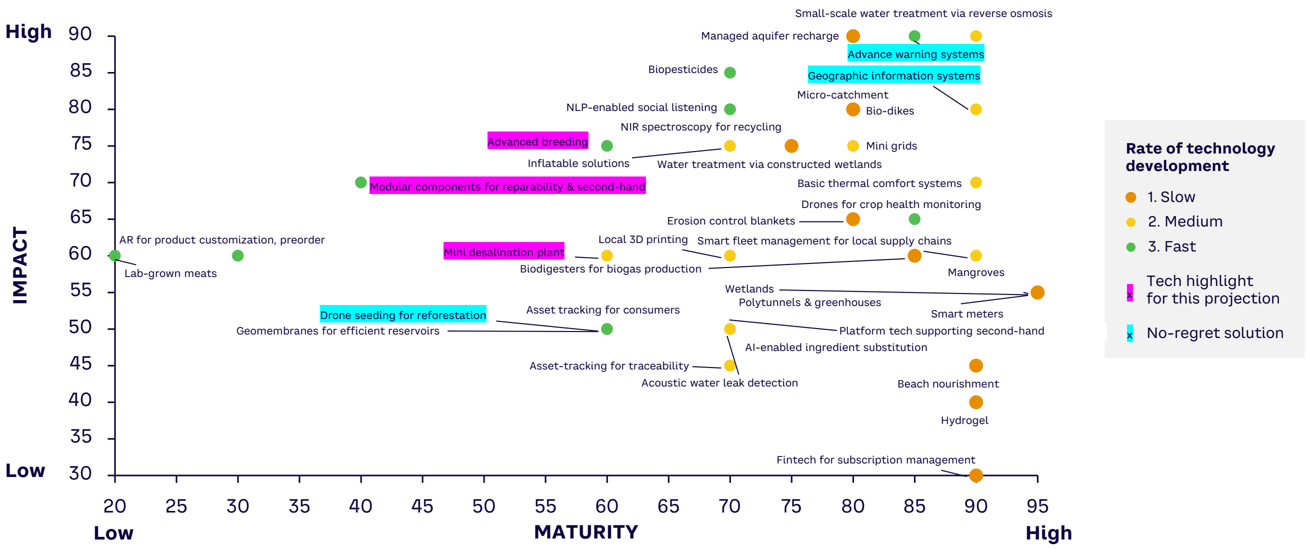
Based on the WIPO resources mentioned above, we have identified 89 technology families that respond to different adaptation challenges and are applicable to a range of different scenarios.

[Disclaimer: The matrixes used in this Report do not constitute a recommendation for any specific technologies nor do they aim to be exhaustive. Instead, they paint a picture of technologies that are likely to flourish in each specific projection.]

Green Communities

The Green Communities projection — with its high consumer behavior shift and limited financial mechanisms — lends itself to community-led initiatives and nature-based solutions, with a particular focus on the food and beverage supply chain (see Figure 7).

Fig 7 — Green Communities: Technology maturity, impact today, and rate of development



AR = augmented reality; NLP = natural language processing; NIR = near-infrared
Note: Technologies may serve several scenarios; some technologies that have arrived at maturity show low rates of development
Source: Arthur D. Little, WIPO

Functional expectations & technologies

Table 3 shows functional expectations for adaptation and potential technologies to deliver on requirements across the source/make/protect/sell categories in the Green Communities projection.

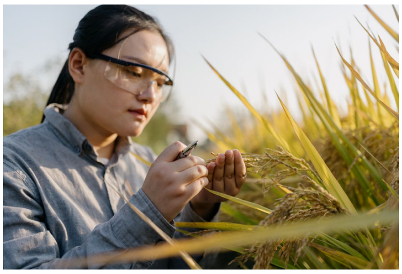
Table 3 — Green Communities functional expectations and technology

AREA	FUNCTIONAL EXPECTATION	TECHNOLOGY
SOURCE		
Water scarcity	Affordably managing/preserving water supplies; decentralizing water distribution networks & water treatment	Mini desalination plants; small-scale, decentralized water treatment via reverse osmosis or constructed wetlands; water harvesting, including micro-catchments, managed aquifer recharge, geomembranes for efficient reservoirs
Crop production	Allowing for low-cost cultivation of crops in new locations, closer to consumers; affordably boosting resilience of crops	Advanced breeding, drones for crop health monitoring, biopesticides, polytunnels, greenhouses, hydrogel
Critical materials	Systematically identifying raw materials with similar properties for replacement; making reuse & recycling business models viable	Lab-grown meats, AI-enabled ingredient substitution, near-IR spectroscopy for recycling & reuse
Disrupted supply routes	Enabling shift toward more local supply chains; managing delays & disruptions	Asset tracking for traceability, smart fleet management for local supply chains, local 3D printing
MAKE		
Energy & water usage	Identifying/adjusting energy inefficiencies; reducing water waste	Mini-grids, smart meters, acoustic water leak detection, biodigesters for biogas production
Productivity improvement	Integrating customers' adaptation demands into manufacturing processes while keeping costs low	Modular platforms allowing for repairability & second-hand market
Working conditions	Keeping workers cool & dry	Basic centralized thermal comfort systems (heat management, evaporation, A/C, shade, ventilation)
PROTECT		
Detection & alert	Predicting meteorological hazards, adjusting to conditions in real time	Early warning systems & monitoring, social media apps for information crowdsourcing in emergencies
Shielding	Minimizing or cushioning local climate impacts on production, at low cost	Nature-based solutions (e.g., mangroves, wetlands, bio-dikes), inflatable solutions to keep goods dry, drone seeding for reforestation
Remediation	Maintaining lifeline for communities during/after climatic disasters	Renewable energy-powered mobile units, satellite connectivity for disaster recovery, beach nourishment
Relocation	Facilitating relocation of key assets in lower-risk areas & to reflect shorter supply chains	Geographic information systems
SELL		
New products & services	Identifying customers' changing needs & habits; anticipating future consumption trends	NLP-enabled social listening for changing, niche consumption trends
New consumption patterns	Facilitating new business models borne out of changing consumption patterns	Online platform tech supporting second-hand products & goods, fintech for subscription management, AR for product customization & preorder
Sales channels	Supporting reconfiguration of supply chains; managing customer expectations	Asset tracking for consumers

Source: Arthur D. Little

Example technology profiles

Stress-tolerant rice varieties



- **Technology maturity level:** Medium
- **Potential impact:** High
- **Pace of development:** Fast

Firms

IRRI International Rice Research Institute, AfricaRice, CGIAR, CIAT

Why is it needed?

Rice is the primary food staple for 50% of the world's population, and environmental stresses constrain rice production, affecting about 30% of the 700 million poor in Asia who live in rain-fed rice-growing areas. In the face of climate change, rice crops must be able to withstand extreme environments like drought, salinity, flood, and submergence. In the past, this type of initiative required public funding, but since the 1970s, the knowledge has been dispersed in emerging countries' communities.

How does it work?

The International Rice Research Institute and its partners are utilizing advanced breeding techniques, specifically marker-assisted breeding, to develop extreme climate event-tolerant rice varieties. Marker-assisted breeding allows breeders to incorporate specific desirable traits into new varieties with more accuracy and speed.

What is the impact?

More than 150 global stress-tolerant varieties have been released in countries like India, Philippines, and Nepal. The average yield increase is 0.8 to 1.2 tons per hectare under drought. Plant breeders have also developed flood-resistant rice through discovery and isolation of the SUB1 gene, which allows resistance to submergence for up to 14 days, leading to a yield increase of 1 to 3 tons for a 10- to 15-day flood.

GREEN COMMUNITIES

- *Improving crop resistance without requiring state intervention*

Sources: Arthur D. Little, WIPO, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), AfricaRice.org

Solar-powered mini desalination plant

- **Technology maturity level:** Medium
- **Potential impact:** Medium
- **Pace of development:** Medium

Firms

elemental water makers, Solar Water Solutions, NEWater Bring New Life For Water

Why is it needed?

As climate change exacerbates water scarcity, these plants provide a decentralized and renewable option to augment freshwater supplies. Unlike large plants often relying on public investment, these mini plants have the advantage of being privately owned by businesses.

How does it work?

The process utilizes reverse osmosis technology. By reusing residual energy from the brine, energy input and number of solar panels can be reduced. The desalination technology can also be modified to use solar or wind energy to pump seawater into a tank positioned high on a hill. This allows the system to use gravity to provide pressurized seawater for the reverse osmosis process.

What is the impact?

The solar-driven mini desalination plants are suitable for use in off-grid rural areas, remote islands, and deserts and are delivered in a container for speed and ease of installation and maintenance. Water production ranges from 5,300 to 500,000 liters a day.

GREEN COMMUNITIES

- *Decentralizing water treatment*
- *Implementing low-tech & small-scale solution*

Source: Arthur D. Little, WIPO

Modular designs for product customization

- **Technology maturity level:** Low
- **Potential impact:** High
- **Pace of development:** Fast

Firms

MQB = Modular Transverse Toolkit; CNG = compressed natural gas
Source: Arthur D. Little

Why is it needed?

As climate change disrupts business operations (e.g., material scarcity, delivery delays), production costs are increasing, making it more expensive for end customers. Consisting of distinct components, modular products are considered an important enabler for delivering customized products competitively and extending their lifecycle by enabling second-hand sales through customization.

How does it work?

Modular design is a design strategy that splits a system into smaller modules that can be independently developed, modified, replaced, or exchanged. Each modular component is designed to be easy to assemble/disassemble due to fewer number of parts, the incorporation of fasteners to eliminate the need for screws and bolts, and standardized and interchangeable components.

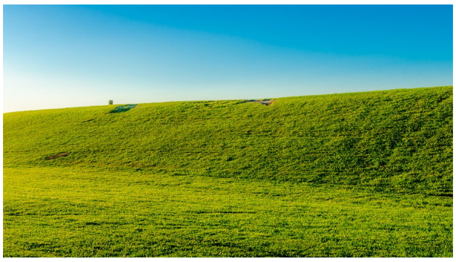
What is the impact?

Modular products allow companies to offer customers a wide range of options without hindering production efficiency. For instance, the MQB platform enables Volkswagen to offer various powertrain options, including petrol, diesel, CNG, electric, and plug-in hybrid systems within the same model from Polo to SUV.

GREEN COMMUNITIES

- *Enabling second-hand sales through customization*
- *Lowering customers' cost of ownership*

Bio-dikes



- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Slow

Communities

Practical ACTION

UMOJA CONSERVATION TRUST

Source: Arthur D. Little

Why is it needed?

As climate change leads to more frequent and severe weather events, such as heavy rainfall and storms, the risk of flooding has increased. Bio-dikes offer a sustainable and low-cost alternative to mitigate these risks and protect communities.

How does it work?

Bio-dikes are constructed using locally sourced materials, such as sand, rocks, soil, shrubs, and bamboo. Principles include maintaining an adequate riverbank slope and building a dike along that slope and length of the river using bamboo. The dike is then filled with sandbags and covered with fertile soil to provide a basis for vegetation.

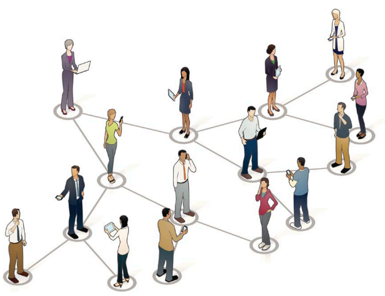
What is the impact?

By acting as natural barriers, bio-dikes help absorb wave energy, stabilize shorelines, and reduce the risk of flooding and property damage.

GREEN COMMUNITIES

- *Cushioning local climate impacts at low cost but with environment-friendly solutions*

AI-enabled social listening tool



- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Fast

Firms

Meltwater BRAND24 ARTEFACT Brandwatch

Source: Arthur D. Little

Why is it needed?

As climate change becomes a top concern for consumers globally, there is a growing expectation for brands to demonstrate their commitment to environmental responsibility by developing innovative products and services.

How does it work?

AI social listening tools utilize advanced algorithms and NLP techniques to monitor social media platforms and interpret consumer conversations, comments, and feedback. By identifying keywords, sentiments, and trends, AI social listening tools can provide real-time insights into consumer attitudes.

What is the impact?

By staying ahead of trends and understanding consumer sentiment, businesses can tailor strategy to improve competitive advantage and market positioning by enabling them to develop innovative and differentiated products.

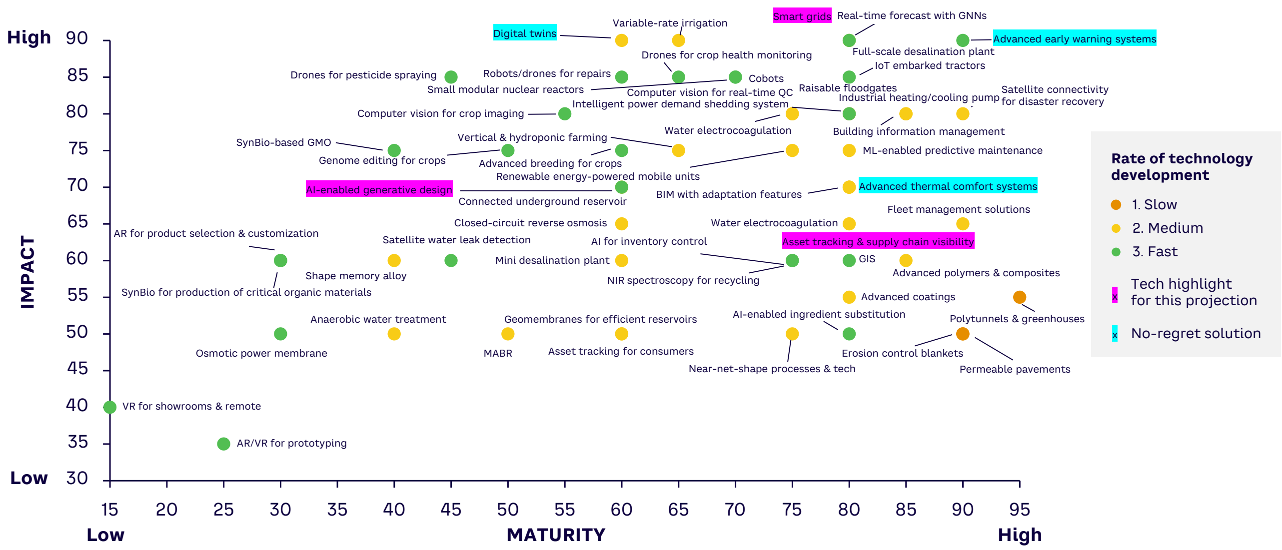
GREEN COMMUNITIES

- *Identifying customers' changing needs/habits & anticipating future trends*
- *Developing differentiated products*

Lonely at the Top

The Lonely at the Top projection — with no consumer behavior shift and high competitive pressure — prioritizes tech-heavy solutions that enable productivity gains in heavily concentrated industries (see Figure 8).

Fig 8 — Lonely at the Top: Technology maturity, impact today, and rate of development



GNN = graph neural network; QC= quality control; GMO = genetically modified organism; BIM = building information modeling; GIS = geographic information system; VR = virtual reality; MABR = membrane-aerated biofilm reactor
Note: Technologies may serve several scenarios; some technologies that have arrived at maturity show low rates of development
Source: Arthur D. Little, WIPO

Functional expectations & technologies

Table 4 shows functional expectations for adaptation and potential technologies to deliver on requirements across the source/make/protect/sell categories in the Lonely at the Top projection.

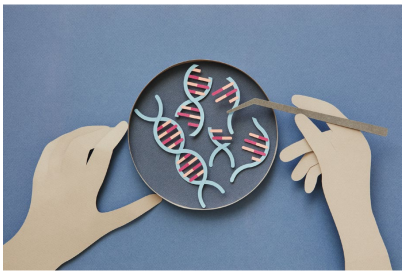
Table 4 — Lonely at the Top functional expectations and technology

AREA	FUNCTIONAL EXPECTATION	TECHNOLOGY
SOURCE		
Water scarcity	Managing lower/unpredictable water supply in industrial basins	Connected underground reservoirs, full-scale desalination plants, mini desalination plants, geomembranes for efficient reservoirs
Crop production	Growing plant species that withstand climate hazards; relocating crops while serving customer preferences	Vertical & hydroponic farming, SynBio for crops, genome editing for crops, advanced breeding, polytunnels & greenhouses, drones for data collection, computer vision for crop imaging, drones for pesticide spraying, IoT-embarked tractors
Critical materials	Identifying substitutes — cheaper, more available raw materials to maintain offerings & profitability	3D printing, near-IR spectroscopy for recycling, AI-enabled ingredient substitution, SynBio production of materials
Disrupted supply routes	Improving efficiency & reliability as supply chains reconfigure (frequent disruptions, end of "just in time")	Asset tracking & supply chain visibility platforms, AI for inventory control, fleet management solutions for more efficient & resilient routes
MAKE		
Energy & water usage	Preserving/reusing water effectively & across processes; securing access to quality & consistent power supply	Smart grids, intelligent power-shedding systems, industrial heating/cooling pump, osmotic power membrane, membrane-aerated biofilm reactors (MABR), water electrocoagulation, anaerobic water treatment, closed-circuit reverse osmosis, satellite water leak detection
Productivity improvement	Achieving adaptation as by-product of productivity improvement in manufacturing	Digital twins, collaborative robots, AI for real-time quality control, near-net-shaped techniques & supporting technologies, AI-enabled material substitution, building information management (BIM) with adaptation features, AR/VR for prototyping
Working conditions	Improving working conditions for employees & maintaining business continuity	Advanced thermal comfort systems (smart HVAC systems, insulation, building automation systems [BAS] with HVAC integration)
PROTECT		
Detection & alert	Predicting meteorological hazards; adjusting to conditions in real-time	Advance warning systems, real-time forecasting with GNNs
Shielding	Protecting sites & humans with small-scale infrastructure & construction enhancements	Raisable floodgate systems, advanced polymers and composites, advanced coatings, erosion control blankets
Resilient design	Increasing resilience of buildings & sites by design	BIM with adaptation features, shape memory alloys, advanced coatings, permeable pavements, reinforced building materials, breakaway walls, green facades
Remediation	Quickly, effectively & safely recovering production capacity lost to climate hazards	Robots/drones for critical repairs, satellite connectivity for disaster recovery, renewable energy-powered mobile units
Relocation	Supporting relocation of industrial assets to less vulnerable locations	GIS
SELL		
New products & services	Accelerating rate of product innovation to enrich existing offering while adapting to climate change	AI-enabled generative design to quickly develop adjacent product concepts
Sales channels	Better connecting with customers through adaptation narrative; enabling purchasing convenience; allowing for new modes of online customer engagement	Advanced biodegradable packaging, AR for product selection & customization, VR for showrooms & remote brand experiences, asset tracking for consumers, autonomous vehicles for delivery

Source: Arthur D. Little

Example technology profiles

Crop gene-editing using CRISPR technology



- **Technology maturity level:** Medium
- **Potential impact:** Medium/high
- **Pace of development:** Fast

Firms

pairwise, CORTEVA agriscience, Yield10 BIOSCIENCE

Source: Arthur D. Little

Why is it needed?

As a result of climate change, more crops will be affected by severe climate events, such as heat waves, droughts, floodings, and increased pests and diseases, forcing farmers to adapt how they perform business.

How does it work?

CRISPR technology works by using a guide RNA to direct Cas9 protein to a specific gene in the plant's genome. Cas9 protein cuts the DNA, allowing researchers to introduce desired changes during repair process, ultimately creating plants with improved traits for adaptation to climate change and other challenges. (Read more about SynBio in the 2024 ADL Blue Shift Report: "The Brave New World of Synthetic Biology.")

What is the impact?

It enables development of crops that can better withstand changing environmental conditions, resist pests and diseases, and utilize resources more efficiently.

LONELY AT THE TOP

- *Engineering more robust crop species*
- *Growing counter-seasonal crops*

Supply chain visibility platforms

- **Technology maturity level:** High
- **Potential impact:** Medium
- **Pace of development:** Fast

Firms

FOURKITES, project44, SHIPPEO, GOCOMET, OVERHAUL

Source: Arthur D. Little

Why is it needed?

Due to more severe climate events, such as droughts in canals and flooding of roads, there are increased risks of disrupted supply routes. Companies must invest in technologies that will enable enhanced decision-making and improved efficiency of supply chains.

How does it work?

Data from sources like IoT sensors, GPS, RFID tags, and barcodes provide real-time information on goods' location and status. This data is integrated into a centralized system for easy access and analysis. AI then processes the data, generating a layer of information on top with insights for data-driven decisions, such as optimizing inventory and improving demand forecasting. Supply chain visibility fosters collaboration, proactive issue identification, and continuous performance monitoring, leading to enhanced efficiency, reduced costs, and increased customer satisfaction.

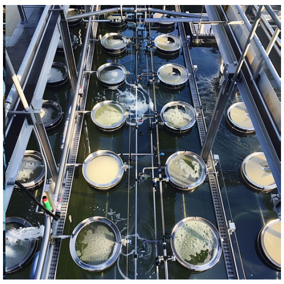
What is the impact?

Impacts include enhanced resilience to climate-related disruptions, better customer satisfaction, better decision-making of supply chain routes, improved efficiency and productivity, reduced emissions through optimized operations, and more.

LONELY AT THE TOP

- *Ensuring traceability of assets on entire supply chain*
- *Improving supply chain efficiency*

Membrane-aerated biofilm reactors (MABR)



- **Technology maturity level:** Medium
- **Potential impact:** Medium
- **Pace of development:** Medium

Firms

OXYMEM a DuPont brand, fluence, VEOLIA

Source: Arthur D. Little, WIPO

Why is it needed?

As water scarcity becomes a pressing issue due to climate change, efficient wastewater treatment technologies help conserve water resources by producing high-quality effluent suitable for reuse.

How does it work?

MABR is a relatively new technology for aerobic wastewater treatment, meaning it promotes a high rate of oxygen transfer to the microbes, which break down pollutants in wastewater. MABR uses a permeable membrane to transfer oxygen directly to these microorganisms, as opposed to the traditional method of pumping air and diffusing it in the form of bubbles. The process requires less energy and chemicals.

What is the impact?

MABR technology can be used for small and medium-sized installations, as well as the retrofitting of existing plants. MABR enables energy savings as high as 90% compared to conventional plants, making it suitable for use with alternative off-grid energy sources and decentralized treatment. MABR also allows for a 50% increase in biological treatment capacity, as well as a 50% reduction in sludge.

LONELY AT THE TOP

- *Reusing water waste effectively & across processes*
- *Reducing water waste costs*

Geographic information systems

- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Medium

Firms

esri HEXAGON Trimble CARTO

Source: Arthur D. Little

Why is it needed?

As climate change events, such as floods, sea level rise, and heat waves, affect areas where companies have their production and/or manufacturing sites, there is a growing need for companies to make informed decisions about where to relocate assets and infrastructure to be less vulnerable to climate change events.

How does it work?

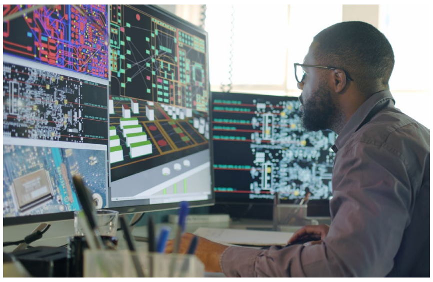
GIS works by collecting, storing, analyzing, and visualizing spatial data. The data is collected from a variety of sources, including satellite imagery, aerial photography, and ground-based sensors. GIS software allows users to overlay different layers of data, such as land use, population density, and climate projections, to identify patterns and relationships that can inform decision-making. GIS capabilities are now significantly augmented by computer vision for image analysis and machine learning for pattern recognition across a broad range of variables.

What is the impact?

By using GIS technology, companies can make better-informed decisions about where to relocate assets and infrastructure, reducing the risk of damage from climate change impacts. GIS can also help identify areas that are vulnerable to climate change, allowing for targeted adaptation measures to be implemented.

LONELY AT THE TOP	• *Identifying most favorable relocation zones*

GenAI-enabled generative design



- **Technology maturity level:** Medium
- **Potential impact:** High
- **Pace of development:** Fast

Firms

cubix. cognizant ALTAIR

Source: Arthur D. Little

Why is it needed?

In the face of climate change and evolving consumer preferences, the strategic deployment of AI-enabled generative design solutions is a pivotal tool for companies seeking to drive sustainable innovation and remain responsive to the changing market landscape. GenAI can drive innovation, especially by considering multiple adjacent combinations or unusual design options at low cost and high speed.

How does it work?

GenAI utilizes advanced algorithms and ML techniques to generate new content, such as images, text, or product designs. It involves analyzing large data sets of consumer preferences, market trends, and product attributes to identify patterns and develop sophisticated algorithms generating new designs or features. Feedback from consumers and stakeholders is incorporated into the generative AI system to refine and improve the generated products over time. (Read more about digital twins in the 2023 ADL Blue Shift Report, "Generative Artificial Intelligence: Toward a New Civilization?")

What is the impact?

It helps businesses be more agile and enables the development of new and differentiated products to position them as leaders in the transition.

LONELY AT THE TOP	• *Increasing profile of powerful industry leaders by developing products adjacent to current range*

Smart grids

- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Medium

Firms

stem SUNVERGE uplight Itron

Source: Arthur D. Little, WIPO

Why is it needed?

Storm-related power outages are happening more often. These fluctuations in supply and grid system instability are causing business interruptions, which negatively impact productivity and costs.

How does it work?

Smart grids are electricity networks that can intelligently integrate actions of all users connected to them — generators, consumers, and those that do both — to efficiently deliver sustainable, economically viable, and secure electricity supplies. Smart grids can automatically collect and store power from renewable energy sources during the day for peak-time use or when grid goes down. Smart grids can also tie together virtual power plants (i.e., networks of decentralized medium-scale power generating units and storage systems).

What is the impact?

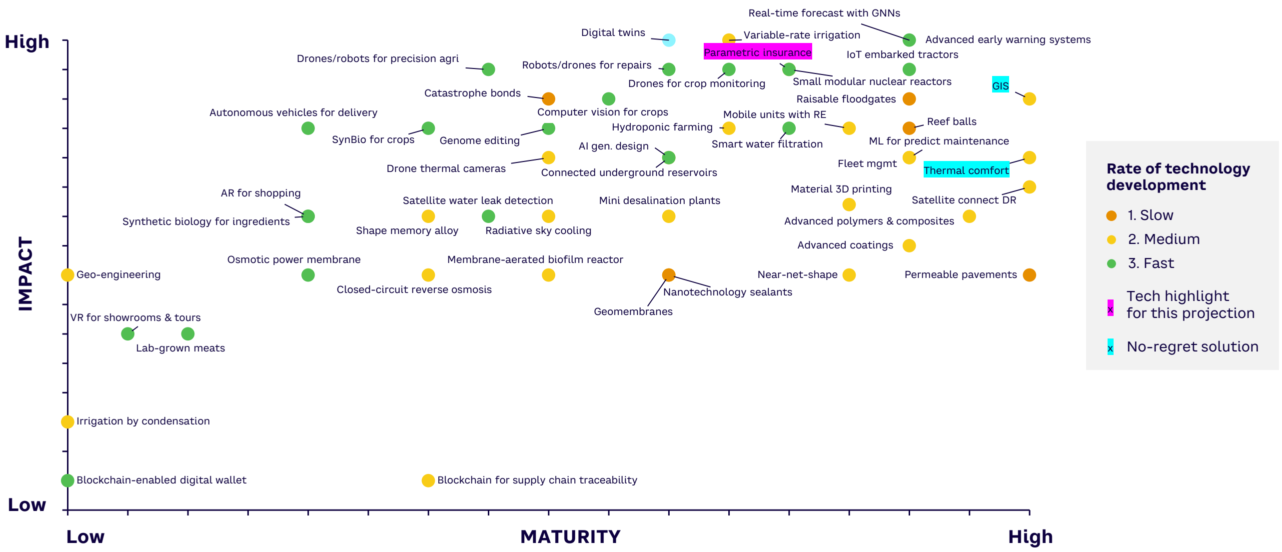
Smart grids enable industrial sites to automatically adapt to varying demand and power flows to support a more balanced network during both normal and emergency situations (e.g., extreme weather events). During periods of disruption to the grid, VPPs can shift or shed loads, supplementing large-capacity energy sources.

LONELY AT THE TOP	• *Securing access to a quality and consistent power supply* • *Optimizing energy consumption*

Wild Green West

In the Wild Green West projection (with abundant financing for adaptation and little regulation), the doors are open to experimentation of all kinds, leading to a focus on less mature solutions with high perceived ROI (see Figure 9).

Fig 9 — Wild Green West: Technology maturity, impact today, and rate of development



RE= renewable energy; DR = disaster recovery
Note: Technologies may serve several scenarios; some technologies that have arrived at maturity show low rates of development
Source: Arthur D. Little, WIPO

Functional expectations & technologies

Table 5 shows functional expectations for adaptation and potential technologies to deliver on requirements across the source/make/protect/sell categories in the Wild Green West projection.

Table 5 — Wild Green West functional expectations and technology

AREA	FUNCTIONAL EXPECTATION	TECHNOLOGIES
SOURCE		
Water scarcity	Securing enough fresh water for irrigation, including in dry regions	Small desalination plants, connected underground reservoirs, variable-rate irrigation, geomembranes for efficient reservoirs, irrigation by condensation
Crop production	Maintaining agricultural output; satisfying consumers' preferences for availability, quality, seasonality & price	Vertical & hydroponic farming, SynBio for resilient crops, genome editing for resilient crops, computer vision for crop imaging, drones for pesticide spraying, IoT-embarked tractors, meteorological geoengineering
Critical materials	Securing continued access, such as through crop/material optimization/efficiency over substitution	Material 3D printing, SynBio for the production of rare & critical organic ingredients, lab-grown meats
Disrupted supply routes	Securing traceability in a decentralized & unregulated way	Blockchain-based traceability
MAKE		
Energy & water usage	Securing access to quality, consistent power supply; reusing water effectively & across processes	Small modular nuclear reactors, osmotic power membranes, MABRs, smart water filtration devices, closed-circuit reverse osmosis, thermal imaging via drone to identify leaks, satellite water leak detection, nanotechnology sealants
Productivity improvement	Dramatically transforming manufacturing processes to increase productivity while limiting vulnerability to climate change	Digital twins for productivity enhancement, near-net-shape & supporting technologies, ML-enabled predictive maintenance
Working conditions	Improving working conditions for employees; maintaining business continuity	Advanced thermal comfort systems (smart HVAC systems, warehouse temperature monitoring), advanced radiative cooling
PROTECT		
Detection & alert	Predicting meteorological hazards, adjusting in real time	Advanced early warning systems, real-time forecasts with GNNs
Shielding	Protecting assets against climate change	Raisable floodgate systems, reef balls, advanced polymers & composites, advanced coatings
Resilient design	Increasing resilience of buildings & sites by design	Shape memory alloys, permeable pavements
Remediation	Insuring assets against climate events at affordable premiums, quickly recovering capacity lost to climate hazards	Parametric insurance, satellite connectivity for DR, robots/drones for urgent repairs in difficult conditions, catastrophe bonds, renewable energy-powered mobile units
Relocation	Supporting relocation of industrial assets to less vulnerable locations	GIS
SELL		
New products & services	Enabling radical innovation paths; offering online customization options; accelerating prototyping & product development	AI-enabled generative design for new product concepts
Sales channels	Allowing for direct sales to support start-up style fast pace of innovation; enhancing marketing tactics for brands to connect to their audience	AR for product selection and customization, VR for immersive sales experiences that visualize the need for adaptation, blockchain-based digital wallets for commerce in climate emergencies, fintech-enabling subscription models, autonomous vehicles for delivery

Source: Arthur D. Little

Example technology profiles

Supply chain verification on a public blockchain for traceability

- **Technology maturity level:** Medium
- **Potential impact:** Low
- **Pace of development:** Medium

Firms

IBM, PAPER TALE, SAP, ORACLE

Source: Arthur D. Little

Why is it needed?
With increasing disruptions on routes due to extreme weather events, businesses want to make their supply chain more trustworthy and transparent. Public blockchains can be leveraged as a solution for verifying asset location logs, movements, and transactions. Consumers also demand visibility to make informed purchasing decisions (e.g., ethical sourcing, protection of workers, compliance with regulations).

How does it work?
By integrating blockchain-enabled supply chain verification into existing ERP and product lifecycle management systems, firms can track the flow of materials and monitor social and environmental data in real time. Data is securely recorded on a public blockchain, making it virtually impervious to tampering and bolstering trust in the process. At product final stage, consumers can easily scan an NFC tag or QR code to access a comprehensive record of its journey, including the artisans who contributed to its creation and confirmation of their compensation. Using IoT, this technology also showcases products' environmental footprint (water usage, carbon emitted, transportation).

What is the impact?
An ecosystem that captures the supply chain of a product from cradle to grave, in real time, incentivizing all members of the supply chain to be more transparent.

WILD GREEN WEST

- *Preventing/responding to supply chain disruptions with increased visibility & control of assets*

Digital twin platform

- **Technology maturity level:** Medium
- **Potential impact:** High
- **Pace of development:** Medium

Firms

RisingMax, Akila, QiO, Ansys

Source: Arthur D. Little

Why is it needed?
Climate change is leading to scarcity of critical resources, resulting in the increasing need to enable more sustainable and efficient design to reduce waste and resource consumption and to enhance energy efficiency.

How does it work?
Digital twin technology works by creating a virtual replica of a physical object or system (e.g., factories, buildings, and products). It is bidirectionally connected through sensors to transmit data from the real-world counterpart. Together with AI and advanced algorithms, data is then structured in a virtual model that can be used for simulation, analysis, and real-time monitoring, providing valuable insights that can be used to automatically optimize performance, reduce waste, and so on. (Read more about digital twins in the 2023 ADL Blue Shift Report: "The Industrial Metaverse.")

What is the impact?
Digital twins are helping businesses analyze, optimize, and reduce energy consumption, manage waste data, enable proactive maintenance, and evaluate building resilience to climate risks. Future development to cover entire supply and manufacturing chains could significantly improve business resilience.

WILD GREEN WEST

- *Creating digital replicas of physical systems to simulate & predict in advance*

Parametric insurance for agriculture

- **Technology maturity level:** Medium
- **Potential impact:** High
- **Pace of development:** Fast

Firms

AGTUALL, DESCARTES, AGVESTO

Source: Arthur D. Little

Why is it needed?
Climate change poses significant challenges to agriculture worldwide, with Asian and African farmers being particularly vulnerable. From erratic weather patterns to severe events like floods, droughts, and storms, farmers face multiple challenges in safeguarding their livelihoods.

How does it work?
Traditional insurance models often fall short in adequately addressing the unique risks farmers face. High operational costs (partly due to in-farm nature of assessing damages) often lead to unaffordable premium rates and drawn-out claims assessment processes. Parametric insurance models offer an alternative approach that delivers swift payouts based on predefined triggers, such as rainfall levels or wind speeds, eliminating the need for time-consuming claims assessments.

What is the impact?
By providing rapid payouts, parametric insurance helps farmers bounce back from weather-related losses and invest in resilient farming practices. It has the potential to act as a catalyst for increasing access to finance and could act as a de-risking instrument for crop loans and make the small-scale farmer segment more attractive for financial institutions.

WILD GREEN WEST

- *Insuring assets against climate events at affordable premiums*

Challenges for Asian farmers

Asia, home to a significant portion of the world's population, is highly dependent on agriculture for food security and economic stability. However, climate change poses a formidable threat to this vital sector. According to the Asian Development Bank (ADB), the region is particularly vulnerable, with the frequency and intensity of extreme weather events on the rise.[1] For instance, in Southeast Asia, where agriculture employs a substantial portion of the workforce, changing precipitation patterns and rising temperatures are disrupting traditional farming practices. The IPCC warns that by 2050, Southeast Asia's agricultural yield could decrease by up to 30%, exacerbating food insecurity in the region.[2] In addition to yield losses, climate change also amplifies financial risks for farmers. According to the Food and Agriculture Organization (FAO), over the last 30 years, an estimated $3.8 trillion worth of crops and livestock production has been lost due to disaster events, corresponding to an average loss of $123 billion per year.[3]

Parametric insurance: A lifeline for farmers

Traditional insurance models often fall short of adequately addressing the unique risks faced by farmers. High operational costs (partly due to the in-farm nature of assessing damages) often lead to unaffordable premium rates and drawn-out claims assessment processes. Parametric insurance models offer an alternative approach that delivers swift payouts based on predefined triggers, such as rainfall levels or wind speeds, eliminating the need for time-consuming claims assessments. This innovative insurance mechanism holds immense promise for Asian farmers.[4] By providing rapid payouts, parametric insurance helps farmers bounce back from weather-related losses and invest in resilient farming practices. Parametric insurance has the potential to act as a catalyst for increasing access to finance for Asian farmers. It could act as a de-risking instrument for crop loans and make the small-scale farmer segment more attractive to financial institutions.

Example: Agtuall parametric insurance adoption

Agtuall, an agricultural insurtech firm, has designed a data platform that streamlines the design, distribution, and administration of parametric insurance, thus making it accessible to small-scale farmers across the world. The platform integrates weather data, satellite imagery, and ML algorithms to accurately assess climate risks and customizes insurance products to suit farmers' needs. Such data-driven approaches enhance the precision of risk assessment and facilitate a quicker design process for actuaries, thereby reducing time to market. Such an approach also enables crucial partnerships with input providers (seeds, fertilizers) and financial institutions (banks and micro-finance institutions) that act as key distribution partners. These partnerships reduce distribution costs and ultimately result in more affordable products for farmers. Since its launch in 2022, the Agtuall platform has been used to design products that have protected almost 50,000 farmers in countries such as India, Zambia, Tanzania, and Sudan.

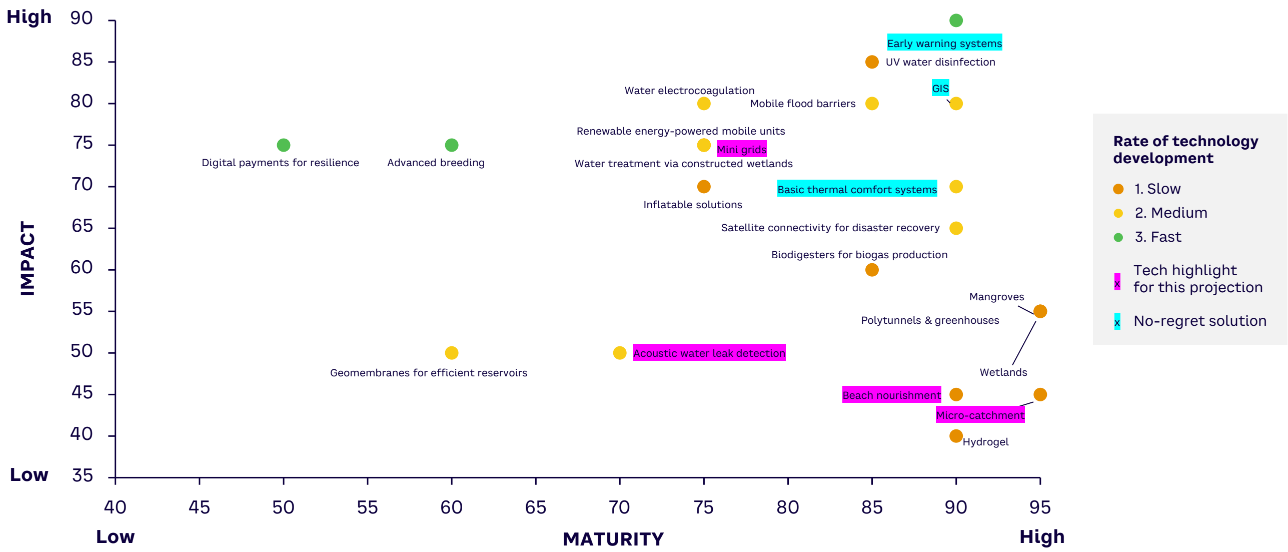
Vikram Sarbajna is founder and CEO of Agtuall BV, a Dutch insurtech company dedicated to providing affordable risk coverage for small-scale farmers worldwide. Previously, Mr. Sarbajna worked at Rabobank, a leading food and agriculture bank. He holds a master's degree in computer science from the Technical University of Delft.

1 "Climate Change Impacts Severely Impede SDGs, Says ADB-UN Report." ADB, 20 February 2024.
2 Parry, M.L., et al. (eds.). "Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge University Press, 2007.
3 "The Impact of Disasters on Agricultural and Food Security." FAO, 2023.
4 "How Agricultural Index Insurance Can Promote Risk Management and Resilience in Developing Countries." University of California, Davis Feed the Future Innovation Lab for Markets, Risk & Resilience (MRR), accessed May 2024.

Don't Look Up

In the Don't Look Up projection (characterized by limited financing for adaptation and no consumer behavior shift), technology development is constrained, focusing on cheap ways to cope and adapt (see Figure 10).

Fig 10 — Don't Look Up: Technology maturity, impact today, and rate of development



UV = ultraviolet
Note: Technologies may serve several scenarios, some technologies that have arrived at maturity show low rates of development
Source: Arthur D. Little, WIPO

Functional expectations & technologies

Table 6 shows functional expectations for adaptation and potential technologies to deliver on requirements across the source/make/protect/sell categories in the Don't Look Up projection.

Table 6 — Don't Look Up functional expectations and technology

AREA	FUNCTIONAL EXPECTATION	TECHNOLOGY
SOURCE		
Water scarcity	Offering affordable options for water preservation & treatment	Drip irrigation, constructed wetlands for water filtration, geomembranes for efficient reservoirs
Crop production	Limiting climate impacts on crops	Advanced breeding, hydrogel, polytunnels & greenhouses, inflatable solutions to protect fruit trees from hail, heat & frost
Disrupted supply routes	Managing supply chain delays & disruptions	RFID/barcodes for basic traceability of goods
MAKE		
Energy & water usage	Low-cost, local efforts to adjust to unreliable energy supply; reducing water waste by conserving & reusing water	Mini grids, biodigesters for biogas production, UV water disinfection, water electrocoagulation, acoustic water leak detection
Productivity improvement	Improving productivity; keeping manufacturing running	Collaborative robots (implemented for productivity but achieving a dual purpose with adaptation)
Working conditions	Limiting disruptions to production schedules with basic and/or localized thermal regulation	Basic decentralized thermal comfort systems (A/C cabins)
PROTECT		
Detection & alert	Predicting local meteorological impacts	Advance warning systems
Shielding	Limiting damages to assets & goods through temporary and/or low-cost solutions	Inflatable solutions to keep goods dry or protect areas, temporary and mobile flood wall barriers, mangroves, wetlands
Remediation	Effectively & cheaply repairing/recovering production capacity lost to climate hazards	Renewable energy-powered mobile units, satellite connectivity for disaster recovery, beach nourishment after coastal erosion
Relocation	Facilitating relocation of key processes to more favorable climates	GIS
SELL		
Sales channels	Decreasing costs while maintaining convenience in context of pressure on distribution routes	Digital payments for transactions amid climatic disasters

Source: Arthur D. Little

Example technology profiles

Rainwater conservation and irrigation

- **Technology maturity level:** Medium
- **Potential impact:** Medium/high
- **Pace of development:** Medium

Firms

PAVE Irrigation Systems · Naireeta Services x BHUNGROO

Why is it needed?

As climate change exacerbates water scarcity, low-capital and easily scalable solutions can revolutionize water management practices in agriculture and safeguard livelihoods in poor and vulnerable areas.

How does it work?

A simple rainwater infiltration and storage technology containing an underground unit filters, injects, and stores excess farm or stormwater. The unit top consists of a cemented pit and is installed on land where there's a slight tilt. Connected to the cemented pit is a pipe descending to a depth of up to 100 m, allowing water to be stored in coarse sand soil layers, then pumped for irrigation during the dry season.

What is the impact?

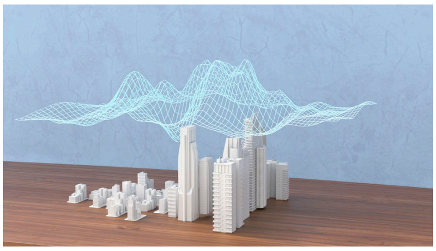
Rainwater conservation systems help save crops from becoming waterlogged during monsoons and save/collect more than 2,000 million liters per year, benefiting 15,000 farmers in India, Bangladesh, Vietnam, Rwanda, and Ghana and contributing to a more than 30% increase in farm productivity and a 22% increase in farm income.

DON'T LOOK UP

- *Implementing basic local solution for water retention*

Source: Arthur D. Little, WIPO, International Water Management Institute (IWMI)

Mini grids



- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Medium

Firms

INENSUS · GRIDLESS · AYO Tropical Technology Ltd · SUNKOFA Energy

Why is it needed?

As extreme weather event frequency and intensity increase, mini grids help secure energy supply in remote or underserved areas where traditional grid infrastructure is unreliable.

How does it work?

Mini grids consist of a network of localized power generation sources (e.g., solar panels, wind turbines) connected to distribution infrastructure to deliver electricity to nearby communities or facilities. Advanced technologies, including smart meters, energy storage systems, and grid management software, are often integrated to optimize energy production, distribution, and consumption.

What is the impact?

Mini grids provide an affordable, decentralized, and resilient energy solution that can operate independently or in conjunction with larger grids, reducing dependency on centralized fossil fuel–based power and sustaining operations even during extreme weather events.

DON'T LOOK UP

- *Implementing low-cost & decentralized energy supply alternatives*

Source: Arthur D. Little

Acoustic leak-detection system to reduce nonrevenue water

- **Technology maturity level:** Medium/high
- **Potential impact:** Medium
- **Pace of development:** Medium

Firms

fibsen · ECHOLOGICS · Digital Water Solutions

Why is it needed?

An estimated 30%-40% of water in large-scale water systems is lost to leaks. Water scarcity is increasing due to climate change, causing more extreme weather events like droughts and floods. Therefore, it becomes more important to protect and secure water in water supply systems.

How does it work?

Acoustic leak detection works by using sensitive microphones or sensors capable of monitoring the sounds of water leaks in pipelines underground, along with advanced signal processing algorithms to filter out background noise. The data is then analyzed to pinpoint the leak location, allowing for efficient repairs and water conservation.

What is the impact?

By finding and fixing water leaks more efficiently, acoustic leak detection helps save water, reduce waste, and ensure there is sufficient clean water.

DON'T LOOK UP

- *Identifying energy inefficiencies at low cost*
- *Reducing water waste & associated cost*

Note: Nonrevenue water is water that has been produced and is lost before it reaches the customer
Source: Arthur D. Little, WIPO

Mobile flood barriers

- **Technology maturity level:** Medium/high
- **Potential impact:** High
- **Pace of development:** Slow

Firms

GARRISON FLOOD CONTROL · NOAQ Flood Protection AB · FLOODCONTROL INTERNATIONAL

Source: Arthur D. Little, WIPO

Why is it needed?

Climate change will accelerate sea level rise and extreme precipitation events, which will increase the risk of flooding in areas with assets and infrastructure. Mobile flood barrier components are much lighter (about 1% of the weight) than corresponding sandbag dikes and faster to deploy.

How does it work?

A mobile flood barrier is a temporary mobile barrier made of materials such as plastic that can be rapidly deployed to protect vital infrastructure, commercial properties, and homes. Designed to be free-standing, lightweight, and easy to handle without the need for tools, it is anchored in place by utilizing only the weight of the floodwater itself.

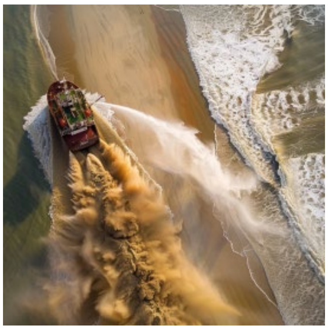
What is the impact?

Mobile flood barriers allow individuals to plan for and deal with low-level flooding, reducing damages and loss. They offer cost-effective solutions, faster response times, and minimal environmental impact, enhancing community resilience against climate change and extreme weather events.

DON'T LOOK UP

- *Implementing temporary low-cost solutions during extreme climate events*

Beach nourishment vessels



- **Technology maturity level:** High
- **Potential impact:** Low/medium
- **Pace of development:** Slow

Firms

Pacific Maritime Group · RN · Boskalis · SOUTHERN DREDGING & MARINE

Why is it needed?

Beach nourishment vessels help replenish sand on eroded beaches, providing protection against storm surges and preserving coastal ecosystems and infrastructure.

How does it work?

Dredgers collect sand from the seabed and deposit it either through floating and submerged pipelines, rainbowing, or offloading through the vessel bottom.

What is the impact?

By maintaining healthy beaches and protecting coastal communities from erosion and storm damage, beach nourishment vessels contribute to the preservation of valuable coastal assets and attractions. This, in turn, supports property values along the coast as well as local economies dependent on tourism.

DON'T LOOK UP

- *Quickly, effectively & cheaply restoring damages*

Note: Rainbowing is a process by which a dredging ship propels sand that has been claimed from the ocean floor in a high arc (resembling a rainbow) to a particular location
Source: Arthur D. Little

Digital payments applications for resilience

- **Technology maturity level:** Medium
- **Potential impact:** High
- **Pace of development:** Fast

Firms

africell · MoMo · ahli البنك الأهلي الأردني Jordan Ahli Bank · brac

Source: Arthur D. Little

Why is it needed?

In the aftermath of a natural disaster, traditional banking services or transportation networks can be disrupted. Digital payment technologies can enhance the resilience of communities and businesses by offering a reliable means of transferring funds even when physical infrastructure is damaged or in the case of limited mobility or to reduce physical contact due to epidemics.

How does it work?

During and after disaster events, mobile wallets can be used to pay those affected and response workers. Due to limited opportunities to carry out physical identification verification, unique identification numbers can be created through interagency coordination to provide users access to the digital wallets and funds. Payment cards can be issued at a later date and integrated with the digital wallets.

What is the impact?

During the Ebola crisis, digitization reduced payment times from over one month to less than a week, ending payment-related strikes from response workers with the use of apps like MoMo and infrastructure provided by Africell. Cost savings result from the elimination of double payments, payment-related identity fraud, and reduction of costs associated with physical cash transportation and security.

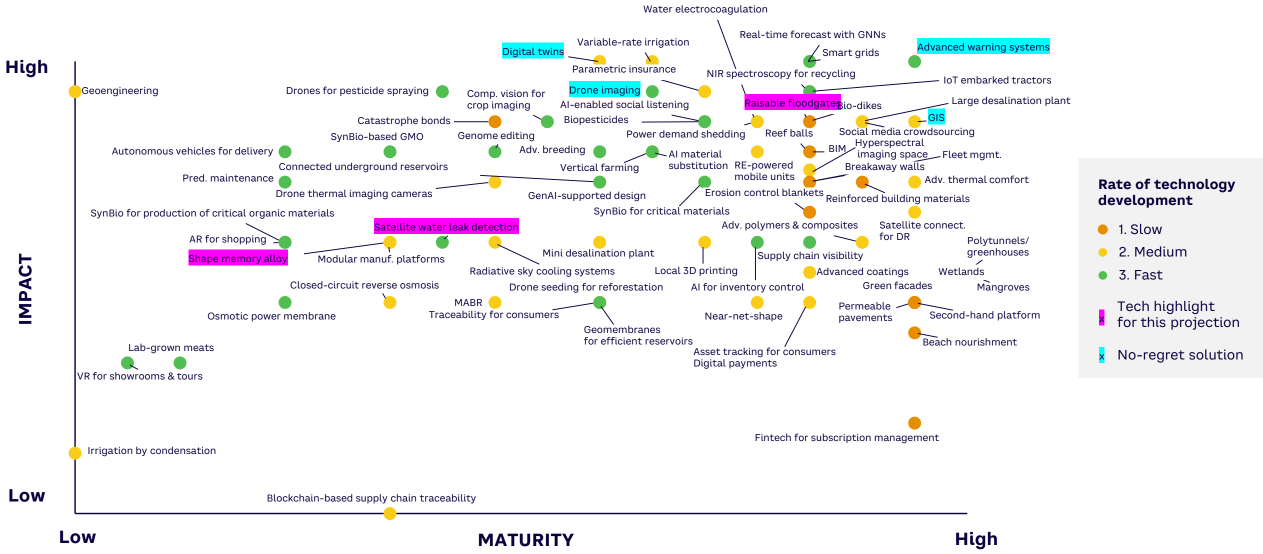
DON'T LOOK UP

- *Enabling transactions when physical contact & mobility are constrained*

Adaptation Surge

The Adaptation Surge projection — with strong competitive pressure, strong regulation, abundant financing, and massive customer behavior shift — sees most adaptation technologies flourish, particularly ones that require investment and the coordination of stakeholders. These technologies then compete among themselves, as illustrated by the complexity shown in Figure 11.

Fig 11 — Adaptation Surge: Technology maturity, impact today, and rate of development



Note: Technologies may serve several scenarios; some technologies that have arrived at maturity show low rates of development
Source: Arthur D. Little, WIPO

Functional expectations & technologies

Table 7 shows functional expectations for adaptation and potential technologies to deliver on requirements across the source/make/protect/sell categories in the Adaptation Surge projection.

Table 7 — Adaptation Surge functional expectations and technology

AREA	FUNCTIONAL EXPECTATION	TECHNOLOGY
SOURCE		
Water scarcity	Enabling long-term resilience of local water supply; maximizing efficiency in agricultural uses of water	Connected underground reservoirs, geomembranes for efficient reservoirs, full-size & mini desalination plants, variable-rate irrigation, irrigation by condensation
Crop production	Securing quality, yield & availability of crops in changing climate in sustainable manner	Vertical & hydroponic farming, GMO via SynBio, genome editing, advanced breeding, drones for crop health monitoring, computer vision for image analysis
Critical materials	Increasing use of alternative & recycled materials in response to customer demand & regulatory pressure to reduce waste	Near-IR spectroscopy for recycling, SynBio for production or critical organic materials, lab-grown meats, AI-enabled material substitution research
Disrupted supply routes	Ensuring traceability & transparency for entire supply chain; bringing production closer to markets	IoT asset tracking & supply chain visibility, blockchain-based supply chain traceability, AI for inventory control, fleet management for more efficient routes, local 3D printing
MAKE		
Energy & water usage	Securing energy supply & water availability; reducing reliance on traditional energy sources during long-term shortages & droughts; identifying & reducing inefficiencies	Smart grids, intelligent power shedding systems, osmotic power membranes, membrane-aerated biofilm reactors, closed-circuit reverse osmosis, water electrocoagulation, drone thermal imaging for leak & dysfunction identification, satellite water leak detection
Productivity improvement	Standardization & speeding up of manufacturing processes; anticipating downtime; implementing lean manufacturing	Digital twins for complex system modeling & productivity gains, near-net-shape processes & supporting technologies, IoT-based & AI-augmented predictive maintenance, modular manufacturing platforms for reparability & second-hand products & goods
Working conditions	Securing high productivity while meeting working hour regulations & increased heat waves; monitoring vital signs & environmental conditions	Radiative sky cooling systems, advanced thermal comfort systems
PROTECT		
Detection & alert	Predicting disasters & impact on exposed areas	Advanced early warning systems, real-time forecasts with GNNs
Shielding	Civil engineering to reduce vulnerabilities of communities/industrial hubs to climate change	Nature-based solutions: mangroves, wetlands, bio-dikes; drone seeding for reforestation; reef balls; raisable floodgates; erosion blankets; advanced polymers & composites; advanced coatings
Resilient design	Advanced resilient design to decrease vulnerability of assets & buildings	BIM with adaptation features, shape memory alloys
Remediation	Enhancing disaster recovery planning to ensure business continuity, minimizing downtime	Parametric insurance (including index-based), catastrophe bonds, renewable energy-powered mobile units, satellite connectivity for disaster recovery, beach nourishment
Relocation	Support with risk assessments of vulnerable/"safe" zones	GIS
SELL		
New products & services	Anticipating future consumption trends; increasing portfolio of market leaders by developing products adjacent to current range	AI-enabled social listening for consumption trends, AI-enabled generative design to quickly develop adjacent product concepts
New uses & buying patterns	Making products repurposable/more easily reparable & developing circular economy platforms, including recyclable or biosourced materials by default; offering sustainable ways of consumption	Platform tech supporting second-hand marketplaces, fintech for subscription management, AR for product customization and preorder
Sales channels	Promoting more local/informal retail networks; supporting farm-to-fork business models; relocalizing delivery networks; better connecting with customers through adaptation narrative; allowing for new modes of online engagement with customers	Advanced biodegradable packaging, VR for showrooms & tours, digital traceability for end customers, autonomous vehicles for delivery, asset tracking for consumers

Source: Arthur D. Little

Example technology profiles

Satellite-based leak-detection systems

- **Technology maturity level:** Medium
- **Potential impact:** Medium
- **Pace of development:** Fast

Firms

ASTERRA, suez

SAR = synthetic aperture radar
Sources: Arthur D. Little, WIPO, Smart Energy International

Why is it needed?

As climate change increases water scarcity, it becomes more important to protect and secure the water in our water supply systems. For businesses covering larger-scale areas, satellite-based leak-detection systems are a good solution for this compared to acoustic leak detection, which is used for smaller-scale areas.

How does it work?

Satellites capture raw images using SAR sensors. The sensors send out signals that react differently when they detect water mixed with soil. Data from the satellites is then analyzed and filtered. The location of each potential leak is overlaid onto a geographical map, allowing areas to be identified. Satellites can detect leakages up to 3 m below the surface.

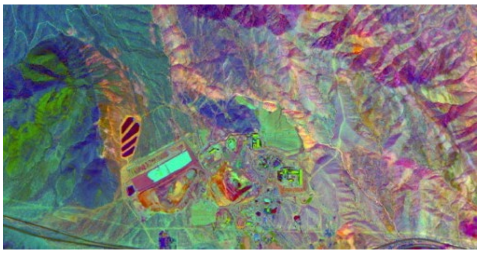
What is the impact?

By offering large-scale monitoring, satellite-based leak-detection systems enable early identification of water leaks, reducing water waste. The systems improve resource management, saving costs on manual inspections and minimizing infrastructure damage. A 38% leak reduction in municipal water networks has been reported.

ADAPTATION SURGE

- *Identifying & reducing water inefficiencies with sophisticated systems*

Hyperspectral imaging platforms in space



- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Slow

Firms

ARGOS, Globalstar, inmarsat, planet., MAXAR, ORBCOMM, iridium, AIRBUS Defence & Space, Copernicus

Why is it needed?

Climate change is causing rapid shifts in environmental conditions that are difficult to detect and monitor using traditional satellite imaging. Hyperspectral technology enables much more detailed observation of Earth's surface, allowing for early detection of subtle changes in vegetation health, water quality, soil composition, and other critical environmental factors.

How does it work?

Hyperspectral imaging captures data across hundreds of narrow, contiguous spectral bands, creating a detailed "spectral signature" for each pixel. This is achieved through advanced sensors that can detect light across a wide range of the electromagnetic spectrum, from visible light to infrared (0.4 µm to 12µm), and even microwaves. The resulting bidimensional projection of the hyperspectral image, or "data cube," contains information about the chemical and physical properties of observed materials.

What is the impact?

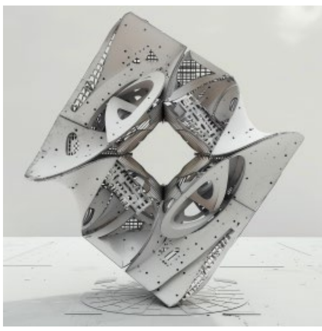
In agriculture, hyperspectral imaging allows for early detection of crop stress and precise management of resources, improving yields and reducing chemical use. For environmental monitoring, it can track deforestation, assess water quality, and detect pollution with unprecedented accuracy. In geology, it aids in mineral exploration and mapping.

ADAPTATION SURGE

- *Boosting resilience of crops*
- *Monitoring soil composition*
- *Monitoring forest health*

Sources: Arthur D. Little, World Economic Forum, European Space Agency, NASA

Shape memory alloy (SMA)



- **Technology maturity level:** Low
- **Potential impact:** Medium
- **Pace of development:** Medium

Firms

Empa Materials Science and Technology, re-fer.eu strengthening solutions

Why is it needed?

Climate change is triggering an increased frequency of natural disasters (e.g., seismic events, heat waves) that could severely damage infrastructures. SMA can help enhance structural resilience and adaptability by integrating self-repairing capabilities into infrastructures and thermal comfort by dynamically adjusting a building's configuration in response to temperatures changes.

How does it work?

SMA uses a phenomenon called the "shape memory effect," where it can undergo reversible deformation when subjected to temperature changes. At temperatures below the transformation temperature (martensite form), SMA can be deformed. When heated above this temperature, SMA can return to its original shape, "remembering" its initial (austenite) form.

What is the impact?

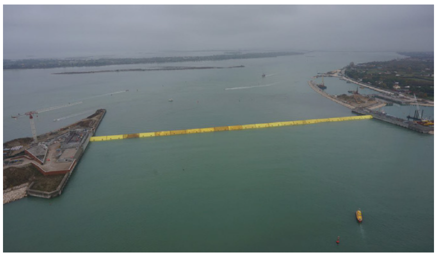
SMA offers a material-driven design approach that contributes to sustainable building practices and reduces the energy consumption required for climatization. Examples of SMAs include nickel-titanium, copper-aluminum-nickel, and iron-manganese-silicon.

ADAPTATION SURGE

- *Increasing resilience of assets & buildings with advanced design*

Source: Arthur D. Little

Raisable floodgates



- **Technology maturity level:** High
- **Potential impact:** High
- **Pace of development:** Slow

Firms

MOSE

INERO FLOOD PROTECTION

GEODESIGN BARRIERS

Source: Arthur D. Little

Why is it needed?

Raisable floodgates provide a way to protect coastal areas from flooding due to sea level rise and extreme weather events. As sea levels continue to rise, coastal areas are becoming more vulnerable to flooding, which can cause significant damage to infrastructure and communities.

How does it work?

There are different types of floodgates, some of which provide a barrier, directly in the sea, that prevents water from entering coastal areas during high tides or storm surges. The floodgates are designed to be raised and lowered as needed, allowing water to flow through when it is safe to do so and providing a barrier when necessary. The floodgates can be operated manually or automatically, depending on the design.

What is the impact?

Raisable floodgates protect infrastructure and communities from damage, reducing economic and social costs of climate change impacts as well as improving resilience of coastal areas.

ADAPTATION SURGE	• *Reducing vulnerabilities of communities & industrial hubs with advanced civil engineering alternatives*

No-regret technologies

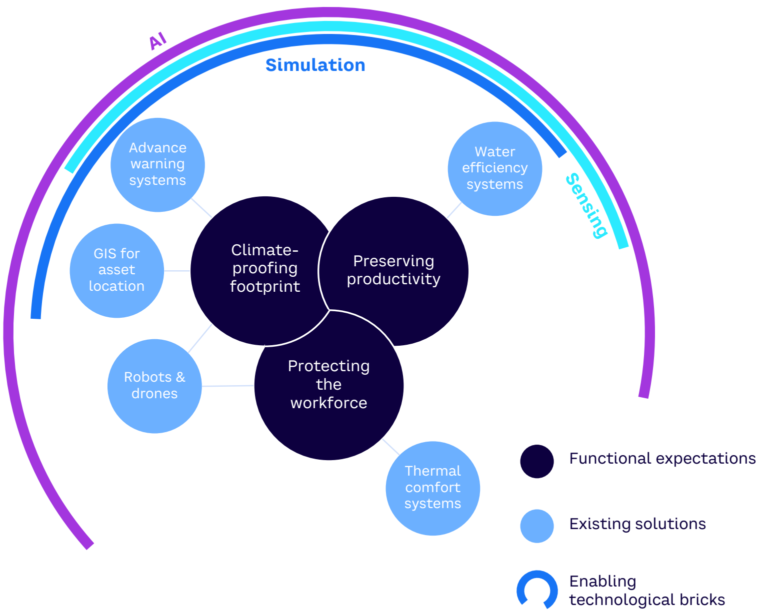
While future projections for adaptation are difficult to predict, some no-regret moves apply across industries, no matter which projection comes to pass. Three major functional expectations recur across projections: (1) climate-proofing your footprint, (2) protecting the workforce, and (3) preserving productivity, including efficiency and optimization. These are best addressed by implementing a selection of solutions, themselves enabled by general technological bricks and key capabilities (see Figure 12).

Functional expectations

As mentioned, three major functional expectations recur across projections:

1. **Climate-proofing** — involves minimizing impacts on operations across the entire value chain, protecting assets but also securing key suppliers and routes (relevant for the protect and source challenges).
2. **Protecting the workforce** — almost always involves shielding employees from future heat waves (more rarely from cold) by controlling temperatures in working environments or by robotizing tasks. It also includes, more broadly, securing decent work conditions, expertise, and schedules despite rising temperatures and risks (relevant for the make challenge).
3. **Preserving productivity** — often hinges on two key resources: power and water. Both must be used efficiently. While alternative energy sources and innovation in distribution may help maintain access to power, the lack of fresh water is much harder to remedy, hence the critical nature of water-efficiency systems. Soil health is also key for preserving agrifood productivity.

Fig 12 — No-regret capabilities, solutions, and enabling technologies



Source: Arthur D. Little

Capabilities

Meeting these functional expectations requires businesses to develop the necessary underlying capabilities to underpin climate adaptation:

- **Data science.** Deep learning expertise will be critical to accurately predicting local climate phenomena and quantifying their impact.
- **Design for scarcity.** Because technology on its own rarely suffices to solve an adaptation challenge, the ability to design solutions in a resource-constrained environment is key (e.g., redesigning airflow within a building).
- **Nimble risk assessment.** Risk assessment for climate adaptation involves significant uncertainty, hence the importance of flexibility in risk assessment methodologies, including a focus on dynamic sensing and responding approaches. Data science and AI expertise are also highly relevant.
- **Local partnerships.** Responses to climate impacts require solutions tailored to the local environment, often best supplied by local providers. The ability to identify partners and contract locally is key to an effective, timely, and affordable response.

Enabling technological bricks

Sensing technologies, digital twin simulation, and deep learning are all key enabling technological bricks of no-regret solutions:

- **Sensing technologies,** including IoT and remote sensing, allow for the precise and granular measurements of key metrics (e.g., humidity, pressure, or smoke for advanced warning systems, leaks and water pressure for water efficiency)

Innovations are dramatically enhancing our ability to monitor and understand Earth's systems.

- **IoT**
  - **Technology.** Sensors collecting data on a hyper-local scale, including humidity, temperature, vibrations, and exposure to light and wind, provide a nuanced understanding of climate impacts and underpin a nuanced response. Growth of low-energy connectivity protocols (including long range [LoRa]) and 5G make IoT increasingly attractive.
  - **Maturity** (TRL 9 — system proven in operational environment). Enables data collection for precision agriculture, including precision irrigation, monitoring of leaks in water distribution systems, and follow-up of geological risks to machines in factories. Also allows for productivity gains via the monitoring of resource spend in agriculture, manufacturing, and logistics.
  - **Future developments.** Minimally intrusive sensors fully tailored to the data needs of specific uses (e.g., vineyards); affordable international connectivity.
- **Remote sensing**
  - **Technology.** *Satellites* observing Earth and weather play a vital role in comprehensive environmental monitoring and analysis. These space-based platforms enable extensive surveillance, providing essential insights into climate patterns, land use changes, and ecological dynamics. Satellite sensors are passive or active. Passive sensors (e.g., optical/thermal sensors on Landsat OLI and Sentinel-2 MSI), capture reflected solar radiation and emitted thermal energy. In contrast, active sensors (e.g., LiDAR on ICESat-2; SAR on Sentinel-1) emit energy pulses toward the Earth's surface and record the returning signals.
  - **Maturity.** (TRL 9 — system proven in operational environment: in 2023, there were ~1,200 active satellites with the main purpose of earth observation/earth science). Wide-area monitoring already helps with applications contributing to climate action, including climate monitoring/modeling, tracking pollution, monitoring biodiversity levels, and observing oceans, fires, floods, agriculture, land use, etc. It is particularly valuable for adaptation in agriculture, forestry, and coastal management.
  - **Future developments.** Higher-resolution imagery, automated processing, and onboard AI/ML integration enable faster data analysis and reduced transmission needs. These improvements, coupled with data fusion techniques combining multiple sensors, significantly increase data availability and quality. Miniaturization and lower launch costs are expanding satellite fleets, enhancing global coverage. The resulting wealth of data feeds AI foundational models, facilitating the detection of large-scale patterns like global warming. Together, these innovations are dramatically enhancing our ability to monitor and understand Earth's systems.

- **Technology.** *LiDAR* is a method for detecting distant objects and determining their position, velocity, or other characteristics by analyzing pulsed laser light reflected from the object to the receiver.
- **Maturity** (TRL 9 — system proven in operational environment). LiDAR systems are particularly helpful in creating real-time, high-resolution 3D maps or point clouds of local environments, with multiple applications for climate adaptation, including forest monitoring and fire prevention, surveys of elevation and exposure in agriculture, or the generation of digital twins for construction sites.
- **Future developments.** Lower costs, higher resolution, and longer ranges are expected with the development of new iterations such as solid-state LiDAR and MEMS LiDAR.

- **Digital twins** enable a large range of simulation use cases by summarizing and visualizing (e.g., assessing climate impacts on a locality to help with asset localization, modeling of full industrial systems to calibrate the amount of resources needed, or prediction of possible paths of a storm)[22]
  - **Technology.** Digital twins are 360-degree virtual models representing an end-to-end real-world industrial system, including variables outside the company.
  - **Maturity** (TRL 8 — system complete and qualified). Enables supply chain optimization and firm-wide adaptation risk simulations. Also allows for productivity gains and non-climate risk mitigation.
  - **Future developments.** GenAI and advances in computing power will allow systems to simulate more possible futures based on existing ones.

Traditional physics-based models are proving slow and computationally intensive.

- **Deep learning** (specifically GNNs) enables a vast range of applications in meteorological prediction (e.g., real-time prediction), robotics (e.g., drone swarms), and more broadly a vast range of optimization problems (including resource efficiency)
  - **Technology.** Traditional physics-based models, which solve the equations underlying meteorological phenomena, are proving slow and computationally intensive. Multilayered ML models are used to augment those, notably by correcting identified biases in physical models (e.g., the direction in which storms tend to move). Some GNNs, such as Google GraphCast, boast +90% prediction accuracy versus traditional approaches.
  - **Maturity** (TRL 9 for DNN augmentation, TRL 6 for fully AI-powered forecasts). Enables real-time forecasting, localization of regional forecasts, and physics model bias correction.
  - **Future developments.** Increasing computing power and AI-generated training data sets are expected to fuel improved performance.

No-regret adaptation solutions

No-regret adaptation solutions are already available off-the-shelf, mature, or maturing fast and are likely to become broadly implemented. Among the many potential candidate technologies, we highlight advanced warning systems, GIS for asset location, thermal comfort systems, robots and drones, and water-efficiency systems as particularly important:

Advanced warning systems

- **Sophisticated climate models,** occasionally augmented by neural networks, to identify patterns and trends and predict future events
- **Real-time monitoring** of weather conditions, such as temperature, precipitation, and wind speed to provide up-to-date information on potential weather hazards (e.g., via IoT sensors)
- **Communication and outreach** efforts to inform the public and relevant stakeholders

GIS for asset location

- **Climate risk and topography assessment,** providing the ability to identify lower-risk areas by analyzing climate hazards, elevation, and topography data
- **Infrastructure and land use analysis,** evaluating infrastructure vulnerability and land-use patterns
- **Integrated resource management** (e.g., integrated coastal zone management, watershed management)
- **Proximity and demographic insights,** resource access, transportation networks, and local community impacts
- **Scenario modeling and forecasting**

Thermal comfort systems

- **Designing buildings for optimal temperature,** including exposure to light and airflow, aided by advanced materials (e.g., isolation and reflecting surfaces)
- **Redesigning processes for heat,** such as using electric power
- **Cooling systems,** including AC, cold/heat pumps, and cooling reservoirs, if energy efficient and based on renewable energy sources
- **Nature-based solutions,** such as trees in city centers to avoid heat islands, green walls, and so on

Robots & drones

- Drones for **aerial imaging and data collection**
- Drones and autonomous marine vehicles (AMV) to perform large-scale **agricultural tasks,** including seeding forests and mangroves or distributing pesticides
- Drones and AMV to perform **maintenance** of hard-to-reach assets or in perilous climate conditions
- Automation/robotization of multiple manufacturing tasks to **prevent worker exposure** to heat and other climate-induced hazards

"We now conduct much more in-depth climate risk analysis on our greenfield and brownfield developments."

Head of Research & Innovation, Food and Beverage Group

"We have AC cabins or AC workshops in place, but we are also considering adapting our times of operation and automating new parts of the process. Solutions will be decided locally, based on 'good practices' shared by the Group."

Pascal Eveillard, Director of Sustainable Business Development, Saint-Gobain

"I believe drones in agriculture and reforestation will be absolutely huge."

Henri Seydoux, CEO, Parrot

"In the context of our 2030 sustainability program, we have changed our processes to use more concentrated water solutions, and we also work on less water-consuming technologies like MVR as an example. In particular, we are looking to reuse purified water, including for cooling machines."

Virginie Dubois, Executive Vice President Research & Development, Roquette

Water-efficiency systems

- Closed-loop and semi-closed-loop **water recycling systems**
- Reverse osmosis–based **filtering systems,** particularly for making water fit for new uses within a plant (e.g., from reagent to cooling), are still the most effective industrial water cleaning method despite being energy-intensive, requiring high maintenance, and producing waste
- **Nature-based solutions,** such as wetlands for drinking water filtration

Capabilities

To support the above, businesses will need to develop, or have access to, some key underlying capabilities, including:

- **Data science.** Deep learning expertise will be critical to accurately predicting local climate phenomena and quantifying their impact.
- **Design for scarcity.** Because technology on its own rarely suffices to solve an adaptation challenge, the ability to design solutions in a resource-constrained environment is key (e.g., redesigning airflow within a building).
- **Nimble risk assessment.** Risk assessment for climate adaptation involves significant uncertainty, hence the importance of flexibility in risk assessment methodologies, including a focus on dynamic sensing and responding approaches. Data science and AI expertise are also highly relevant.
- **Local partnerships.** Responses to climate impacts require solutions tailored to the local environment and are often best supplied by local providers. The ability to identify partners and contract locally is key to an effective, timely, and affordable response.
- **Understanding complex systems.** A complex system is a system composed of many interacting units showing emergent properties that cannot be understood in terms of the properties of the individual isolated components. Ultimately, climate is a complex system, and modeling its impacts at the local level is critical to a nuanced and effective adaptation strategy. Neural networks have proven apt and fast at pattern identification and prediction among large arrays of data points and considerable complexity. Yet they are limited insofar as they can only learn from the past, and we have only one past to offer for training, which is insufficient. Moreover, the future climate impacts we seek to model are not contained in that past: there will likely be multiple butterfly effects and uncertainties in every possible future. Neural networks need to learn from a large array of plausible situations. Digital twins of a company, ecosystem, or city can be used, with GenAI, to simulate the multiple training representations needed for a comprehensive training set. Complex systems allow us to disentangle the relationships between seemingly contradictory goals, such as carbon neutrality objectives and profitability. In our view, this is perhaps the most fundamental capability of all if we are to address climate adaptation effectively.

"Complex systems are particularly suited to addressing supply chain disruptions due to unforeseen events, such as a halt to traffic in the Suez or Panama Canal."

Michel Morvan, Cofounder & Executive Chairman, Cosmo Tech

CHAPTER 5

TAKING ACTION

5 Taking action

Obtacles to adaptation

Despite the urgency to adapt, and the general availability of mature technology, companies face considerable hurdles in implementing adaptation initiatives.

Overall, a lack of knowledge among corporate executives on the best course of action is perceived as the main hurdle to business adaptation (see Figure 13). The difference in knowledge between experts and executives is striking. Executives also emphasize limitations with current technology (53%) and lack of financial resources (53%) as challenges, while academic experts emphasize cultural resistance to change (61%). Comparing the academic and business viewpoints, companies are focused more on external hurdles to adaptation (e.g., technology), whereas experts see internal, human factors like lack of knowledge, culture, and governance as obstacles. Experts also highlight the lack of financial rewards and regulations required to drive technological advances as key hurdles for companies not adapting.

"At Michelin, we developed our own warming trajectory combining various development strategies adopted by public and private actors, resulting in a GHG emissions scenario, which we converted into warming based on IPCC models."

Gael Queinnec, Expert in Corporate Foresight and Development (former Foresight Director at Michelin)

"In my industry, which is strictly B2B, consumer behavior shift won't have a great impact unless my customers adjust to it."

Chief Technology Officer, Advanced Materials Manufacturer

Addressing implementation hurdles

To address the implementation hurdles highlighted in our research, businesses need to address four key questions outlined below.

How to predict?

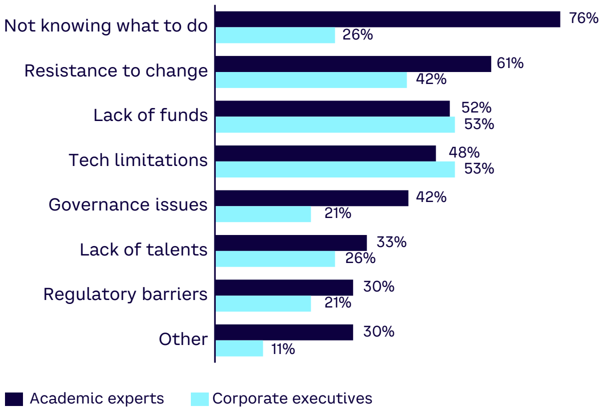
Build assumptions

Decision makers should begin the adaptation process by creating their own global warming trajectory assumptions. The IPCC offers several RCP trajectories — companies should choose which they wish to adopt given their circumstances, monitoring their choice regularly to ensure it remains relevant.

From this, they should select the shaping factors most relevant for themselves and their market. This could depend on factors such as their place in the value chain (e.g., B2C players are directly affected by shifts in consumer behavior), market positioning (players in a stronger market position are more likely to lead on adaptation, while others follow), the location of their industrial footprint and of the markets they serve, and the specific drivers of their industry, including the role of regulation and the structure of R&D.

Fig 13 — Hurdles preventing climate change adaptation

Experts: What are the hurdles preventing companies to move faster with adaptation?
Corporates: What are the hurdles preventing your company to move faster with adaptation?



Source: Arthur D. Little

"A scenario with adaptation funding but no regulation is not realistic in my industry."

Isabelle Esser, Chief Research & Innovation, Quality & Food Safety Officer, Danone

They then need to identify the most relevant projections from the five outlined earlier in this Report. Some specific combinations of factors may not be consistent or relevant for all companies; conversely, the tension between some factors may lay at the core of their adaptation and broader strategy.

Assess risks

Once these working hypotheses are in place, organizations should carry out a site-by-site assessment to understand potential risks, both acute and chronic. Analytical tools, such as GIS, can help provide a comprehensive picture of potential risks, along with growing volumes of relevant, freely available data. Understanding this data and using it for insightful decision-making requires analytics capabilities, which should ideally be built in-house or outsourced to a third party (e.g., an insurer). The most critical operations may benefit from being digitally twinned to anticipate the occurrence and severity of climate impacts. A granular approach is possible here, where only the most critical machines or workshops are monitored thoroughly. As indirect risks are harder to identify and model, they are best addressed by a separate stream that involves members of the supply chain function.

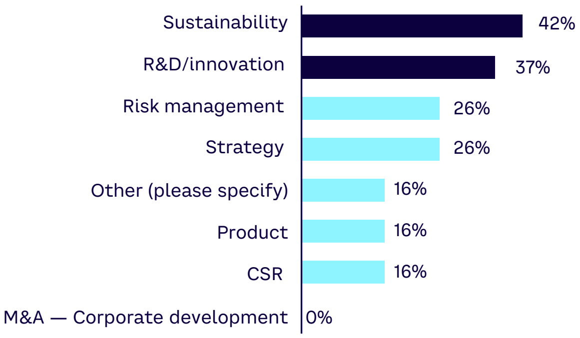
Launch pilot projects

Impact-quantification tools can first be deployed on a specific, well-bound, and local adaptation problem. For example, ADL worked with the executive committee of a railway operator to create a forward-looking risk capability to better anticipate negative issues caused by severe climate events that led to fallen trees on its lines. Focused on a specific area, it ran an eight-week proof of concept to create an interactive map-based dashboard that brought together real-time meteorological and geographical data to model risk using AI and then provided risk scores over a 24-to-120-hour time horizon.

How to decide?

Currently, adaptation topics are handled by a range of functions across organizations, most commonly within sustainability, R&D, and risk teams, as shown in Figure 14. In the most adaptation-conscious companies (self-rated as the most mature), the CEO and R&D department are both involved. However, most often, parts of the adaptation agenda are owned by different functions, creating information loss, friction, and inefficiencies.

Fig 14 — Current responsibilities for climate change adaptation



Source: Arthur D. Little

Create a dedicated team

To ensure clear focus and accountability, we recommend creating a dedicated adaptation task force, able to centralize:

- The culture of climate science, which evolves rapidly
- An understanding of strategic and operational impacts across all parts of the company
- Knowledge of available technologies
- Knowledge of private and public adaptation ecosystems
- The ability to own account experimentation with adaptation solutions
- Approaches to building resilience and seizing opportunities (new products, services, channels) from adaptation

We recommend adaptation be managed separately from mitigation as the impacts on the top line and the influence of regulation differ largely between both goals. However, we advise an overarching governance structure that covers both adaptation and mitigation efforts, as some investments, such as water-efficiency systems, serve both. The adaptation task force should propose criteria and tools to measure the effectiveness of its actions, over and above traditional risk management efficiency.

Understand & overcome challenges

There are three key challenges around adaptation decision-making, and all need to be understood and addressed:

1. **Adapting risk metrics.** New metrics need to be considered as new types of risks emerge (e.g., production time lost to heat or faster asset degradation). Risk thresholds also must be reassessed and adjusted to position climate impacts as a core variable, while multi-speed timelines must be considered. For example, risk profiles for specific assets or operations may change gradually and then suddenly — a change from traditional linear risk profiles.
2. **Listening to the customer's voice.** Traditional methods of listening to customers to uncover their preferences may not apply in the adaptation context as it is outside the experience and immediate understanding of many individuals and businesses. To collect valid customer insights, it is better advised to analyze customer behaviors in response to events that foreshadow the new normal (e.g., shortages, epidemics, catastrophic storms); for example, by using NLP or neural network-augmented social listening tools.
3. **Thinking global.** Climate-related risk will disproportionately affect some locations, leading some regional business units to bear the brunt of the adaptation cost and risk and become unproductive or unprofitable. This could bias corporate decision-making, leading to suboptimal choices (e.g., exiting lower-cost, vulnerable countries altogether). Global governance supported by investment vehicles in adaptation is therefore needed to correctly assess strategic options regarding the overall production footprint.

Climate-related risk will disproportionately affect some locations.

Assigning priorities

Decision makers may need to prioritize effort and investment between different adaptation goals. Using a heat map approach such as in the example shown in Figure 15 — which refers to sustainability, efficiency, and resilience (SER) — can often be useful in this respect.

How to finance?

Mobilizing funding for adaptation requires updating financial metrics. This includes pricing climate-risk vulnerabilities in terms of damage to assets, production loss, and possible reputational effects. Less intuitively, it may also involve the complex task of pricing positive externalities (productivity gains, employee retention) and potential market opportunities from adaptation (market share gains or new product-market fit). It also requires working with longer timelines (>15 years) than customary for most corporate decision-making.

Blended finance solutions, which combine concessional public funds with private capital, can be leveraged when corporate adaptation investments impact communities (e.g., via the financing of infrastructure, as is often the case in emerging markets). Blended finance may use instruments such as bonds and notes (privately placed securities or public issuances). The Climate Resilience and Adaptation Finance Technology Transfer Facility (CRAFT) is an example of a blended finance initiative, offering companies that invest in adaptation solutions grants for technical assistance (funded by concessional support). It may also rely on facilities like private equity funds or fund-of-funds structured with concessional capital.[23] However, to this day, adaptation-blended finance remains timid, mostly flourishing when hybridized with mitigation investments, and even then, mostly in the agricultural sector.

Fig 15 — The SER heatmap: Net zero carbon example

Blocking — Neutral — Enabling

GOALS & DELIVERY PLAN

			SER IMPACT			
			Sustainability			
Goals	Delivery plan		Environment	Social	Efficiency	Resilience
High-level objectives determined in Step 1	*Specific activities to achieve high-level goals*	*Impact*	*Minimize emissions, waste & resource use*	*Increase social & economic value*	*Make best possible use of resource*	*Respond & adapt to threats & opportunities*
Net zero carbon by 2050	100% of transport energy from renewables	3	(1)		(4)	(2)
	All suppliers must have a net zero strategy	2				(3)
	Phase out old rolling stock & replace	3			(5)	(6)
	Reduce use of concrete in capital projects by 30%	5	(1)			(7)
	Electrification of busiest routes	4				
	Stop unnecessary business travel	1	(1)			
	Utilize demand-responsive transport	5	(1)		(8)	

(1) The specific elements of the net zero carbon-delivery plan have obvious strong sustainability benefits.
(2) Reducing diversity in the organization's energy mix will leave the organization exposed to supply issues.
(3) Highly prescriptive procurement requirements significantly reduce supplier diversity.
(4) Incremental benefit from reducing the organization's overall energy demand.
(5) Significant investment of resource and capital to upgrade fleet.
(6) A more modern energy-efficient fleet will reduce overall operational risk.
(7) Reliance on alternate construction methods requiring specialized resource & expertise exposes the organization to single points of failure.
(8) Significantly improves operational efficiency by removing underutilized services.

Source: Arthur D. Little

How to build?

Once decision-making hurdles have been overcome and finance is in place, the building of solutions is best undertaken with local partners, under a clear IP regime and with ample time for experimentation. In practice, this will be a continuous and repeated process over many years.

Develop an ecosystem of local partners

Adaptation problems require local solutions, often best supplied by local providers with a deep understanding of local climate issues, who can operate on-site quickly and affordably. That means that developing local ecosystems of partners, beyond single opportunistic collaborations, is essential, requiring organizations to build the capability to identify and contract with partners locally.

It is important to set clear ground rules for how IP will be managed.

Be savvy with IP

To ensure a well-functioning partner ecosystem to build innovative adaptation solutions, it is important to set clear ground rules for how IP will be managed. These should clarify rules for IP identification, ownership, usage, and documentation. Clarity on IP is also key for attracting finance and for supporting transfer and diffusion of adaptation technologies. Patent databases are useful sources for innovation scouting. Among the most comprehensive are WIPO's PATENTSCOPE and the European Patent Office's Espacenet.

Factor in experimentation times

Adaptation solutions often require longer experimentation times than other innovation solutions due to three factors:

1. **The longer-term nature of the process** (e.g., it takes time to regenerate agricultural soils).
2. **The nature of climate risk** (e.g., floods may not occur every year, and average temperature increases may be linear but can take time to cause impacts).
3. **Stakeholder acceptance** (e.g., many adaptation solutions require time to generate acceptance and uptake such as communities required to change their agricultural practices).

Experimentation times should therefore be factored into adaptation investments, requiring even longer-term planning.

CONCLUSION

HARNESSING TECHNOLOGY TO ADAPT TO CLIMATE CHANGE

Conclusion: Harnessing technology to adapt to climate change

Our study focused on harnessing technology to help businesses adapt to the impacts of climate change. From this research, we draw the following conclusions:

1. The value that technology brings to adaptation does not lie so much in cutting-edge performance or breakthroughs but rather in **applying existing technologies to solve very specific and local problems** at an acceptable **financial, environmental, and social cost** for all stakeholders involved. This points to **adaptation-focused low-cost design** as a key lever for innovation.

2. Some functional expectations recur no matter the adaptation future under consideration, including **climate-proofing the business footprint, protecting the workforce, and maintaining productivity.** These expectations are addressed by a number of mature, off-the-shelf technologies, the implementation of which is a no-regret move because they will prove useful in most futures and for a large range of industries. These include GIS, advanced warning systems, thermal comfort systems, water recycling systems, robots, and drones.

3. Most of these solutions are supported, fully or in part, by three major technological enablers: **(1) IoT for data collection, (2) augmented and virtual reality for simulation,** and **(3) AI including computer vision and GNNs.** These three bricks are at least dual-use, in that they serve both adaptation and productivity purposes (e.g., by unlocking the benefits of the industrial metaverse) — making them definite drivers of competitive advantage in the future. Building capabilities for data science, flexible risk assessment, complex systems, design in a context of scarcity, and striking local partnerships will be essential to reap the benefits of these technological bricks for adaptation.

4. Beyond these common solutions, enablers, and capabilities, **there is no single best approach to solve adaptation challenges.** What is needed is a nuanced consideration of the impact of a business's ecosystem on its operations, and vice versa, to identify the most relevant solutions. Climate change will become an increasingly consequential constraint on business strategy and forward planning. By 2040 and beyond, we may already be in a situation where adaptation strategy has become almost inseparable from business strategy.

5. **Technology alone will not solve adaptation challenges.** As our future projections illustrate, the effectiveness of adaptation responses will be the result of how governments, businesses, societies, and individuals interact and behave. In particular, it is both very uncertain and very consequential whether consumers change habits, whether regulation is enacted, whether financial mechanisms are developed and funds unlocked, and whether large companies assume leadership in adaptation.

6. Adaptation tends to require localized solutions, yet **focusing only on self-interest, discrete outcomes and "tried and true" metrics will fail to address the system-level global challenges** and increase the risk of maladaptation solutions where the remedy is worse than the cure. Behaviors toward adaptation are prone to the prisoner's dilemma: is it better to postpone costly adaptation investments and maintain competitive advantage or to invest now and rely on others to do the same for mutual benefit?

7. The way out of the dilemma requires a **new type of collaboration between governments, local communities, businesses, and individuals** that combines local, national, and global system–level interests and challenges. Such collaboration is extremely challenging to achieve and will involve painful trade-offs. Nevertheless, change does come from necessity. Businesses will play a key role in shaping this future and ensuring that "wait-and-see" does not result in lasting damage.

Climate change will become an increasingly consequential constraint on business strategy and forward planning.

APPENDIX

TAKING ACTION ON EXTREME HEAT

This appendix, authored by ADL partner Climate Resilience Consulting, provides a more detailed exploration of the impacts of extreme heat and what can be done to combat its impacts.

Appendix: Taking action on extreme heat

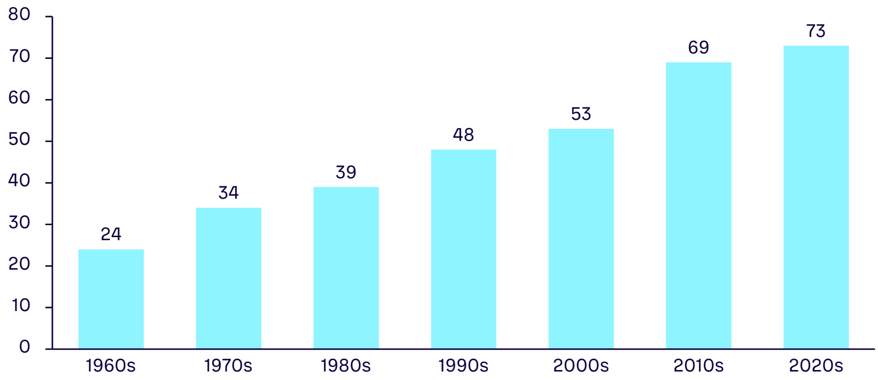
Globally, numerous studies have shown that exposure to extreme heat results in more deaths than any other climate-related hazard, and the impacts are increasing. Rising global temperatures, primarily caused by climate change due to GHG gas emissions, are leading to more frequent and severe heat waves. Alongside the impact on human health, heat waves also affect economies and infrastructure and can compound other climate and non-climate risks, such as drought and wildfires.

2023 was the hottest year on record thus far, rising to 1.5°C (above preindustrial averages). Multiple heat waves were recorded in every continent, and more than 80% of the global population experienced heat that was amplified at least threefold by climate change.[24]

The threat of extreme heat will continue to increase. In India, by 2030 under a high-impact (RCP 8.5) climate change scenario, between 160-200 million people could live in regions with a 5% average annual probability of experiencing a deadly heat wave that exceeds the "survivability threshold" for a healthy human being.[25] This "wet bulb" temperature threshold of 35°C (95°F) was close to being met in multiple cities in 2023 and has already been exceeded in some areas of Pakistan and the Gulf region.[26]

In the US, extreme heat events are lasting longer and becoming more frequent and intense. Additionally, the extreme heat season is also lasting longer, meaning more places are experiencing heat that impacts both indoor and outdoor situations. Figure 16 shows that the average annual length of the heat wave season in the US increased by over 200% between the 1960s and 2020s.

Fig 16 — Average number of days between first and last heat wave day per year for the 50 largest metropolitan areas in the contiguous US



Source: Climate Resilience Consulting, EPA

Disproportionate vulnerability

Extreme heat's impacts on human health and the economy are unequal and depend on vulnerability and exposure. The regions most vulnerable to extreme heat are in low-latitude and low- and middle-income countries with a greater proportion of outdoor workers. However, few areas are immune to the impacts of extreme heat, as demonstrated by deadly heat waves in Europe (in 2003, 2019, and 2023), Russia (in 2010), and most recently in the Southwestern US in 2023.

Exposure

While extreme heat can occur in most populated areas, the intensity is accentuated in urban areas, with dense populations and economic activity. The "urban heat island" (UHI) effect magnifies ambient temperatures due to buildings and built surfaces absorbing and retaining heat in densely developed areas. People living and working in highly built-up areas experience increased exposure to extreme heat for longer.

Few areas are immune to the impacts of extreme heat.

Where people work is an additional factor for exposure to extreme heat; physically active people who work outside in environments without access to shade and cooling have greater exposure. The same is true for people who work in indoor industrial facilities without adequate cooling. Heat exposure can also occur outside of work hours. For instance, commuters required to wait in unshaded and hot environments or transits without adequate cooling have increased exposure, as do those who live in places without adequate cooling. The combination of exposure to heat in commuting and/or living environments increases overall exposure, since the human body needs time to cool down during a 24-hour period.

Vulnerability

The impact of extreme heat on an individual is highly variable, with some groups being more vulnerable, including people with chronic diseases, older people and the very young, low-income individuals, underserved populations, people living alone, pregnant women, and unhoused people. Risk to extreme heat is a function of exposure and vulnerability. In areas with high vulnerability (e.g., underserved, lower-income populations in large urban areas) and high exposure (e.g., heavily built-up areas with low levels of vegetation cover), people are at greater risk of illness and death due to extreme heat.

Health, labor & transportation impacts

Extreme heat exposes populations to multiple negative outcomes, impacting health, the workforce, productivity, and transportation.

Health

Exposure to heat can have severe impacts (e.g., heat exhaustion and heat stroke). Impacts on health vary significantly, with socially vulnerable groups living in underinvested areas being much more at risk.

In extreme heat events, emergency services become stretched. Heat wave events increase ambulance callouts, leading to slower response times for all medical emergencies. This has the greatest impact on people with underlying health conditions and those living in underserved areas where resources are already stretched. Studies in European cities showed that for every degree Celsius increase over the heat wave threshold, overall mortality increased by between 2.9% and 5.5%.[27]

Impacts on health vary significantly.

Access to air-conditioning is a critical mitigant of health risks from heat. As extreme heat events become more common, greater strain is placed on electricity grid networks and can risk outages, which further increase exposure to heat. Without adaptations to urban and living environments, extreme heat-related deaths in the US alone could increase more than sixfold, to more than 59,000 heat-related deaths per year by 2050.[28]

Labor productivity

Extreme heat reduces productivity in the workforce. It is more difficult to engage in physical activity in extreme heat, with human work capacity decreasing between 22%-66% at 37.5°C, depending on the humidity.[29] Extreme heat also reduces productivity by increasing absenteeism, modifying consumer behavior, and impacting transport infrastructure. Productivity losses are steepest in outdoor work sectors, such as agriculture and construction, but are greatest overall in the service sector.[30] For instance, even exposure to temperatures above ~30°C (85°F) leads to US workers reducing their workdays by an average of one hour.[31]

Exposure to working temperatures above 35°C (95°F) is known to cause workers to work more slowly and make more mistakes. Hot days increase occupational injuries in outdoor and indoor activities. In the US, extreme heat events explain around 120,000 occupational injuries on average per year. Without adaptation, this number could increase nearly fourfold to ~450,000/year.[32]

At a global scale, by 2060, given climate change impacts, global economic losses from extreme heat could reach up to 4.6% of GDP, with these losses attributed to health (37%-45%), labor-productivity loss (18%-37%), and indirect loss from supply chain disruption (12%-43%).[33] Losses from health and labor productivity will be greatest in small- and medium-sized developing countries in South-Central and West Africa and Southeast Asia. Supply chain disruption is more widespread and will hit manufacturing-heavy countries like the US and China.

Extreme heat events already cause huge disruptions to supply chains, which lead to delays in production and distribution, impacting the timely delivery of goods and services to customers and affecting revenue streams and overall business operations. Even single extreme heat events can have global impacts. For example, in China's 2022 heat wave, power shortfalls and extreme heat caused even globally important manufacturers to suspend operations, causing disruptions and delays to global supply chains.

Extreme heat events already cause huge disruptions to supply chains.

Transportation

Extreme heat can wreak havoc on transport infrastructure, posing significant challenges to road, rail, and air travel. It can cause damage to asphalt roads and runways, vehicle overheating, buckled rails, an increased risk of fire, and sagging overhead cables along rail infrastructure. Additionally, heat waves can strain air travel operations, as high temperatures reduce aircraft lift, necessitating weight restrictions and potentially leading to flight cancellations or delays. These impacts are especially profound in places used to moderate climates, such as Europe, and highlight the need for adaptation of new materials, technologies, and practices.

Compounding impacts

Extreme heat can compound or even instigate other climate-related risk events. For instance, the vast wildfires in Canada in June 2023 were exacerbated by extreme heat and impacted air quality across swathes of the Midwestern and Northeastern US.

In especially vulnerable regions such as Sub-Saharan Africa, there is some evidence that hotter climatic conditions can exacerbate the risk of conflict in low-income regions heavily dependent on agriculture. However, the causal pathways of climate change impacts on conflict and migration are extremely complex and situationally dependent.

Resilience opportunity

Creating resilience in economies and communities is a necessity, but it is also an opportunity. Heat resilience stands as a pivotal opportunity for global corporations and organizations of all sizes to innovate and help society adapt. There are multiple measures that can be implemented to adapt to extreme heat, each of which presents opportunities to create new products, improve existing products and practices, and work in new fields. Essentially these opportunities fall into two categories: strategy and technology.

Strategic

Adaptation opportunities are varied and can be implemented at different scales by most businesses and organizations. From a business perspective, they can be viewed as measures which enable them to improve worker productivity, influence consumer spending, and improve health and well-being in communities. We share a selection of strategic opportunities in Table 8.

Table 8 — Example strategic interventions to reduce extreme heat impacts

INTERVENTION TYPE	INTERVENTION GOAL	INTERVENTION EXAMPLES
Workforce-centered interventions	Improve worker health & well-being at work & at home, reducing absenteeism & improving productivity	• Worker education programs on extreme heat safety • Policies for operating during extreme heat • Altered working hours during heat events • Heat stress–monitoring systems • Occupational requirements (e.g., hydration, shading, rest breaks, sundown-to-sunup work schedules) • Infrastructure upgrades (e.g., cooling/ventilation systems)
Education & awareness	Provide information to help protect public health & well-being, reducing disruption to consumer behavior	• Informative public awareness campaigns • Supporting government initiatives (e.g., cooling centers, green infrastructure, air-conditioning, social services) through corporate social responsibility
Regulation	Ensure workplace, housing & infrastructure standards are improved & upheld to protect workers & residents; greater public well-being leads to increased consumer spending	• Government agency/private sector collaboration on heat-adaptation regulations for workforce, school athletics, public transit, etc. • Organization-level climate resilience policies that meet & exceed regulatory requirements • Household utility subsidies
Collaborative design (architecture & construction sector)	Contribute to city/neighborhood resilience by designing & constructing resilient, heat-adapted infrastructure	• Formal consideration of heat resilience in design practices (e.g., including more green space, water features, public space potable water, shade structures, reflective materials) • Use of resilience experts & community engagement via social service intermediaries to ensure designs meet needs

Source: Climate Resilience Consulting

Technology

The need to change and/or improve existing products and services to better protect workers and communities from extreme heat presents technology-focused opportunities. While heat-adaptation measures like air-conditioning have been available for some time, they need reforming and enhancing to make them more effective, energy-efficient, and accessible (i.e., more affordable) to communities

Businesses, particularly those in the energy, construction, and electrical goods sectors, can play a huge part in providing these solutions, bringing turnover and revenue benefits to those who innovate successfully. Table 9 provides examples of where private sector innovation could benefit heat resilience.

Conclusion

Extreme heat increases morbidity and mortality, reduces productivity, and disrupts global supply chains. There are, however, many actions that companies can take to mitigate and adapt to these impacts. Companies that act now will face lower disruption and create new opportunities in the face of increasing global temperatures. Extreme heat mitigation and adaptation can lead to innovation that benefits society and brand image and should be prioritized by forward-looking risk, innovation, and finance officers.

Table 9 — Example technology interventions to reduce extreme heat impacts

INTERVENTION TYPE	INTERVENTION GOAL	INTERVENTION EXAMPLES
Building cooling	Develop more effective, efficient & accessible building-cooling technologies to protect workers & residents from extreme heat	• Technologies to promote passive cooling strategies in buildings (e.g., natural ventilation, shading devices & thermal mass) • High-efficiency HVAC systems • Renewable energy to power HVAC • Design of innovative cooling systems such as evaporative cooling
Construction design	Utilize innovative materials & approaches to ensure buildings & infrastructure reduce UHI impacts	• Cool (highly reflective or vegetative) roofing materials & design • Off-grid cooling such as passive solar design • Nature-based solutions (e.g., tree protection & tree planting, incorporating vegetation into design, replacing hot surfaces with vegetation or lighter-colored surfaces) • Positioning of materials with high thermal mass (e.g., asphalt, away from direct sunlight, in favor of highly reflective materials)
Consumables & products	Empower workers & residents to understand & take action to improve individual & collective resilience to heat waves	• Smart wearables & apps (e.g., equipped with body temperature sensors, hydration monitors & hydration reminders) • Lightweight cooling apparel & accessories (e.g., reflective fabric, apparel including thermostat technology, use of heat-conducting materials such as graphene) • Affordable portable cooling devices • Personal hydration products

UHI = urban heat island
Source: Climate Resilience Consulting

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“The era of procrastination, of half-measures, of soothing and baffling expedients, of delays, is coming to its close. In its place, we are entering a period of consequences.”

— Winston S. Churchill

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