Turning point: Feeding the world sustainably

The costs and opportunities of long-term food system transformation

November 2024

Feeding the world sustainably means that **by 2070, the world needs to feed close to 10 billion people** by producing 40% more calories.

Contents

Foreword

Over the past 10,000 years, the movement from hunter-gatherers to low yield crop farming, to higher yield crop farming, and then to mass production of food through the Green Revolution is a quintessential story of human progress, encompassing growth, development, and technological advancement.

But while feeding the world has largely been a story of success, it is not yet finished as nearly 10% of the world's population—some 730 million people—are undernourished. And, like many stories we've heard before, it has come at a previously hidden cost—loss of biodiversity, degradation of the environment, and a worsening of climate change.

Looking ahead, the three-part challenge we collectively face is that of continuing to feed a growing global population, while increasing food security, all while decarbonizing the agricultural sector and the food system. Feeding the world, sustainably, while lifting people out of undernourishment, is the Turning Point that is the object of this report.

This report highlights five system-level solutions which shift us from business-as-usual to realizing a turning point in feeding the world sustainably.

Accelerating productivity-enhancing technologies across the global food system such as earth observation coupled with precision farming, restoring biodiversity and valuing natural capital, driving behavioral changes in consumption, reducing emissions, and embedding circularity, will take investment, but the dividends more than outweigh the costs:

1. **Action to sustainably transform the global food system, including taking action on climate change to limit warming to below 2°C, could see global economic growth (GDP) gains of $US121 trillion by 2070, while making significant progress toward eliminating food insecurity by lowering global food prices by 16%. In the absence of such actions on climate change, the global economy could face a US$190 trillion hit to**

economic growth as a result of agricultural decline, reduced labor productivity, and damage to capital and land.

2. **Enhancing the sustainability of the global food system could see the world produce an extra 1,030 trillion calories in 2070 - enough to meet the minimum needs of an additional 1.6 billion people in 2070; one-in-five of these extra calories in regions of the world where hunger is more prevalent could support an additional 300 million otherwise undernourished people.**
3. **Over the same period, emissions from the global food system could fall by around two-thirds, aiding the global path to net-zero.**

The reality is that modeling such outcomes is one thing, but it is another to effect change which drives a systemic shift in production and distribution.

As a starting point, there is a need to focus climate finance on the sustainable transition in the food system. While the agrifood system generates one-third of global emissions, it receives only 5% of climate finance today. To shift to a more sustainable global food system, additional investments are required. The World Bank estimates that investment in the food system needs to reach US$260 billion per year (equivalent to 0.2% of global GDP in 2023) between now and 2030 – particularly in the areas of natural capital, mitigation, circularity and behavior change.

Moreover, across the system, every value chain actor—finance, tech, supply chain, government—will need to be involved, a feat of coordination. For example, not all of the solutions needed to create net-zero food systems at scale exist yet, so driving a culture of innovation, diffusing breakthroughs in technology, and driving cost reductions will be critical elements to help close the innovation gap. It will be essential for food producers to collaborate across the supply chain, particularly between large and well-resourced processors and smaller supply chain operators upstream, while the export and import of decarbonization knowledge must be facilitated by global trade.

Feeding the world, sustainably, is a moral, environmental, economic, and indeed security challenge. Together, as we continue to shape this story of human progress, two different paths lie in front of us. Actors across the ecosystem need to come together to take bold actions today that can guide the world down the path that contributes to growth, lifts people out of hunger and strengthens the world we live in. We put forward this report and implore you to join us in making this *Turning Point* a reality.

Jennifer Steinmann
Global Sustainability Business leader

Insights summary

Feeding the world sustainably means that, by 2070, the world needs to feed close to 10 billion people by producing 40% more calories, while limiting the environmental impacts of food production, especially by reducing emissions and limiting warming to well below 2°C. More food, sustainably produced, could contribute to reducing the number of undernourished people by 300 million.

The global food sustainability challenge

For centuries, innovation and natural resources have driven the expansion of food production to support a growing global population, generally improving food security and reducing global food prices. However, these trends have stalled and even reversed in recent years. In the past decade, undernourishment in low-income regions has risen from 22% to 28%,[1] while real food prices have simultaneously increased by almost 20%.[2]

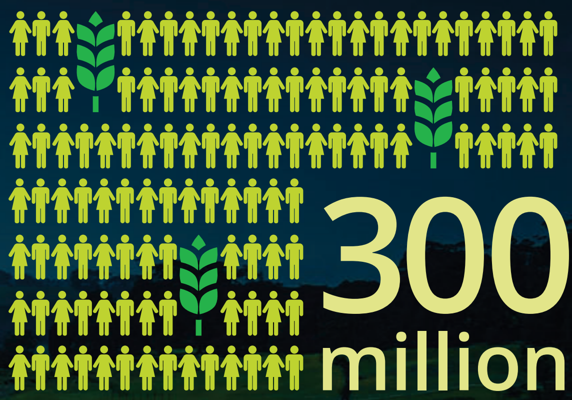
Today, approximately 730 million people—nearly 10% of the global population—are undernourished. After a period of progress, global hunger is no longer falling. Not only does hunger persist, but it has also been rising in many regions.[3]

Historically, increasing food production has had an over-reliance on finite natural resources and causes environmental impacts like climate change and biodiversity loss, which in turn threaten future food security.

In a world that is more than 3°C warmer by the end of the century, unchecked climate change could cost the global economy almost US$190 trillion in present value terms between 2025 and 2070, compared to a baseline that does not account for climate change. Climate damages are estimated to reduce the value of primary food production industries (such as crops, livestock, dairy and fisheries) by US$13 trillion (in present value terms) between 2025 and 2070.[a]

Without significant changes to how food is produced, feeding a growing population will likely require additional natural resources that are already under pressure, especially water and land.

More food sustainably produced could help reduce the number of undernourished people by



Business-as-usual would require land used by agriculture to be 13% larger than it was in 2020. This is the equivalent to an additional 645 million hectares needed to grow more food—an area twice the size of India.[4]

The food system is central to a global "polycrisis," where the dynamics of climate change, loss of biodiversity, competing pressures over finite resources, and falling yields create a vicious spiral when it comes to feeding the world sustainably.[b]

Business-as-usual in the way the world produces food will contribute to slowing progress in reducing hunger, reducing food affordability, and driving food insecurity.

Continuing business-as-usual is not sustainable.

We cannot take historical gains in food production for granted and our current system cannot be relied upon to feed a growing population sustainably (environmentally, socially and economically) into the future.

System-level change is needed to help address the global food sustainability challenge.

[a] Net present value of the incremental change in primary food production output in the feeding the world sustainably compared to business-as-usual, calculated using a 2% social discount rate. Incremental changes for years between 2025 and 2070 (inclusive). All monetary values are in 2023 US$.

[b] The "food system" here captures the processes and actors that convert natural resources and the environment, through agriculture and other activities, through to the downstream processing and manufacturing and retailing.

Doing more with less, in the right places, in the right way

Breaking from business-as-usual means navigating an increasingly narrow path to a world that produces enough nutritious food sustainably for its growing population.

The total production of food needs to increase alongside a shift in its distribution—ensuring food availability for lower-income countries. Economic growth and poverty reduction are concentrated in these regions, which are also the most exposed to climate change.

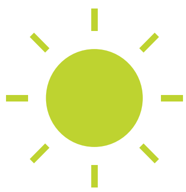
Investing in technology and innovation, as well as improving land management practices to produce more food on each hectare, is critical to helping protect the world's stored carbon in vegetation and soils, and its biodiversity, thereby reducing some of the worst impacts of warming.

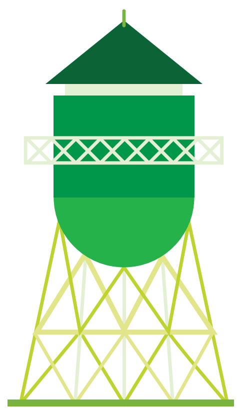
This report highlights a system-level transformation, which shows a path to sustainability is possible in the long-term. Feeding the world sustainably means feeding around 10 billion people by producing 40% more calories than society does today,[c] while limiting warming to well below 2°C.

At the same time, under this system-level transformation, food is more affordable for all, and fewer people would suffer from undernourishment. This increase in food is concentrated in low-income countries, where calories per capita per day increases by 626 kcal (Figure ii), or almost 400 trillion kcal in 2070.

Achieving this could see the world with an extra 1,030 trillion calories in 2070. This is enough to support an additional 1.6 billion people in 2070, at the minimum daily requirements of around 1,800 calories per person per day.

The modeling suggests almost one-in-five of those extra calories will be in regions with higher rates of undernourishment, enough to fully support an additional 300 million of otherwise undernourished people from those regions.[d]





[c] In a dietary context, the term calories and kilocalories (kcal) can be referred to interchangeably. This convention is adopted in this report but note that scientifically the unit of measure that is used is kilocalories (kcal).

[d] Appendix C for the approach to estimating the reduction in undernourished population.

Modeling the economic impacts of transforming the world's food systems

Understanding the potential impacts of addressing global hunger sustainably requires an analytical approach that captures the interlinkages between the macroeconomy, global food markets, trade, and agrifood systems. A multisectoral and global lens is necessary to accurately reflect the position of agrifood systems across different sectors and regions, and within value chains.

Deloitte's in-house D.Climate model was used to analyze the potential of each of these five solutions to sustainably feed the world in the future. As much as possible, the scenarios are grounded to reflect their real-world potential and complemented the modeling with real-world case studies of where, and how, these solutions are already working to help deliver improvements to global food supply.

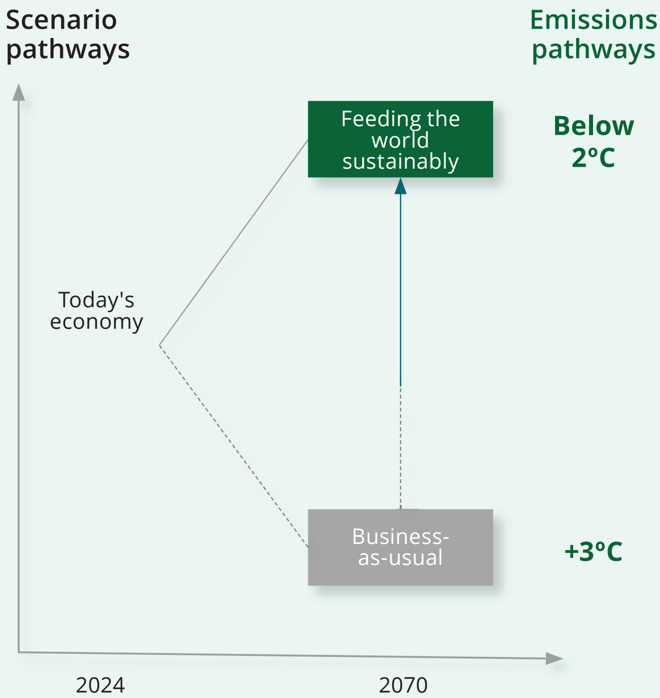
1. Business-as-usual (baseline)

Change in the food system to sustainably increase output is slow. The costs of inaction on climate change are high and materially impact food production. In addition, growing supply-side and demand-side pressures exacerbate hunger and food insecurity in vulnerable countries. Environmental degradation from unsustainable farming practices continues to undermine food production. The economic costs of inaction (Box 1.2) are quantified by comparing the 'business-as-usual' economic growth path, with more than 3°C of warming, to a path that does not account for climate change.

2. Feeding the world sustainably

This scenario reflects a step change in what, where and how food is grown. Countries that invest in agriculture-related innovation and technology will help drive changes in diets, address environmental problems that undermine food production (such as land degradation and biodiversity loss), and implement policies that deliver a more equitable food system. Rapid and coordinated decarbonization would limit the physical impacts of climate change on agricultural productivity.

Figure 1
Economic scenario framework used in the report



Breaking from business-as-usual and achieving global food sustainability

This report focuses on **five possible system-level solutions** to feed the world more sustainably. Deloitte Economics Institute modeling shows that while the world can limit warming, reduce emissions, and sustainably produce more food for a growing population, this cannot be done if we collectively continue on a business-as-usual path.

Reducing emissions to limit global warming to below 2°C is critical to ensure a sustainable food supply.

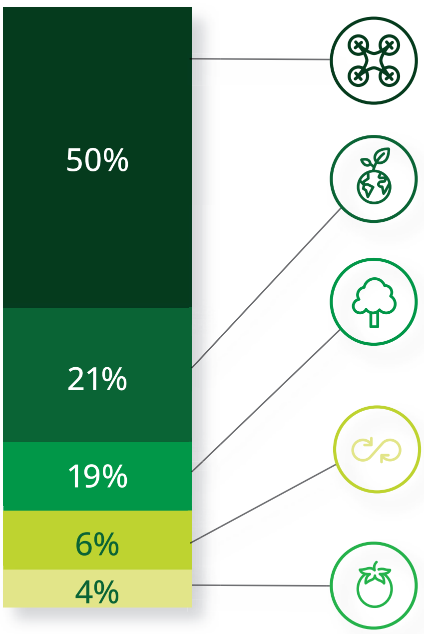
While there is an initial transition cost associated with decarbonization, avoiding the worst impacts associated with unchecked climate change could improve food consumption by more than 100 calories per person per day in 2070 (Figure i).

Indeed, the net gains associated with global decarbonization for global food supply, almost 80 calories per person per day, could continue to grow to the end of the century. This highlights that achieving a net-zero transition sooner is one of the most important actions the world can take now to sustainably secure food supply in the future.[e]

Coupling the global ambition toward decarbonization with investment in other food system interventions is essential. These interventions, such as investing in agricultural research and development, land restoration and management practices, and circularity and promoting behavioral changes, can enable us to collectively harness the benefits of a food system transformation (Figure i).

Solutions to feeding the world sustainably

Figure i Contribution to overall improvement in food supply in 2070 (% share).



Accelerating innovation, technology and productivity improvements at a faster rate than what has been achieved in the past, allowing food producers to do more with less.

Reducing emissions and thereby limiting climate change and the damages it causes is fundamental to a sustainable food system in the long term.

Protecting, restoring, and improving natural capital including the land, the soil, the water, the vegetation, the wildlife, the ecosystem services to improve food production and food security.

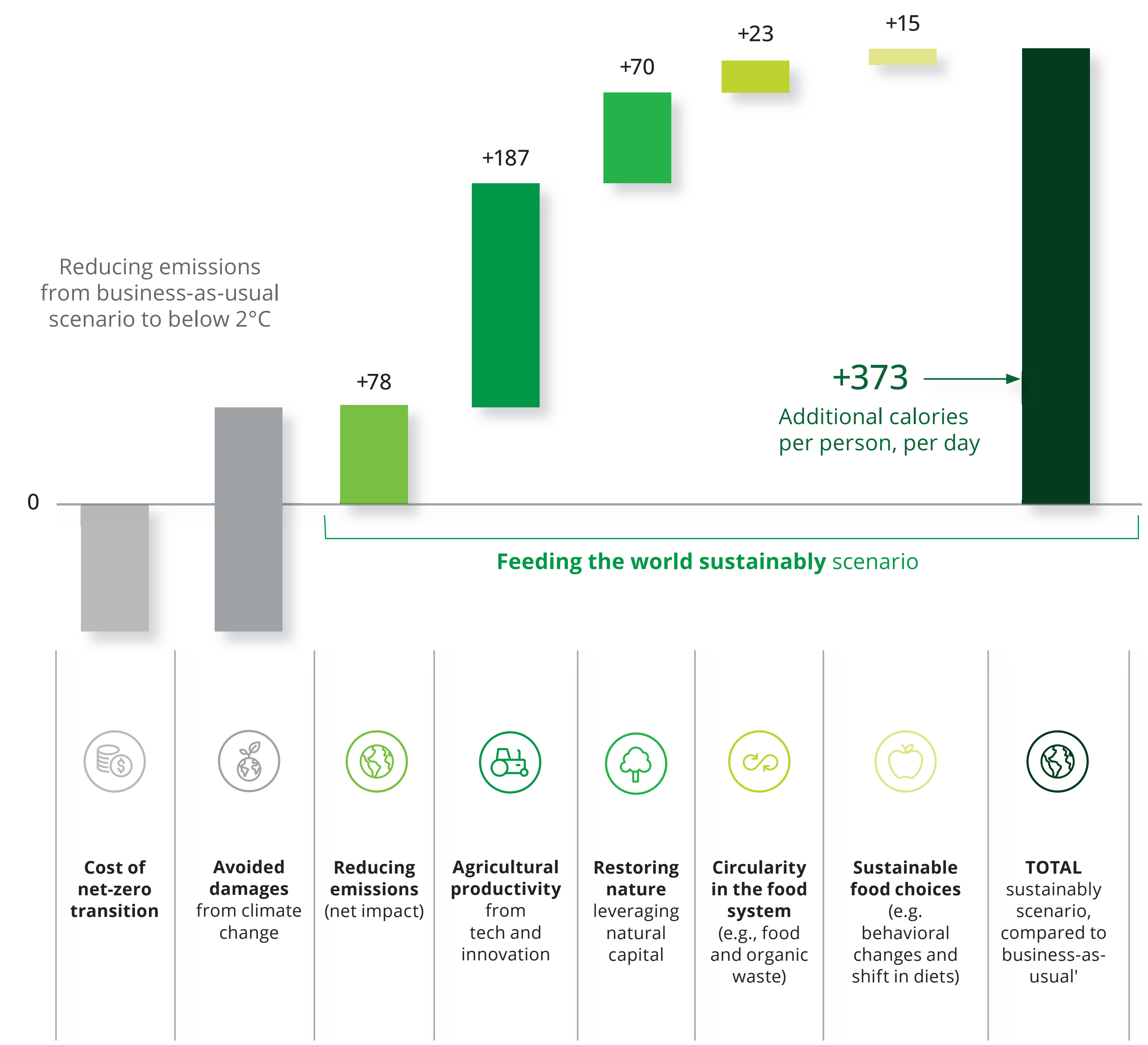
Enhancing circularity in the food system, addressing food waste and using by-products of food production, that redirects material flows from the traditional linear path to an alternative circular path, enhancing efficiency and allowing us to feed more people.

Guiding consumer choice and dietary shifts to support healthier, more nutritious and more sustainable outcomes.

Note: The contribution of reducing emissions is net of the transition costs of reducing emissions. The contribution of the circularity interventions is limited to improvements associated with doubling today's rates of circularity within the food system by 2032.[5] It is not reflecting the contribution that economy-wide circularity measures could make.

Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

Figure ii Decomposition of change in food supply in 2070 (kcal/person/day)



Note: 'Cost' of the net-zero transition represents an economy-wide adjustment and shift in activity towards a low-emissions system. It does not represent the direct abatement costs/expenditures on any individual abatement measure which are instead included in overall economic output (Appendix B).
Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

[e] The 'Below 2°C' scenario has been broken down into two components: one reflecting the cost of transition, the other showing the benefits of reduced climate damages.

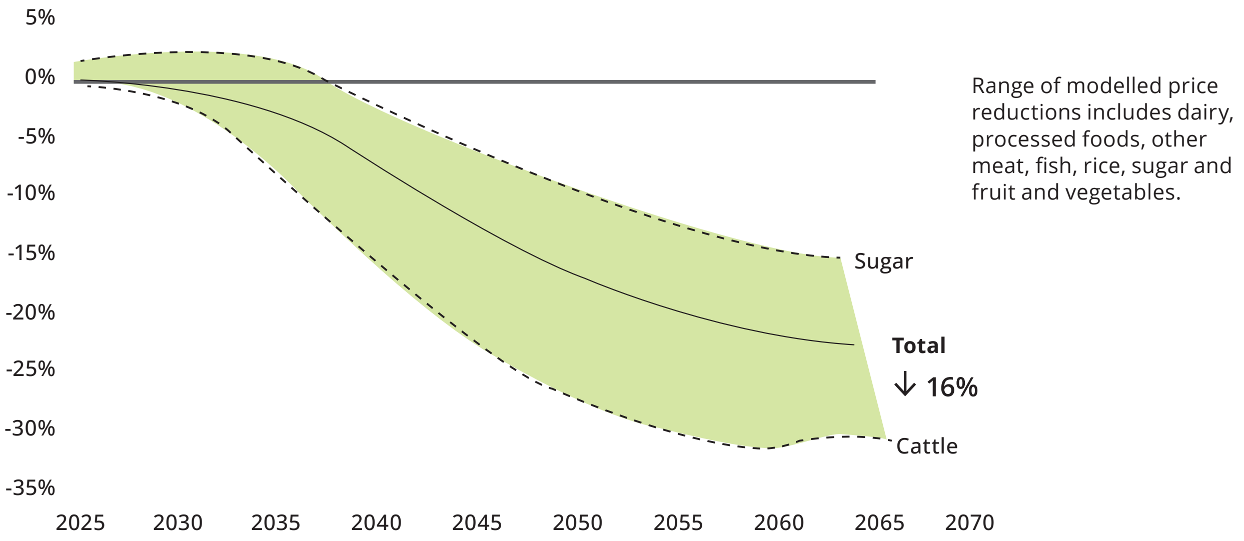
In the "feeding the world sustainably" scenario, global agricultural output **in 2070 is US$1 trillion** larger than business-as-usual

Collectively, across each of the possible solutions modeled, it is estimated that the "feeding the world sustainably" scenario can enhance future food security in several pivotal ways:

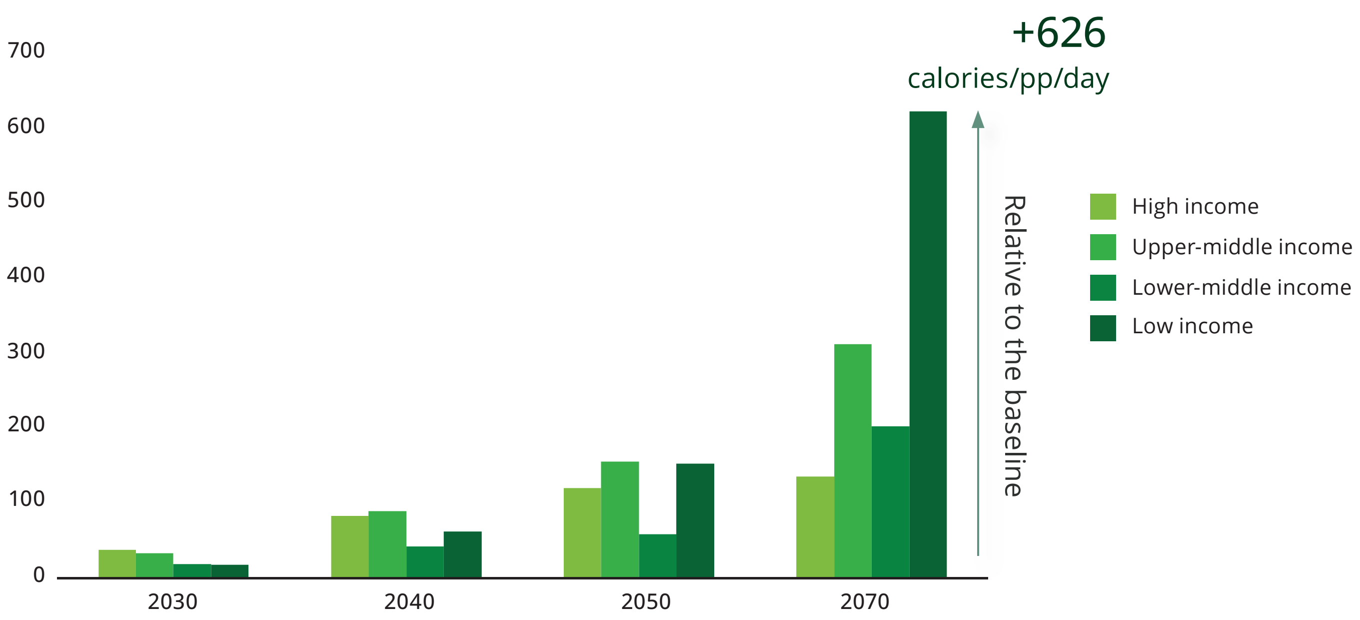
- Reduce global food prices by 16% overall by 2070 (Figure ii). This is driven by two main forces: a greater global supply of food shifts prices down, while a gradual shift toward more sustainable diets helps to drive the changes in prices across commodities, with cattle meat having the largest reduction in prices (due to changing demand and diet preferences), while sugar has one of the smallest reductions.
- Increase the global calorie production by 11% or 1,030 trillion calories, over the baseline by 2070. This increase is concentrated in low-income countries, where calories per person per day increases by 626 kcal (Figure ii), or 400 trillion kcal in total in 2070.
- Although shifts in dietary patterns lead to reduced consumption of emissions-intensive protein sources, there is an overall increase in protein consumption. Globally, protein consumption increases by over 10% above business-as-usual levels in 2070.
- Innovation helps to drive improvements in productivity while simultaneously reducing damages from climate change. The impacts can be large. Global agricultural output in 2070 is US$1 trillion larger than business-as-usual, which is about the equivalent of the current agricultural output of the US and India combined.[6] Between 2025 and 2070, the increase in the food system's output is worth US$22 trillion above business-as-usual levels.
- The global economy also benefits from these food system transformations. Global gross domestic product (GDP) is projected to be US$121 trillion[f] larger between 2025 and 2070, relative to a business-as-usual scenario. In 2070, global GDP is US$16 trillion larger—equivalent to an almost 5% increase in the global economy relative to business-as-usual.

Figure iii Feeding the world sustainably can support increased equity in the food system, increasing food affordability and accessibility in low income countries.

a) World food prices of key commodities deviation (% relative to the business-as-usual scenario)



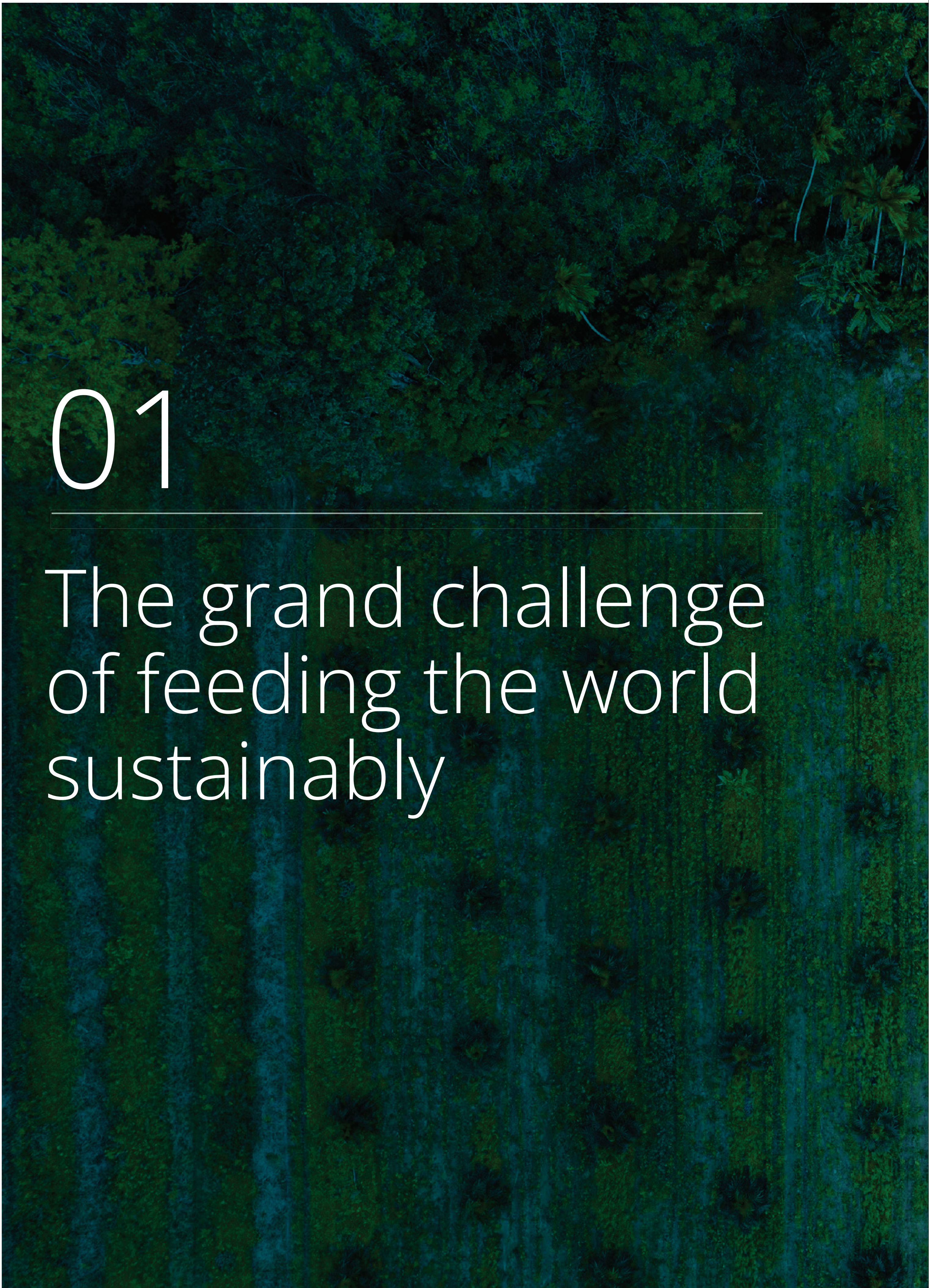
b) Additional daily calories (kcal/person/day) relative to the business-as-usual by income group



Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

These results represent a pivotal shift in the way the world increases its food supply. Food supply grows with less impact on land use change and does so while contributing to reducing global emissions. The food system is interconnected with surrounding systems such as health, ecological, economy and governance, and science and innovation.[7] Achieving a sustainable food system depends on coordinated efforts and interaction with each of these systems to help ensure its long term resilience.

[f] Net present value of the incremental change in global economic output of feeding the world sustainably compared to business-as-usual, calculated using a 2% social discount rate. All monetary values are in 2023 US$.



01

The grand challenge of feeding the world sustainably

1.1

Historically, food production has kept pace with population growth, albeit at the expense of the environment

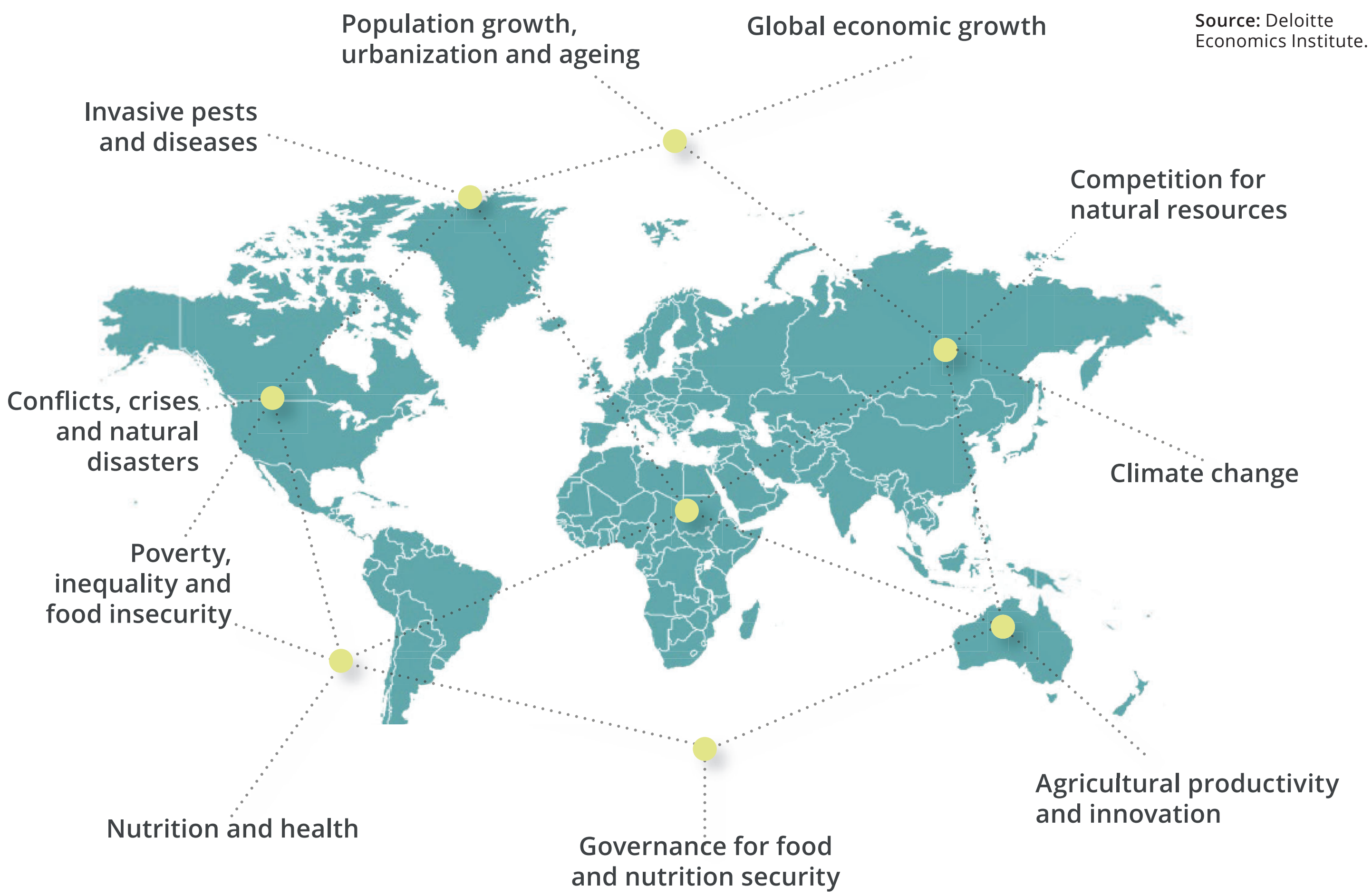
For centuries, humankind has found ways to improve agricultural production and support a growing global population.

While people's well-being has improved, agriculture has increasingly drawn on the natural environment in ways that are unsustainable.

Advancements in agriculture can be tracked across three major revolutions over the past 10,000 years. In the first evolution, known as the Neolithic Revolution, humans transitioned from hunting and gathering to more stationary agriculture, selectively breeding crops and domesticating animals.[8] The second, known as the British Agricultural Revolution, saw farmers replace low-yield crops like rye with higher-yielding ones like wheat and barley, and develop chemical fertilizers, advanced tools and machinery. The third, known as the Green Revolution, emerged around the 1950s. Agricultural productivity increased markedly, driven by new technologies such as inorganic fertilizers, agrochemicals and mechanization. New innovations in plant and animal genetics, food distribution and changes in consumption patterns also transformed the wider food system. The Green Revolution contributed to significantly reducing global hunger and poverty; without it, global caloric availability could have declined by around 11% to 13%.[9]

Although these advances have met growing global food demand in the past, the practices that underpin them cannot sustainably feed the world in the future. Agriculture has increasingly consumed finite natural resources in an unsustainable manner to lift production.

Figure 1.1 Key challenges affecting the global food system



The share of the earth's habitable land used for agriculture has risen from 4% just 1,000 years ago to almost half today.[10] Between 1962 and 2010, the expansion of arable land used for agriculture saw almost 500 million hectares of forests and woody savannas cleared globally.[11]

Land clearing for agriculture is the largest driver of biodiversity loss, which in turn undermines agricultural productivity. Of the 25,000 species that are identified as threatened with extinction, 13,382 are threatened by agricultural land clearing and degradation.[12] Loss of biodiversity directly affects agricultural productivity, as landscapes become less resilient to climate shocks such as drought and floods, as well as pests and disease.[13]

In addition, modern agriculture has contributed significantly to climate change, which in turn threatens the production systems that society has relied upon to increase food production. The global food system contributes almost a third of global greenhouse gas emissions, driven largely by livestock and crop production, land-use change, as well as supply chain emissions.[14] Agricultural production is particularly vulnerable to the impacts of a warming climate via long-term changes in temperature and rainfall, as well as increasing severity and frequency of more acute events such as storms, drought, hail and flooding.

1.2 Unsustainable food production could slow progress in eliminating hunger and reduce food affordability

The world should not take historical gains in food production and nourishment for granted.

The way the world has increased food production in the past is not a sustainable path forward.

There is growing evidence that the recent slowdown in the world's ability to feed itself could be a sign of worsening sustainability problems with the global food system. Concerns primarily relate to:

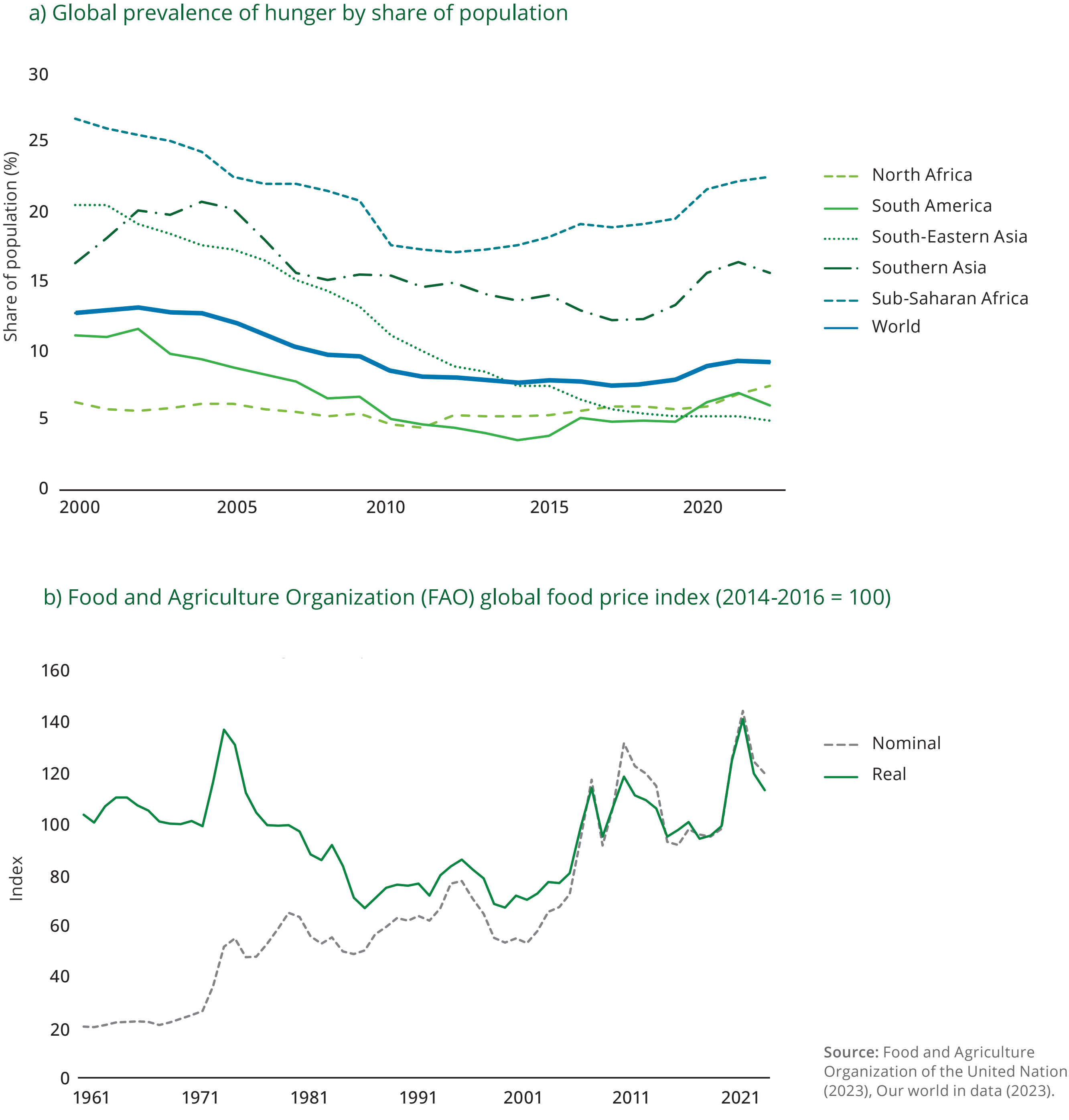
- An increasing draw on finite natural resources for production, such as land, water, fertilizer, fish and other wild species in a way that, because of fundamental limits to nature, cannot be sustained into the future;[15]
- Increasing environmental impacts of food production, some of which are undermining food production itself, such as climate change, loss of critical biodiversity, land degradation, and stressed water catchment and rivers systems that food supply depends upon;[16] and
- The social disapproval of growing inequality in food availability, highlighted by the growing overconsumption problems in the developed world at a time of worsening undernourishment in low-income countries.[17]

Even though food supply has kept pace with global population growth to date, hunger remains prevalent and widespread.[18] After nearly two decades of progress starting in 2000, global hunger rates are no longer falling and began rising in 2018.[19]

The prevalence of hunger is disproportionate, with the largest number of people facing hunger located in Sub-Saharan Africa and Southern Asia.[20] In addition to the uneven distribution of calories, populations in many low-income countries suffer from a lack of micronutrients, which are essential for a healthy diet.[21]

Today, around 730 million people are in a state of undernourishment, equivalent to almost 10% of the global population (Figure 1.2).[22] Global hunger not only persists, but is worsening.

Figure 1.2 Historical trends in global prevalence of hunger and food price changes



Source: Food and Agriculture Organization of the United Nations (2023), Our world in data (2023).

1.3
Looking ahead, current pressures are set to exacerbate the challenge of feeding the world sustainably

The challenge of feeding the world sustainably will not resolve itself.

Compounding factors affecting the supply of and demand for food will likely heighten this challenge. These compounding factors include:

- **Population growth, urbanization and demographic changes:** The overall demand for food continues to rise along with **population growth**. The world population could top 10 billion before the end of the century, and these demand growth trends are set to continue.[23] **Demographic changes** are also shifting food preferences in a way that is placing further pressure on the world's natural resources. Demand for resource-intensive animal-sourced food, especially proteins, has grown steadily over recent decades, driven by population growth and increased consumption resulting from rising incomes, notably in middle-income countries.[24] **Rapid urbanization** is also leading to rising and changing food demand, as well as reshaping land use patterns affecting food production.[25]

- **Climate change**: The production and supply of food is highly climate sensitive. Crops, livestock, fisheries, and access to water rely heavily on environmental factors.

  Climate disruptions can impact not only the production of food, but also carry risks to global food supply chains. Physical damages from climate change are likely to be more acute in developing, tropical and subtropical regions, as agricultural yields are expected to sharply decline—impacting local food supply as well as food prices and the economy.[26]

- **Environmental degradation:** In addition to climate change, there are a host of other global environmental challenges that threaten food supply, which are made worse by current food system production practices. These include land degradation, such as erosion and desertification, pest plants and animals, and stressed river systems threatening water supply for agriculture and other uses.

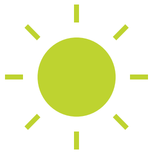
- **Competition for land and water:** Agriculture uses more land and water than any other economic sector. However, these fundamental resources are increasingly sought after for other purposes, including for urban development, energy production, and nature-based carbon sequestration. These uses will put additional demands on land, some of which will also be suitable for food production (see Box 3.1 on page 49).

1.4
How can the world continue to produce more food for a growing population in a sustainable way?

This report takes a scenario analysis approach to understanding this challenge and potential solutions. It tackles a complex question that requires the consideration of interlinkages present between food production, economies, and sustainability.

In this report, the Deloitte Economics Institute presents analysis from the D.Climate framework, which models the outlook for the food system under different climate scenarios. We also consider what could happen if, and when, this food system transformation takes place. In doing so, we identify the potential economic and food supply impacts of different system-level solutions as part of a "feeding the world sustainably" scenario over time.

The results reveal the magnitude of the challenge, but also highlight the opportunities the world still has to drive growth through sustainable food production. Insights are grounded in a framework that accounts for dynamic effects as well as the interlinkages between different regions and sectors across the global economy. In addition, because of the dynamic nature of D.Climate, the timing of costs and benefits of the system-level solutions can be examined.



Box 1.1 Modeling the economic impacts of transforming the world's food systems

The outlook for the food system is analyzed under two different scenarios: "business-as-usual" and "feeding the world sustainably." The findings in this report refer to impacts of the "feeding the world sustainably" scenario.

1. Business-as-usual (baseline)

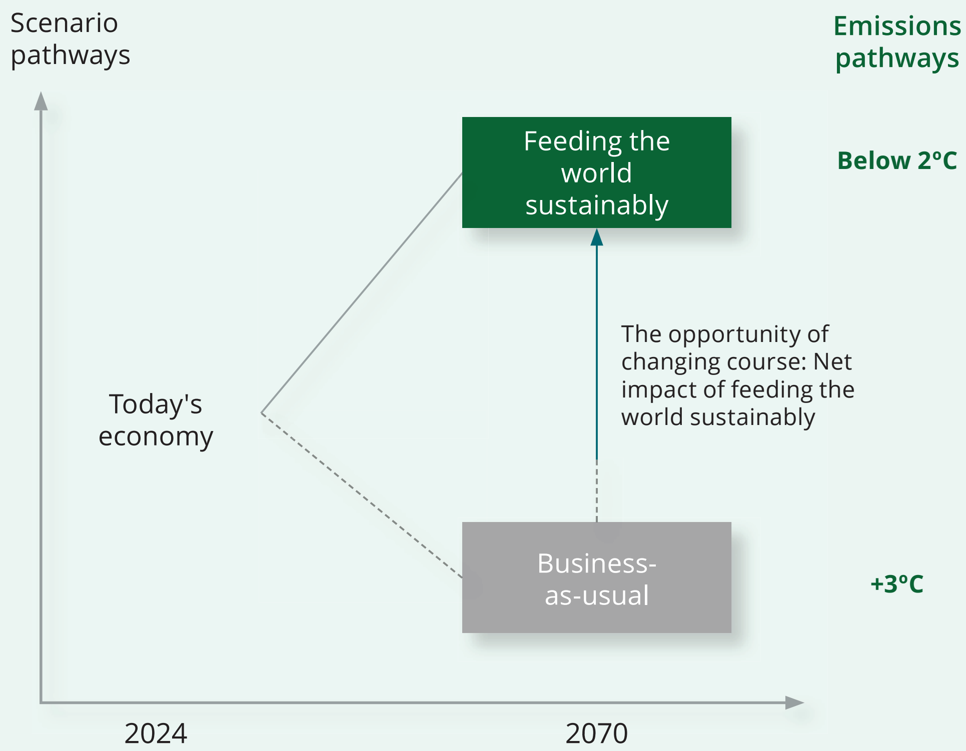
Change in the food system to sustainably increase output is slow. The costs of inaction on climate change are high and materially impact food production. In addition, growing supply-side and demand-side pressures exacerbate hunger and food insecurity in vulnerable countries. Environmental degradation from unsustainable farming practices continues to undermine food production.

The economic costs of inaction (Box 1.2) are quantified by comparing the 'business-as-usual' economic growth path, with more than 3°C of warming, to a path that does not account for climate change (Appendix B, Figure B.3).

2. Feeding the world sustainably

This scenario reflects a step change in what, where and how food is grown. Countries invest in agriculture-related innovation and technology, drive changes in diets, address environmental problems that undermine food production (such as land degradation and biodiversity loss), and implement policies that deliver a more equitable food system. Rapid and coordinated decarbonization limits the physical impacts of climate change on agricultural productivity.

Figure 1.3 Economic scenario framework used in this report



Note: Emissions pathway temperatures are end-of-century outcomes. Refer to Appendix Table B.3 for more detailed descriptions of the emissions pathways adopted in this report.

Source: Deloitte Economics Institute.

Despite the global ambition to limit warming to well below 2°C, continuing business-as-usual will mean that global emissions will likely continue to rise if no further significant action is taken to mitigate climate change from today. The outcome is increasing global average warming towards the end of the century. Compared to a world without climate change, this baseline could negatively impact economic growth.

The Deloitte Economics Institute modeled the economic impacts of a changing climate on long-term economic growth through the following process. This modeling process involved significant research on region-specific climate and economic impacts across the world, which are used as inputs into Deloitte's Regional Computable General Equilibrium Climate Integrated Assessment Model, the D.Climate model (refer to Appendix B for more detail).

1. Without significant additional efforts to constrain emissions, increased atmospheric greenhouse gases (GHG) in the "business-as-usual" scenario cause average global surface temperatures to rise further above pre-industrial levels. Under this baseline, global average temperatures increase to more than 3°C above pre-industrial levels[g] by the end of the century.[27]

   Warming causes the climate to change and results in physical damages to the economy. D.Climate represents six types of economic damages, which are regionalized to the climate, industry, and workforce structure of each defined region globally.

2. These damages to the factors of production are distributed across the economy, impacting GDP. The economy impacts the climate, and the climate impacts the economy.

3. The key variables of emissions, global average temperature, and the nature of economic output across industry structures combine to offer an alternative baseline view of economic growth that accounts for the economic impacts of unchecked climate change. In this baseline, the cost of inaction on climate change is high and materially impacts food production.

4. Specific scenario analysis is then conducted in reference to a revised economic baseline ("business-as-usual") scenario that includes climate change damages. Scenarios can include policy actions that either reduce or increase emissions and global average temperatures relative to the current baseline view.

Box 1.2 The economic costs of inaction

Inaction on climate change is not without cost. Deloitte's modeling shows that unchecked climate change, where global average temperatures rise by more than 3°C, hinders growth across industries in each region. Despite an increase in coordination and commitments around the world, as well as significant scaling up of key technologies, there is still the potential of a climate-damaged economy becoming the new normal.

The analysis shows unchecked climate change could cost the global economy almost US$190 trillion in present value terms between 2025 and 2070, compared to a baseline that does not account for climate change.

Various channels of impact include losses in agricultural productivity, reduction in labor productivity due to heat stress and other health impacts, damaged capital, and loss of productive land due to rising sea levels. Together, these physical impacts impose a significant cost on the global economy. Lower incomes reduce people's purchasing power, and, ultimately, their ability to access nutritious food.

Climate change will likely affect each industry and region, but primary food production industries and lower-middle and low-income regions are particularly vulnerable.

Labor and land intensive sectors, such as primary food production industries, suffer greater damages due to climate change. This is due to the ways in which climate change lowers labor productivity and shifts long-term and seasonal temperature and precipitation patterns, which ultimately affect agricultural output. In a world that is more than 3°C warmer by the end of the century, climate damages could reduce the value of primary food production industries (such as crops, livestock, dairy and fisheries) by US$13 trillion in present value terms between 2025 and 2070. These impacts reverberate through the wider food system, with food manufacturing and food services sectors US$12 trillion smaller in present value terms over this period.

Climate change also has the potential to disrupt global supply chains, impacting trade, investment, and the movement of people. Resource scarcity and uneven regional action towards climate change could result in global trade disruptions. As financial sectors grapple with increased risk from climate-vulnerable sectors, investment in primary production industries could also decline, increasing food insecurity.

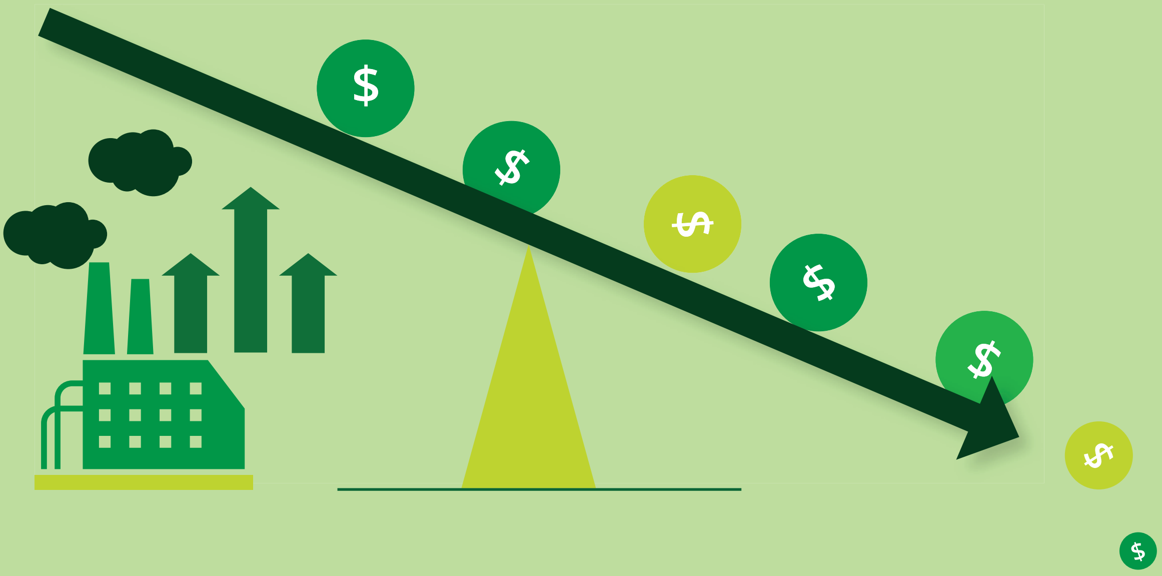
The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2050, an additional 80 million people will be at risk of hunger as a result of worsening climate change.[28]

This is nearly eight times the current population of Azerbaijan, the host of the 29th session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP29), approximately the population of Germany, and greater than the population of the United Kingdom.

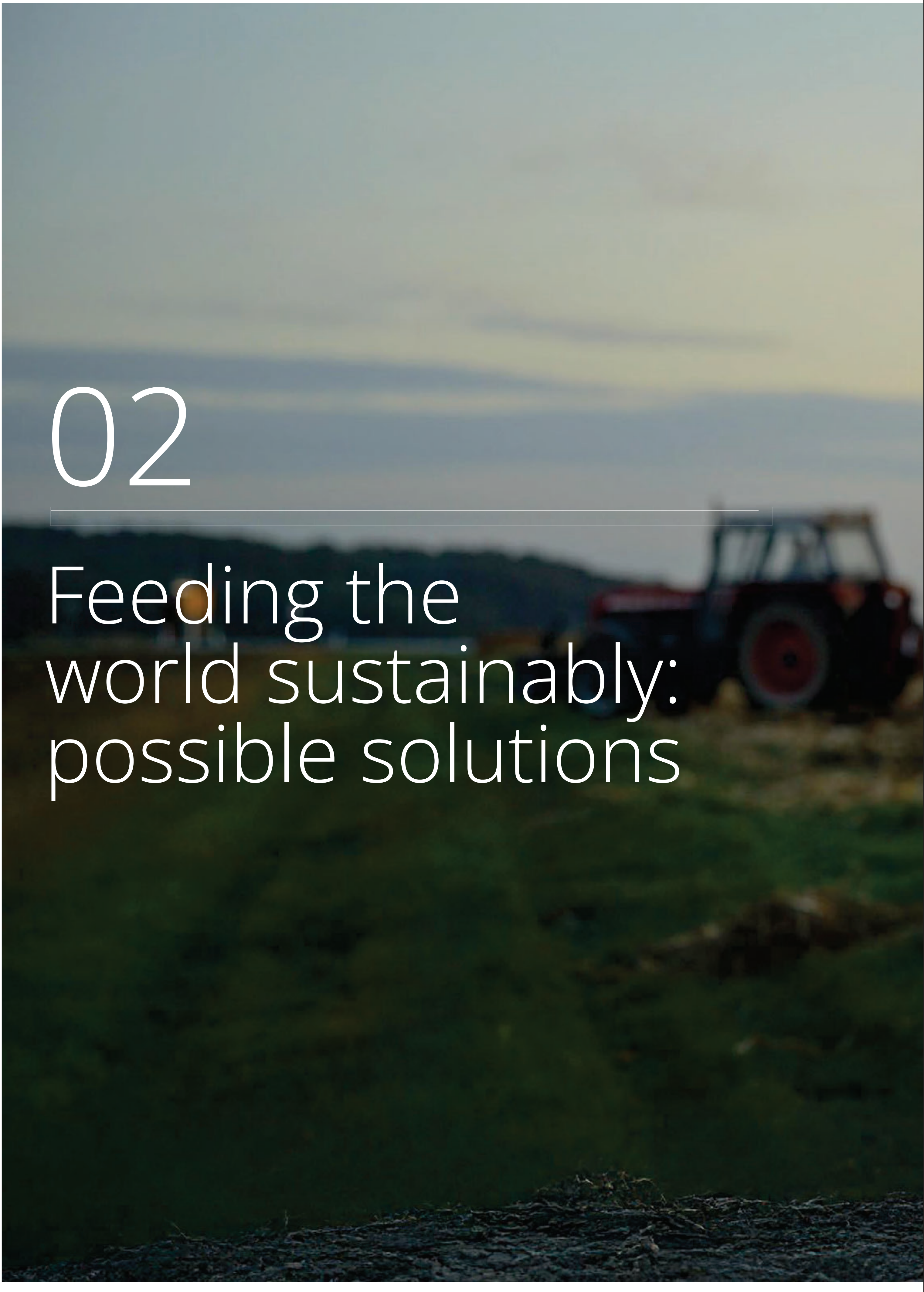
Declining crop yields, reduced livestock, dairy and fish stocks, and disruptions to global food supply chains will make it increasingly difficult for the global population to access affordable and nutritious food. The resulting food scarcity disproportionately affects lower middle- and low-income populations, leading to widespread hunger and increased inequality. Lower-middle income and low-income regions are also disproportionately impacted by climate change, with these regions accounting for 65% of global losses in economic output between 2025 and 2070.

Together, these factors mean that continuing business-as-usual only worsens the hunger problem at hand, deepening existing inequalities. Primary food production industries both contribute to and are vulnerable to the impacts of climate change and ongoing environmental degradation.

Reducing emissions involves transition costs and creates complex trade-offs across the economy and particularly within the agricultural sector agricultural sector, requiring substantial investment and coordinated action to transform this industry for a more sustainable future.



g Preindustrial is defined in IPCC assessments as the multi-century period before the onset of large-scale industrial activity around 1750.



02

Feeding the world sustainably: possible solutions

Feeding the world sustainably requires system-level solutions and a rethink of business-as-usual.[29]

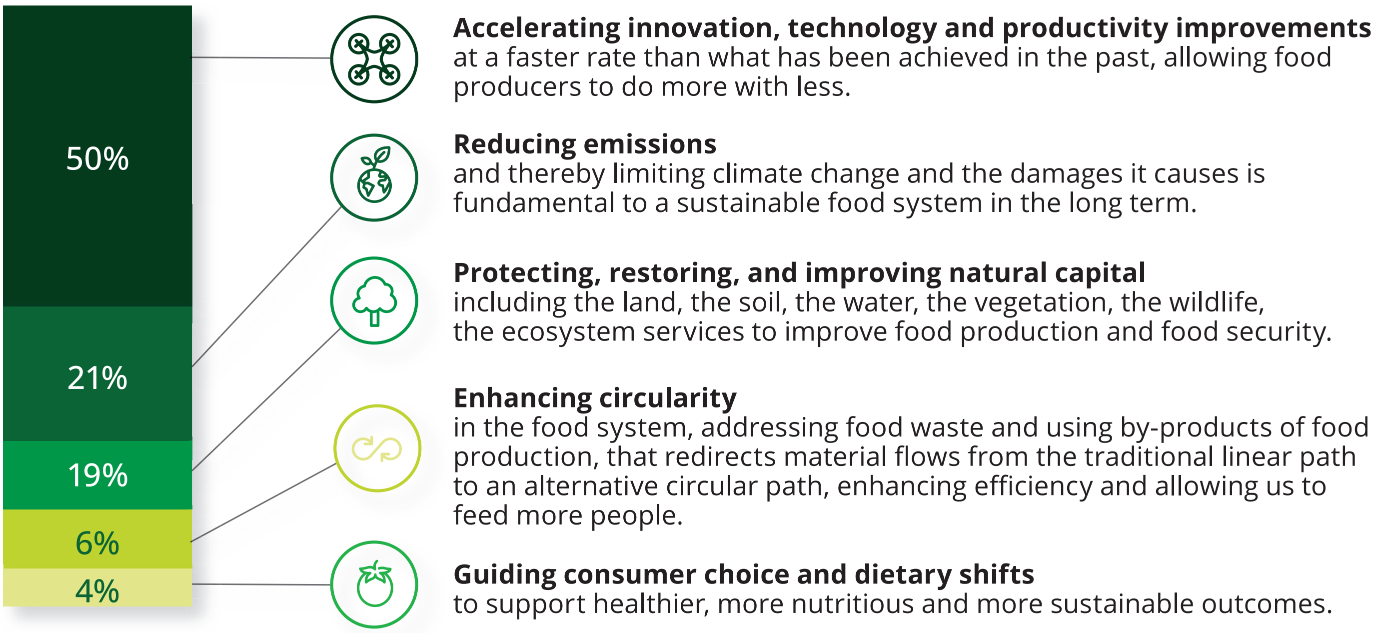
These solutions should not only produce greater quantities in a more sustainable way, but also address the disproportionate allocation of food. Supporting ongoing food security will likely involve developing solutions that address both the inequities in food consumption and the need for sustainable food production. Solutions will need to withstand environmental pressures and evolving policy frameworks as the global economy shifts towards decarbonization.

Fundamentally, innovation and ongoing productivity improvement in the system is critical. From encouraging behavioral change and reducing food waste, to embracing technological advancements and natural capital restoration, this chapter highlights five solutions alongside examples and case studies of leading practices available to help transform the food system to feed the world sustainably.

These five major solutions and their respective contribution to the overall modeled improvement in feeding the world sustainably (detailed in Chapter 3) are illustrated in Figure 2.1.

Solutions to feeding the world sustainably

Figure 2.1 Contribution to overall improvement in food supply in 2070 (% share).



Source: Deloitte analysis based on D.Climate modeling described in Appendix B.

2.1
Tech-driven innovation and boosting agricultural productivity

Technological innovation and productivity growth has historically been a significant driver of food production. Since 1962, productivity growth in agriculture has averaged 1.3% per year.[30]

Rates of innovation and productivity growth will need to accelerate to maintain this historical progress and enable the sustainable transformation of the food system. Innovations in Earth observation and predictive analysis, precision agriculture, vertical farming, automated harvesting, and smart manufacturing have the potential to significantly enhance farming productivity—that is, produce higher yields without requiring additional resources—by enabling farmers to optimize resource utilization and make better, more informed decisions..

Renewable energy sources, smart irrigation systems, and resource-efficient animal protein alternatives are just a few other examples of innovations that can drive this transformation. Not only can these innovations improve agricultural productivity and facilitate the transition, they can also support farmers to withstand the growing impacts of climate change. Technology and information can support adaptation decisions as farmers face increasing exposure to more extreme weather patterns and events such as droughts, floods and heatwaves. Leveraging cutting-edge technologies has the potential to address global food insecurity by enabling higher crop yields with less land, and fostering more adaptable and resilient food systems and optimizing distribution through smarter technologies.

Precision agriculture and Earth observation

A particular area of innovation in food systems is a shift towards precision agriculture, supported by innovations in satellite technology and Earth observation (EO).

EO involves gathering detailed information on Earth's activities and characteristics, both natural and artificial, including physical, chemical, biological and anthropogenic (human) systems. According to a study, the agricultural applications of EO are projected to represent nearly a **US$400 billion economic opportunity** in 2030, with 85% of this growth driven by productivity-enhancing precision agriculture.[31]

Precision agriculture is a practice that helps enable farmers to improve their farm management and optimize resources, leading to higher productivity and efficiency gains. Enabled by EO, precision cropping leverages satellite data to offer farmers a web-based interface for accurate land assessment and comprehensive monitoring. Using this technology, farmers can monitor the performance of their crops and identify where crops are underperforming, enabling them to intervene early and mitigate the risk of low crop yields. Ultimately, precision agriculture offers a powerful tool, among a suite of technological improvements, that can help combat global food insecurity and support a more efficient food system by optimizing resource use, such as water and soil, to increase the quality and quantity of crop yields.

Continuing investment in EO technologies is crucial for boosting agricultural productivity. Both the public and private sectors play important roles in pushing these technological boundaries. Private sector innovation, driven by research and development and venture capital, has helped enable better crop monitoring.

Public sector initiatives, such as partnerships with NASA, highlight the importance of government support. Government funding also helps to drive innovation in academia and private companies. Collectively, these efforts can continue to boost agricultural productivity.

Productivity improvements

- **Weather and climate information** offer seasonal forecasts, helping farmers make informed decisions. Early wildfire detection could reduce agricultural losses by 16%, with weather forecasts value adding US$2.9 per hectare for livestock and US$30.4 per hectare for crops.
- **Precision agriculture** boosts yields per hectare, with crop and livestock output increasing by 5.3% for cotton, 7.5% for wheat, and 13% for cattle and dairy, while also reducing damages to fisheries from harmful algal blooms by 31%.

Emissions reductions

- **Precision agriculture** can significantly reduce greenhouse gas emissions through the variable application of fertilizers, allowing farmers to apply nutrients more efficiently. Fertilizer inputs can be cut down by 4-6%, reducing emissions while maintaining crop yields and minimizing costs. As such, this practice may lead to a total reduction of 27 million tonnes of greenhouse gas emissions.

2.2 Restoring natural capital as a pathway to strengthening global food security

Landscape and ecosystem restoration and enhancement is vital for improving food security, as restoration activities revitalize the ecosystems that are essential to support food production.[32] Natural capital, comprising the world's stocks of natural resources such as land, soil, water, vegetation, wildlife and ecosystems, are foundational assets to food production. Healthy landscapes and ecosystems provide services such as water and air purification, nutrient cycling, pollination, climate regulation, soil protection, and pest control that underpin agricultural productivity.

Food system production processes and land-use change have historically depleted these natural assets and, in turn, have the potential to undermine the future resilience and efficiency of the food system. For instance, intensive agricultural practices such as land clearing, pesticide use, and pollution have threatened pollinators which are key players in global food production.[33] With approximately 75% of global food production relying to some extent on animal pollination, the loss of pollinator habitat poses a significant threat to food security. Therefore, strategies focused on protecting, restoring and improving natural capital are key to boosting food security outcomes as they strengthen ecosystem resilience over time.

In some contexts, there will be trade-offs between strengthening natural capital and food production. Sub-Saharan Africa, for example, is projected to have expansions in land-use converted from natural vegetation to agricultural landscapes as part of its continued economic development.[34]
In farm operations, there will be many examples where clearing land is necessary to achieve a productive outcome. However, feeding the world sustainably will likely require greater incentives and uptake of win-win initiatives, which can achieve both agricultural productivity and natural capital enhancement outcomes. Examples include agroforestry, mangrove and wetland restoration.

Reviving the Amazon: Verified deforestation-free supply chains by Natura &Co

Natura &Co is a global cosmetics and personal care group with bold sustainability targets. Headquartered in Sao Paulo, it is leading efforts to restore the Amazon rainforest while ethically sourcing materials for cosmetics in a way that supports local communities and biodiversity.

In 2020, the company launched its "Commitment to Life" sustainability vision, highlighting the importance of ethically sourcing its natural ingredients.[35]

As part of this vision, Natura &Co has achieved several initiatives and has further committed to leading efforts to reforestation, promoting ecosystem conversation and addressing the climate crisis.

Natura &Co's sustainability vision and commitments promote a 'win-win' outcome by effectively balancing the restoration and protection of natural capital with the sustainable use of resources in its production processes.

By restoring the Amazon and achieving deforestation-free supply chains, Natura &Co directly contributes to natural capital restoration and protection. Meanwhile, agroforestry practices increase the involvement of local communities and promote a more sustainable use of natural resources in production.

Forest restoration

- Commitment to increase the protection and regeneration of the Amazon from **2 million** to **3 million hectares**, an area equivalent to the size of Belgium.[36]
- Natura &Co helped establish the world's first **agroforestry** system for cultivating sustainable palm oil in the Amazonian region. The project demonstrated that **palm oil**, a key ingredient for cosmetics, is more productive and sustainable in an agroforestry system compared to monoculture.[37]

Ecosystem conservation

- Commitment to **assess and report** Nature &Co's **global biodiversity impacts** and dependencies by 2025.[38]
- Commitment to achieve verified **deforestation and conversion-free critical supply chains** by 2030, ensuring that the sourcing of critical ingredients does not contribute to deforestation activities or disrupt ecosystems.[39]

2.3
Reducing emissions and contributing to global net-zero

To limit warming well below 2°C, all sectors of the global economy will have to reduce emissions, while continuing to support economic growth and development. Sectors and regions will move at different speeds toward an overall goal of net-zero emissions. While agricultural parts of the food system are expected to move at a slower pace than other sectors, reflecting technology availability today, it will need to contribute to emissions reductions to support a global net-zero outcome.[40]

Collectively, these emissions represent around a third of the global total.[41] Many agricultural emissions are hard to abate, including methane emissions from livestock, nitrogen and carbon emissions from soil (including fertilizer and lime applications), and agricultural emissions from transport. To help feed the world sustainably, the world will require more food. Doing so while reducing emissions-intensity of hard-to-abate activities and increasing the sequestration potential of the landscape will be essential to limiting warming.

Harnessing the power of climate-smart practices like agroforestry, soil organic carbon activities, feed supplements, sustainable livestock and grazing management and low-till methods can both reduce emissions, and unlock significant co-benefits such as improving soil health and enhancing ecosystem resilience (Figure 2.2).

Figure 2.2 Emissions reduction strategies for the agricultural sector

Sustainable agri-management

Sustainable livestock and grazing management reduce overgrazing and prevent land degradation. No-till or low-till farming practices eliminate or minimize the cost to soil health from tilling activities.

Feed Supplements

Feed supplements used to reduce enteric fermentation assist to decrease methane emissions from ruminant animals whilst also promoting livestock productivity.

Agroforestry

Agroforestry integrates trees and shrubs into agricultural farming systems supporting carbon storage capacity, biodiversity and soil fertility.

Soil organic activities

Soil organic activities, such as cover cropping have the potential to improve soil fertility, prevent soil erosion, promote water infiltration, and limit the risk of pest and disease outbreaks.

Energy use

Biofuels, derived from agriculture or waste streams, offer an alternative to fossil fuels. Electrification of equipment can reduce operational costs. Together, these innovations not only cut emissions, but enhance a more cost-effective and resilient food system.

Source: Deloitte analysis. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

The Dairy Methane Action Alliance

The agriculture sector accounts for 40% of anthropogenic methane emissions, with livestock emissions from manure and enteric fermentation representing about 32% of that total. Methane has a global warming potential about 80 times greater than CO_2 in the 20 years following its release into the atmosphere.[42] Given the high potency of methane, cutting these emissions is critical in the global effort to achieve net-zero.

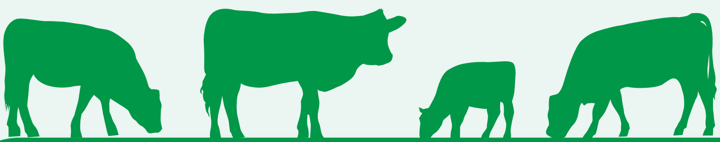
The Dairy Methane Action Alliance, a commitment by global food companies to tackle methane emissions, was launched at COP28 to help drive accountability, transparency and ambitious climate action across the food industry.[43]

The Alliance is led by food and dairy giants representing more than US$200 billion in revenue and include Bel Group, Danone, General Mills, Kraft Heinz, Lactalis USA, Starbucks and Nestlé, collaborating with non-government organizations such as the Environmental Defense Fund and Ceres.

By joining the Dairy Methane Action Alliance, the signatory companies commit to meet two key milestones:

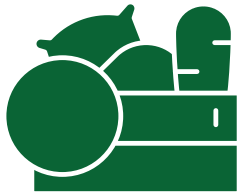
1. Annual accounting for and publicly disclosing methane emissions within their dairy supply chains.
2. Publishing and implementing a comprehensive methane reduction action plan by the end of 2024.

   Many alliance signatories, however, already have actions to reduce emissions underway. One example of these initiatives is the Bel Group's rollout of methane-reducing feed additives.



The **Bel Group**, a France-based multinational dairy company, has made a notable advancement towards producing low-methane milk by adopting the Bovaer feed supplement in Slovakia and France.[44] The feed supplement reduces enteric methane emissions from cows. With over 15 independent studies conducted across Europe demonstrating substantial reductions in emissions—ranging from 22% to 84% depending on dosage and conditions—the company is now initiating a broad roll-out, offering this innovative solution to its dairy producers.[45]

2.4
Shifting habits and empowering sustainable food choices



Consumer behavior is an important lever in fostering transformative food system change. Shifting consumer preference toward more sustainable products will help enhance the economics of the solutions mentioned in section 2.4. This can be achieved by improving the transparency of supply chains and increasing information available to consumers. Dietary shifts will also likely play an important role—in a positive or negative direction. As the global population continues to grow, the availability and accessibility of foods which provide a nutritionally balanced diet, as well as minimize environmental impact, have become more urgent.

In the past decade, a significant body of research has analyzed the impacts of a dietary shift towards more healthy and sustainable food choices:

- A study has projected that adopting a healthier and more sustainable diet by 2050 could reduce costs by an average of 37% across all countries compared to current dietary costs.[46] This highlights the additional financial benefits of increased food affordability, as households spend less of their disposable income on food.
- A study in Europe has found that mortality and cancer rates can be reduced by increasing the uptake of flexitarian diets. Such dietary shifts can also cut greenhouse gas emissions by 50% and decrease land use by 62%.[47] In turn, these benefits have the potential to bolster the agricultural sector's resilience and productivity.

It is well-documented that demand shifts can have a significant impact on global emissions. The challenge is how to enable those changes.

Informing consumer choice plays a critical role in helping drive behavioral change as it helps enable consumers to verify the sustainability claims of products, encouraging more informed decisions. Consumers are increasingly prioritizing sustainability in their food choices, with nearly half of US consumers checking labels for data on sustainability.[48] There is mixed evidence on the extent to which this translates to an increased willingness to pay for those food items. Nevertheless, it is clear that shifting behaviors and encouraging dietary shifts, particularly in developed economies, will have a material impact on the long-term development and sustainability of the global food system.

Building consumer confidence: Climate-smart product certification in Canada

Deloitte Canada recently worked alongside value chain participants, including growers, producers, processors and retailers, to develop an open-source framework outlining the key considerations and methods required for a trustworthy, credible, and future-oriented climate-smart product certification. Greater supply chain traceability and transparency is necessary to support consumers' transition to more sustainable choices and enable the agrifood system to lower emissions on a net-zero pathway.[49]

To help support the widespread adoption of climate-smart products, value chain participants have employed different approaches to product claims. However, the current landscape of product label claims and certifications can be evolved to improve consumer trust levels.

While self-driven company or industry-led claims on food packaging require minimal effort to commercialize, they can lead to much lower levels of consumer trust compared to other approaches.

Regulatory claims and non-profit certifications with third-party verification offer a more robust approach with the potential to increase consumer trust levels, but at a higher level of effort to commercialize.

The open-source framework, developed by Deloitte Canada and value chain participants, proposed four criteria for a standardized, climate-smart product claim and emissions-intensity measurement metrics which can be implemented throughout the value chain to support third-party verification. By establishing these rigorous standards, the framework helps to ensure greater accountability, transparency and traceability, fostering more meaningful environmental stewardship throughout the value chain.[50]

2.5
Closing the loop by embracing circularity in the food system

Historically, food production systems have followed a linear process: extracting raw materials, processing them into products, consuming those products, and ultimately generating waste.[51] A significant amount of consumer-ready food waste is produced globally each year. This represents a large loss—not only in nutritional resources, but also of the energy, labor, land and other inputs required for food production that could have been put to alternative use.

Food waste occurs throughout the entire supply chain, from the farm to the consumer:

- At the farm level, 13% of the world's food produced is lost between post-harvest production and retail due to factors like over-production, weather, disease, inadequate infrastructure and inefficient production processes.[52]
- At the consumer level, 17% of the food available to households, retailers, restaurants and other food services is wasted, often due to a lack of awareness and overpurchasing, resulting in product expiration before use.[53,54]

The combined impact of waste inefficiencies across the supply chain not only exacerbates global food insecurity, but can also cause the avoidable exhaustion of critical resources.

The reuse and regeneration of materials and waste represent an economic strategy focused on minimizing environmental impact and optimizing resource efficiency. A circular food system approach differs from a technological solution, which aims to improve productivity through innovation. Instead, circularity in the food system aims to close the loop by repurposing waste so that it can be used as inputs, thereby reducing demand for new raw materials. The strategy integrates sustainable practices across industries and supply chains to prolong the useful life of materials and ensure circulation within the economy for as long as possible. The management and profitable reuse of food and other organic waste may have a transformative effect on the future of a sustainable food system.

Delivering circularity solutions across regions

The Circularity Gap Report series, published by the Circle Economy Foundation, presents varying circular solutions for food systems that are tailored to local contexts and country profiles worldwide. While the focus for higher-income countries needs to be a shift away from over-consumption, lower-income countries still need to build an economic system that can satisfy their society's basic needs.[55] There are three "types" of countries when it comes to potential circularity transformations:[56]

Shift countries account for a minority of the world's population but consume one-third of materials and generate two-fifths of emissions. This profile fits with higher-income countries, characterized by over-consumption, high food waste, and dependence on imports. Most food waste in these countries occurs at the retail and consumption levels, making these the primary focus of circular solutions.

Build countries are home to 46% of the global population and face challenges such as malnutrition and difficulties to meet other basic needs like education and health care. This profile fits with lower-income countries, characterized by agrarian, biomass-based economies where most waste is generated from agricultural activities. As a result, circular solutions should concentrate on the farm and production end.

Grow countries account for 37% of the global population and are undergoing rapid industrialization to accommodate a growing middle class. This profile fits with middle-income countries, characterized by high population growth and rising incomes. The challenge is to ensure adequate nutrition that can be decoupled from mounting environmental pressures. A shift towards both circular production and consumption are the priorities.

South Korea has made remarkable progress in food waste recovery by increasing the food waste recycling rate from 2% in 1995 to 95% by 2019. This was driven by a ban on landfilling food waste and a "pay-per-use" scheme costing families approximately US$6 per month on average.[57]

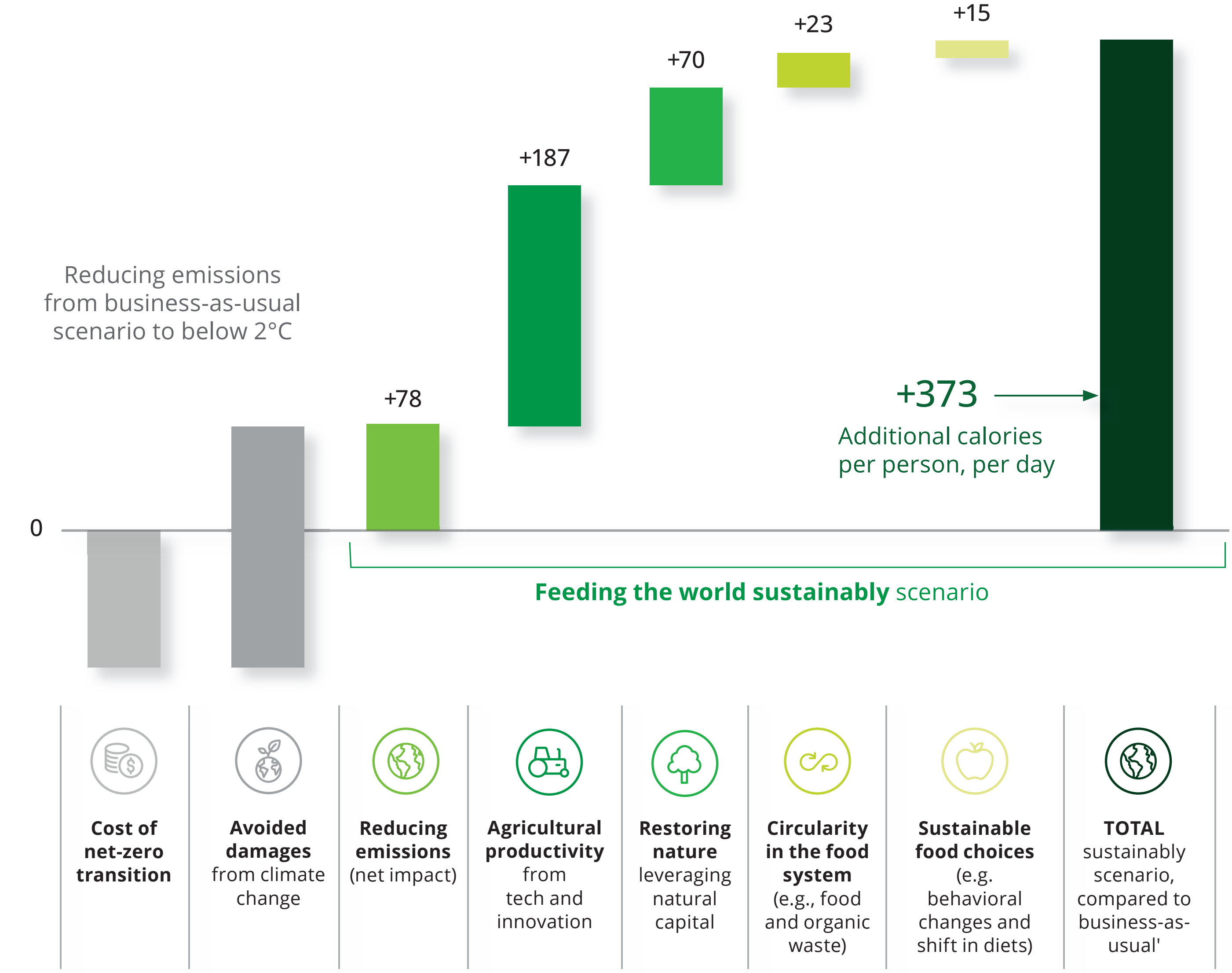
ColdHubs is a small business based in Nigeria and assists farmers and vendors to preserve their perishable products by providing access to solar-powered cold storage. The 24 operational services have saved 20,400 tons of food from spoilage while increasing household income for over 3,500 smallholders and reducing 462 tCO2-e.[58]

Global Bugs, a Thai business, produces crickets at a low cost and requires a fraction of the feed, water and an almost negligible amount of land compared to producing the same quantities of beef. In addition, insects offer a unique solution to food waste challenges by consuming low-value agricultural waste.[59]

03

The turning point: the opportunity of changing course

Figure 3.1 Decomposition of change in food supply in 2070 (kcal/person/day)



Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

The food system serves a unique position in the global economy, fulfilling multiple objectives.[60]

It needs to produce enough calories and nutrients for all, support access to healthy diets, and do so in an economically viable way for producers. Its production is intertwined with the natural world—both drawing on these resources as key inputs (e.g., land and water) and impacting the natural environment.

The food system's current path is not sustainable. While global calories increase (Figure 3.1a) in a business-as-usual scenario, current trends will see hunger persist and emissions increase (Figure 3.1b), causing warming to worsen alongside other environmental degradation.

The "feeding the world sustainably" scenario considers how the implementation of the system-level solutions (Chapter 2) can help the food system break away from this path. A more sustainable food system increases food supply, producing an additional 626 kcal per person per day in low-income countries, while supporting emissions reductions. These system-level changes benefit the global economy, raising GDP by US$121 trillion from 2025 to 2070.

3.1
What does it mean to feed the world sustainably?

The world can produce nearly 3,880 calories per person, per day, by 2070, an 11% increase on the business-as-usual scenario. This is largely driven by the increase in the supply and consumption of food in lower-income countries.

The concentration of benefits to those regions increases over time, as vulnerable economies are able to avoid the worst impacts of climate change, and structural adjustments are made to integrate new and innovative agricultural practices. By 2070, only 8% of the additional calories produced are consumed in high-income countries.

These results have important implications for the prevalence of hunger and undernourishment. The regions that benefit the most in this scenario are those that have the highest rates of undernourishment. One-in-five of these extra calories in regions of the world where undernourishment occurs could support an additional 300 million of otherwise undernourished people in 2070.

The modeling framework shows that the system-level solutions implemented together could reduce global food prices by 16%, driven by a fall in the price of each major food group.

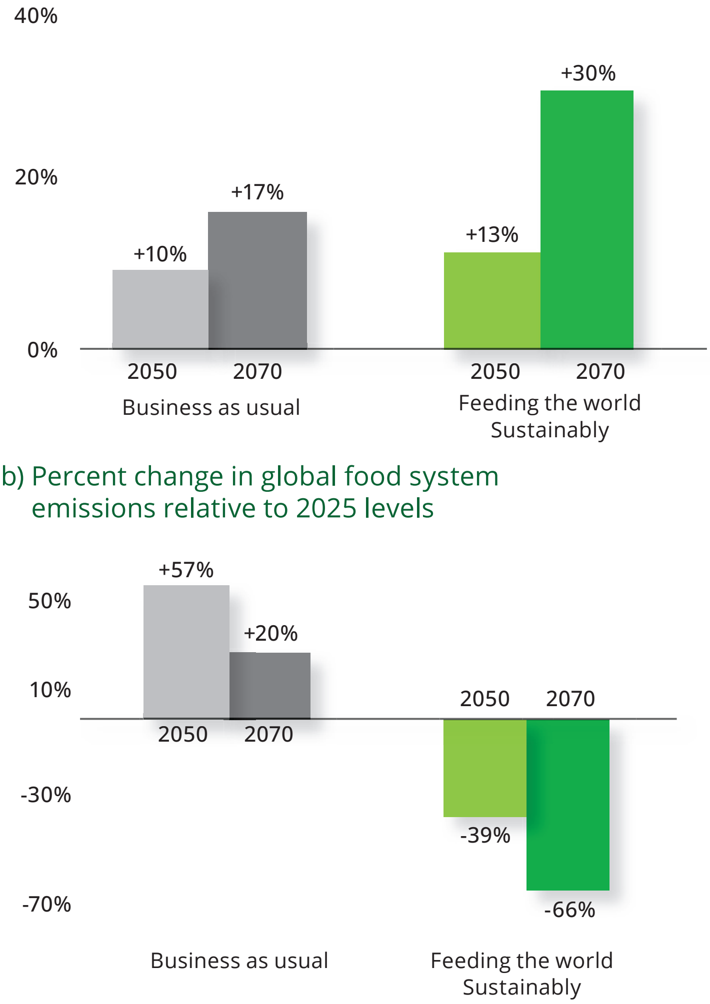
The solutions modeled under this analysis highlight the productivity gains that can be made from investing in technology and innovation, as well as improving land management practices.

Producing more with less is essential to relieving pressure on the environment and limiting global warming.

Table 3.1 summarizes the contribution of each of the five proposed solutions to feeding the world more sustainably.

Figure 3.1 Producing more food with less impact on the climate

a) Global food supply relative to 2025 levels (kcal/person/day)



Source: Deloitte analysis based on FAO and D.Climate modelling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

Table 3.1 Five solutions to feeding the world sustainably

Solution	
	Accelerating innovation and technology can help drive sustainable agricultural productivity growth. Increased investment in research, development and extension (RD&E) accelerates agricultural productivity growth by 0.30 percentage points above "business-as-usual" rates.[h] By 2070, agricultural productivity is 13% higher in the "feeding the world sustainably" scenario.
	Contributing to reducing global emissions and limiting warming to below 2°C helps to reduce the physical damages of a "business-as-usual" path that is over 3°C warmer by the end of the century. The global economy grows faster in a below 2°C world.
	Protecting, restoring, and improving natural capital can help promote biodiversity and support key ecosystem functions critical to the agricultural sector. Increased investment in protecting, restoring and improving natural capital further accelerates agricultural productivity growth by 0.18 percentage points above "business-as-usual" rates. By 2070, agricultural productivity is 5% higher in the "feeding the world sustainably" scenario.
	Enhanced circularity of food waste lifts material efficiency of the food manufacturing sector gradually, reflecting interventions associated with doubling today's rates of circularity in the economy by 2032.[61] This raises material efficiency up to 2.4% higher between 2035 and 2050.
	Consumer and dietary choices shift gradually over the next 25 years. Growth in demand for red meat is on average 0.55 percentage points lower each year, with compensatory increases in demand for plant-based foods. By 2070, global demand for cattle meat is 13% lower in the "feeding the world sustainably" scenario.
Total	

Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

Total additional calories (trillion kcal)	Reduction in food prices	Additional calories (kcal/person/day)	Relative contribution to overall improvement in "feeding the world" scenario
change from baseline in 2070 (% change from baseline in 2070)	*% change from baseline in 2070*	*change from baseline in 2070*	*% of total change*
517 (4.6%)	8.2%	187	50%
215 (1.9%)	3.4%	78	21%
194 (1.7%)	3.1%	70	19%
64 (0.6%)	1.0%	23	6%
41 (0.4%)	0.6%	15	4%
1,031 (9.2%)	16.3%	373	100%

[h] Global agricultural total productivity growth has been 1.3% per annum between 1962 to 2020. After adjusting for historical climate change over the same period, the adjusted total productivity growth has been 1.1% per annum (Ortiz-Bobea et al 2021). In the business-as-usual scenario, agricultural total factor productivity is reduced through the impacts of future warming. Agricultural productivity growth above historical levels peaks in 2050 and is maintained thereafter.

[i] These gains peak in 2050 and are maintained thereafter.

3.2 Ensuring enough food for each person: Food production and consumption increases

3.2.1 Overall increase in food production and calories

These transformations will help enable the food system to become more productive with fewer costs to the natural world, limiting further environmental damages to the food system, while increasing global food supply and distribution.

Modeling indicates that these food system changes will see global food production increase by 9.2%, relative to the business-as-usual scenario—equivalent to a US$22 trillion increase in the output in the food system between 2025 and 2070. In 2070 alone, agricultural output is expected to be nearly US $1 trillion higher, which is equivalent to the current agricultural output of the US and India combined.[62]

This will lead to an additional 373 calories per person, per day, around the world. A more sustainable food system can increase calorie availability, providing approximately 3,880 kcal per person, per day, by 2070—around 11% more calories than the "business-as-usual" scenario. This includes an increase in the availability of macronutrients including carbohydrates, fats, and proteins.[j]

Overall, protein consumption continues to grow, even as dietary patterns shift away from emissions-intensive protein sources. Globally, protein consumption increases to 10.4% above "business-as-usual" levels by 2070, with emissions-intensive protein sources being substituted with other meats, poultry, and legumes. Lower prices increase affordability of "healthier" diets, such that people can access adequate calories composed of a mix of carbohydrates, fats and proteins.

While D.Climate does not include a land-use model, separate land-use competition analysis finds that it is possible to feed a growing population sustainably while managing land-use demands for emissions reduction activities.[63]

Box 3.1 Land use change

To help feed a growing population sustainably, minimizing the reliance on clearing additional land for agriculture (where this is not offset elsewhere) should be a priority. The world should focus on maintaining and making the best use of the current stock of land used for agriculture.

Historically, increased demand for food has been met, in large part, by expanding the land used by the agricultural sector. Agricultural land use has increased four-fold since the beginning of the Industrial Revolution. Between 1962 and 2010 alone, almost 500 million hectares (Mha) of forests and woody savannas were cleared for agriculture.[64] The latest estimates suggest that almost half (46%) of the world's habitable land is used for agriculture (crops, pastures and livestock).[65]

Looking ahead, scenarios from the IPCC, consistent with warming above 3°C, are associated with agricultural land use continuing to significantly expand. The baseline analyzed here would suggest an increase of agricultural land use by 645 Mha—an area that is twice the size of India.[66] Over this period, 350 Mha of forest cover could be lost, which is the equivalent to almost two-thirds of the Amazon.[67]

Although a low-carbon future and the challenges associated with feeding the world sustainably entail complex land use trade-offs, future land use changes to support emissions reduction activities do not necessarily imply that agricultural production is disrupted on a global scale.

Contemporary land use competition analysis of a 1.5°C climate stabilization scenario also shows that despite increased demand for land for emissions reduction activities such as nature-based solutions (carbon sinks in the form of woody biomass), bioenergy production, and wind and solar power generation, global land is sufficient to provide increased per person food production over the century, even without significant dietary changes.[68] Although there is a marginal increase in land use for food production (1.5%) between 2015 and 2100, a larger proportion of agricultural land incorporates nature-based solutions, and food production is increasingly decoupled from land use expansion.[69] Instead, the agricultural system transforms to meet future food demand in more sustainable ways.

While D.Climate does not explicitly model land use changes, improvements in agricultural output modeled as part of this analysis are a result of improvements in agricultural productivity. The volumes of implied production, which are increasing relative to the baseline, will likely have significant implications for land use. Although beyond the scope of this modeling, supporting long-term food production by making better use of land dedicated to food production today should remain a significant focus of sustainability efforts.

[j] Impact on availability of macronutrients is unavailable, as this data as not been mapped to GTAP sectors.

3.2.2 More affordable global food

As farmers and food manufacturers become more productive by adopting technology and innovation, as well as practicing better land management, they are able to produce more at a lower cost. Breakthroughs in technology play a role, including improvements in resilient crops and emissions-reducing feeds, alongside increased adoption and diffusion to low-income markets. Investments in monitoring and improving natural capital on productive land also contributes.

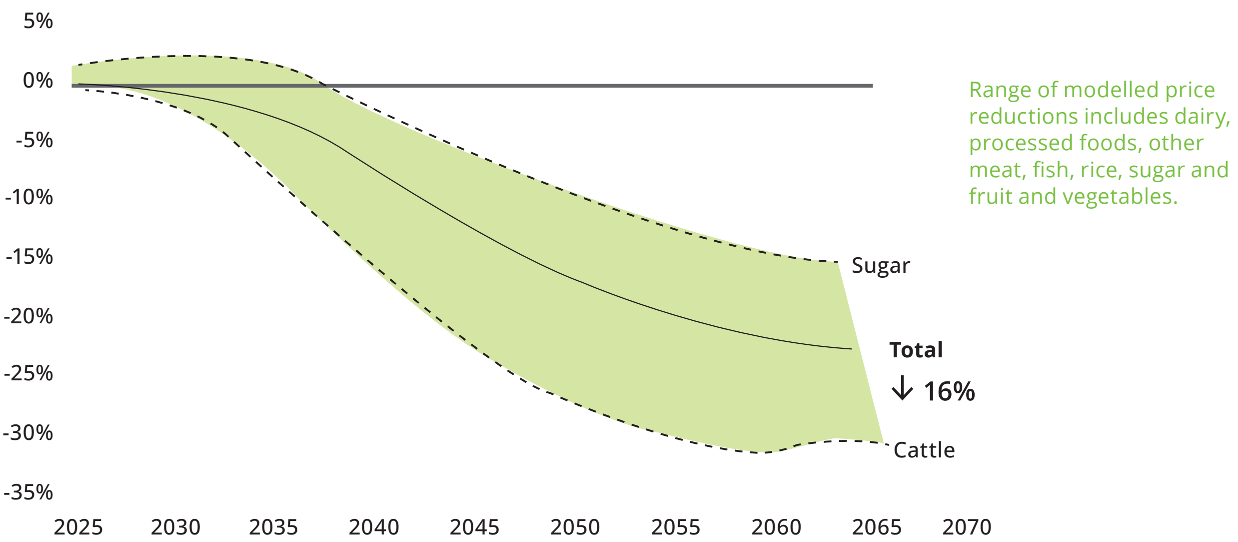
Lower producer prices flow through the supply chain and end up reducing prices at retails stores and markets, where households typically purchase food.

Overall, global food prices are expected to decline 16% by 2070 (Figure 3.2).

A greater global supply of food will shift overall prices down, while a gradual shift towards more sustainable diets will drive the changes in individual food commodities. Cattle meat will see the largest reduction in food prices, due to the changes in demand and diet preferences, namely, a switch to plant-based and alternative diets. Conversely, sugar sees one of the smallest price reductions.

Improvements in food affordability are expected to disproportionately benefit lower-income households, as spending on food typically represents a bigger share of discretionary income.

Figure 3.2 World food price deviation
(% relative to the business-as-usual scenario)



Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

3.2.3 Increased volumes and value of production in large food producing countries

The effects of actions to limit global warming to well below 2°C and feed the world sustainably will differ around the world. Each region eventually benefits from a more sustainable global economy that avoids the worst physical damages associated with unchecked climate change.

The “feeding the world sustainably” scenario sees food system output grow, an increase in economic activity and an uplift in the overall food availability for multiple regions. Output from the food system can be consumed domestically or traded between countries, which allows for equitable distribution of food around the world, particularly for countries that may not be large agricultural producers.

For large agricultural producers, increased food system output not only means increased food availability in their countries, but also flow-on benefits to the rest of their economies (Table 3.2). Brazil, Indonesia and India see the largest percentage increase in food availability per person of the selection of large food producers.

Investment in research, development and extension (RD&E) leads to new technologies and lower costs of production that benefits each region under the “feeding the world sustainably” scenario. Investments in restoring nature vary in their impacts by region, but do not constrain the largest food producers which continue to grow. For much of the global economy, particularly beyond the food system, avoided climate damages enabled by the transition to net-zero supports significant productivity growth.

Table 3.2 Selection of large food-producing countries, ranked by the percentage increase in additional food calories supplied, food system output and GDP (deviation from business-as-usual scenario)

Region	Additional calories (kcal/person/day	Additional food system output	Additional GDP
	change from baseline in 2070 (% change from baseline in 2070)	*NPV, 2025-2070 US$ billions*	*NPV, 2025-2070 US$ billions*
Brazil	590 (18.0%)	1,000	12,600
Indonesia	430 (14.7%)	1,590	9,300
India	190 (9.9%)	2,200	23,200
China	350 (9.3%)	3,840	38,200
USA	170 (4.2%)	3,780	8,000
Europe Union and the UK	100 (2.7%)	1,590	13,900

Note: All values rounded.
Source: Deloitte analysis based on D.Climate modeling described in Appendix B. © 2024. For information, contact Deloitte Touche Tohmatsu Limited.

3.2.4 More calories in lower income countries

Low-income countries have the largest increase in food consumption per person, with half of all additional global calories being consumed in these countries. This translates to an average increase in consumption for these countries by 626 calories per person, per day in 2070 (Figure 3.3). This is likely to significantly lower the risk of people going hungry, as approximately one-third of undernourished people currently reside in low-income regions,[70] and reflects improved global food equity by increasing supply for those who need it the most.

The concentration of benefits to those regions increases over time, as global efforts to reduce emissions result in vulnerable economies particularly benefiting from avoiding the worst impacts of climate damages, and structural adjustments are made to integrate new and innovative agricultural practices.

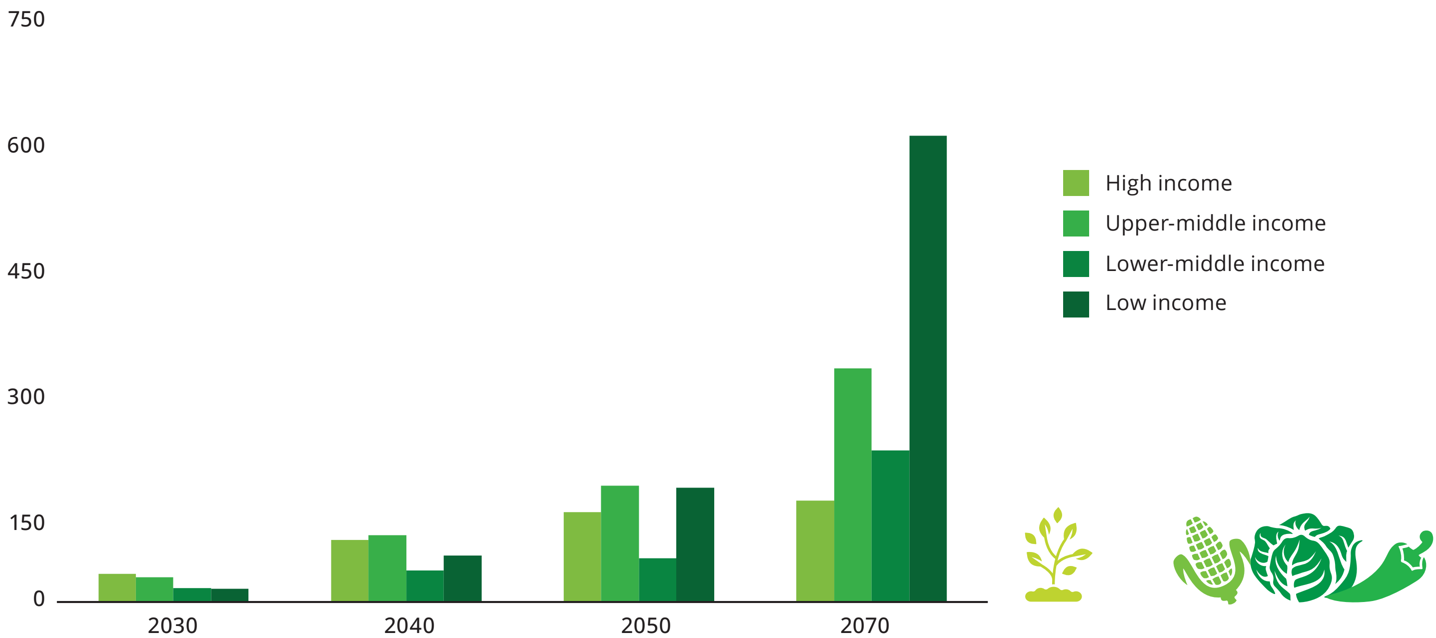
By 2070, only 8% of the additional calories produced are consumed in high-income countries.

Not only are low-income regions disproportionately affected by hunger, but their economies are also more reliant on food production as a source of employment and income. As such, these regions are highly exposed to climate risks and transition costs associated with decarbonizing the food production system. Limiting the damages associated with climate change, coupled with productivity improvements in the food system, will likely drive significant economic gains in these regions, while enhancing food security.

3.2.5 More calories will meaningfully contribute to a reduction in global hunger

The "feeding the world sustainably" scenario could significantly reduce global hunger by increasing the availability and affordability of food, particularly in low-income countries.

Figure 3.3 Additional food consumption by country-income group (kcal/person/day)



group (kcal/person/day)

Source: Deloitte analysis based on D.Climate modeling described in Appendix B.

Today, the world faces persistent undernourishment. The latest estimate shows that 730 million people, or 10% of the global population, are undernourished. While ongoing economic growth and development, particularly in Asia, continues to reduce the absolute number of people facing undernourishment, under current trends, the Food and Agriculture Organization of the United Nations (FAO) projects that the world will miss its target to eliminate hunger by 2030.[71]

Extending the FAO's current outlook for the undernourished population, hunger would persist in the long-term under a "business-as-usual" scenario, but fall to around 6% of the global population in 2070.[l] The "feeding the world sustainably" scenario, by contrast, sees the world with an extra 1,030 trillion calories in 2070. This is enough to support an additional 1.6 billion people in 2070, at the minimum daily requirements of around 1,800 daily calories per person. The modeling suggests almost one-in-five of those extra calories will be in regions of the world where undernourishment occurs, enough to fully support an additional 300 million of otherwise undernourished people from those regions (Appendix C).

This emphasizes how the interconnected nature of potential solutions—the required decarbonization and transition of global food systems—can ultimately contribute to reducing rates of undernourishment.

Calorie availability is an important aspect of food security but is one part of the challenge to reducing world hunger.

Addressing undernourishment goes beyond just calories. It also involves ensuring access to micronutrient-rich foods that are essential for a healthy diet. While staple food such as maize, wheat and rice provide the bulk of calories in low-income countries, they are often lacking micronutrients.[72] Foods rich in micronutrients, including fruits, vegetables and animal products, are less accessible to low-income countries. Policy solutions can also lie within individual countries and their social policies, which are beyond the scope of this report.

3.3 A more productive global economy

By undertaking this transformation of the food system, the world economy could be larger by US$121 trillion between 2025 and 2070.[m] Relative to the "business-as-usual" scenario, on average, global GDP increases by US$1.7 trillion each year until 2070, with higher growth achieved post 2055—once the bulk of the food system transformations have been achieved. In 2070, global GDP is US$16 trillion larger, which is equivalent to an almost 5% increase relative to "business-as-usual."

Lower-income countries, like Sub-Saharan Africa, Southeast Asia, Oceania, and South America appear to experience the most significant increase in GDP under "feeding the world sustainably." These could see a 12% boost in GDP resulting from transformations to the food system and increased supply of food. There is a modest reduction in GDP in high-income countries relative to the business-as-usual scenario, but these economies are still growing. However, this reflects a more equal distribution of global resources.

[k] Undernourishment is defined as the inability to obtain enough food to meet the minimum required caloric intake. The "depth of food deficit" indicator provides the average number of calories missing from the diet of undernourished people to reach the minimum required caloric intake. This data was leveraged to estimate how much an improvement in the availability of calories could make to closing the average food deficit gap in the "feeding the world sustainably" scenario relative to a baseline projection of undernourishment.

[l] This analysis accounts for global population growth, which reaches 9.5 billion people by 2070 based on IPCC projections.

[m] Expressed in net present value terms at 2% between 2025 and 2070.

04

Sowing the seeds of change

4.1 Enabling the system-level solutions requires coordinated action from today

Swift global action is needed to shift onto a path of feeding the world more sustainably. This section sets out the scale of the short-term actions and investments needed to enable the system-level transition from each part of the food system.

Feeding the world sustainably requires action across the food, climate and natural systems. From the local to the international level, each part of the economy has a role to play in enabling a more productive food system that is less harmful to the environment and contributes to reducing emissions to limit temperature rises to well below 2°C. Chapter 2 highlighted several specific examples of progress within industries and countries across a range of interventions that can help address the challenge of feeding the world sustainably.

At the international level, some notable initiatives have included:

- The UN Food Systems Summit (2021), which generated global momentum and collaboration towards systemwide transformation that is underpinned by sustainability, equity and health. This momentum has continued, with the fourth summit planned for 2025 UN Food Systems Coordination Hub.[73]
- The Apulia Food Systems Initiative (AFSI), launched by the G7 in June 2024, to develop systemic approaches to enhancing food security and nutrition. Building on the joint commitment announced two years prior—to mobilize US$14 billion annually for food security— AFSI aims to build resilient and productive food systems.[74] This can enable both sustainability and enhanced access to adequate nutrition in the face of the increasing impacts of climate change, and can also mobilize key

actors across multilateral organizations, private sector and philanthropies toward galvanizing innovation and action ahead of the 2025 Paris Nutrition for Growth Summit.

- Further updates to the National Biodiversity Strategies and Action Plans (NBSAPs) to better reflect and operationalize critical food system pathways to achieve the Kunming-Montreal Global Biodiversity Framework, ahead of the Biodiversity COP16 in Cali, Colombia.[75]

4.1.1 Climate action plays a central role

The long-term sustainability of the food system and its capacity to feed a growing population is fundamentally linked to the climate. While there is uncertainty around the pace and local impacts of warming, a business-as-usual pathway that sees warming increase by 3°C will put significant strain on the productivity of the system.

Deloitte has published several previous analyses of the economics of climate action: the Turning Point series, establishing the case for climate action across the economy, outlined Pathways to decarbonization and Financing the Green Energy Transition, identifying cross-cutting actions. This report builds on these bodies of work, by considering climate change and climate action as the context within which the food system transformation will take place. It is not, however, a detailed exposition of the system's decarbonization itself, which has been well covered recently.[76]

The development of new and investable nationally determined contributions (NDCs) for submission under the United Nations Framework Convention on Climate Change (UNFCCC) by early 2025 are a critical next step. Increased commitments by corporations are also playing a significant role. Continued investment in climate technology and development is already bringing down the costs, particularly in the energy sector. Further work will be needed in the food system, the next frontier for climate technology, to achieve similar cost reductions in clean technologies and realize global net-zero emissions ambitions.

Climate financing is critical to help hard-to-abate sectors reduce their emissions. The agrifood system currently receives 5% of all global climate financing for mitigation and adaptation across all sectors, despite contributing almost one-third of all GHG emissions. Climate financing to target reducing agrifood emissions will need to increase by 18 times - an average of US$260 billion per year - to shift food emissions on a pathway to net-zero. As it currently stands, the majority of climate financing is directed toward other sectors such as renewable energy or low-carbon transportation, which receive 51% and 26% respectively.[77] More investment in the food system is essential to accelerate its required structural transformation.

Nature-based solutions can have dual climate and food-system enhancing benefits. These need to be rapidly adopted by farmers, mostly by mid-century, and in a way that maintains trends in crop yield improvements.[78] As one component of nature-based solutions, climate finance for forests accounts for 1.5% (US$3.2 billion) of global public climate funding (US$256 billion), and 0.1% of total public and private land-sector funding in countries with high levels of deforestation ($1,495 billion).[79]

4.2 How much would it cost?

This analysis focuses on what is required to help ensure the long-term sustainability of the food system and its capacity to feed the world. The question then arises, what would such a transformation cost?[n]

The World Bank estimates that investment in the food system needs to reach US$260 billion per year (equivalent to 0.2% of global GDP in 2023) between now and 2030[80] to deliver actions that both put the world on a path to net-zero and are aligned to the broader sustainability of the food system. These actions include:

- Investments in improving natural capital increasing by up to US$37-142 billion per year, ideally financed through environmental markets;[81]
- On-farm mitigation measures that can be implemented today, including climate-smart and regenerative practices, irrigation efficiency, organic and biofertilizer production, and expansions in diversified protein supplies that could attract US$52-66 billion per year;[82] and
- A transition to circular systems, which will require some up-front investments of US$23-75 billion per year and promoting healthy diets would cost US$30-35 billion per year.[83] Behavior change initiatives will likely have the lowest costs and these costs tend to vary significantly depending on the interventions, which would include a mixture of traceability and consumer information initiatives as well as educational and awareness.

While it can be difficult to precisely estimate the global agricultural RD&E value across public and private sources, historical estimates suggest this has grown at around 2.8% per annum[84]. Between 2025 and 2030, this growth rate in annual investment in RD&E will need to significantly accelerate to achieve the improvements in productivity presented here. Improving the productivity of the food system is a key pillar of long-term sustainability.

4.2.1 Short-term actions to help address hunger today and support food security on a path to net-zero emissions

Separate from, but closely related to, this report is the shorter-term imperative to meeting Sustainable Development Goal (SDG) 2, which aims to end global hunger by 2030. Estimates from similar modeling have found that the up-front investments to reduce hunger over the next six years, lifting 700 million people out of hunger and malnutrition by 2030, is estimated to cost an additional US$93 billion annually.[85]

Short- to medium- term actions to reduce emissions towards net-zero should also focus on minimizing transition costs and supporting food security on this path. Decoupling the global economy from growth based on emissions will likely require substantial change in each sector of the economy. Actions and investment in the food system should balance these considerations and potential trade-offs during this transition.

The World Bank estimates a minimum investment increase OF UP TO $260 billion is required by 2030

4.3
Next steps for each segment of the food system

Mobilizing the financing and delivering the long-term sustainability solutions outlined above will involve each actor within the food value chain and require action beyond spending alone.

Technology and research actors will play a pivotal role in driving future improvements to productivity and yields, central to feeding the world sustainably.

- Not all the solutions needed to create net-zero food systems at scale exist yet, so breakthroughs in technology and cost reduction are critical to close the innovation gap.[86] Digital farm management tools, new crop varieties feed supplements, and cost-effective measurement technologies are just some of the ways that innovation can optimize farm-level activity and create value chain traceability and transparency. In many regions, efforts to extend leading practice can move countries toward the production frontier, without compromising environmental outcomes.[87]
- Increased investment in research and development won't be enough; extending and commercializing solutions that are fit-for-purpose across varied regions and sectors should be an increased point of focus.

The **food system value chain** is incredibly varied in its structure, and a wide range of actions will be needed within the value chain to adopt sustainable solutions.

- There are millions of farmers, many operating small-hold businesses. Globally, there are few processors and manufacturers, many with large multinational value chains. The largest 136 agri-food firms, generating more than US$5.2 trillion of revenue, are committed to reducing emissions by 50% relative to 2022 by 2050, much of this through reductions on farms among their suppliers.[88] These commitments, the actions that accompany these, and the implications this could have up and down the supply chain will be transformative for the sector. To align with Paris Agreement targets, these will also need to increase over the next five years.
- Collaboration across the supply chain will be essential, particularly between large and well-resourced processors with smaller supply chain operators upstream. The farming community is faced with an increasing number of demands and requirements while having to deal with difficult and worsening farm economics and climate shocks. Expecting farmers to self-inform on the importance and technical knowledge of climate-smart agriculture is unrealistic.

[n] These investments are implicitly captured in the "feeding the world sustainably" scenario. The capital expenditure of firms is an economic decision taken to maximize profits, but it not differentiated into different "types" of expenditure (e.g., investment in property versus climate technology or another other capital good). The outcomes of these investments are explicitly modeled as shocks.

- Adoption of technologies, such as traceability instruments, can not only help actors manage their transformation journey through improved data and analytics, but can also increase transparency across the supply chain, ensuring actors are better positioned to collaborate toward a shared future.

Policy makers and civil society will set a direction of travel for what sustainability could mean across regions.

- Farmers and value-chain players should be supported by an enabling environment that incentivizes the transition to climate-smart agriculture. Policies that subsidize climate-smart practices, encourage private sector investment, and clarify messaging to consumers are likely to accelerate the transition.[89]
- Similarly, some practices within the food system value chain generate costs and benefits (including social and environmental) which are borne by others—whether within the value chain, by producers, processors, distributors, or consumers, or society. These externalized costs and benefits are not typically reflected in market prices, which ultimately makes it harder to incentivize change and drive change-positive investment decisions.[90] In aligning incentives towards sustainable, socially responsible, agriculture, it is important that the true costs and benefits generated by players across the value-chain are understood, measured and used to shape decisions around future policy and investment.
- Private sector actors, such as non-government organizations and other civil society, can help drive change by advocating for these reforms.

Financial sector and other service providers will need to continue supporting farmers and offering products and services that encourage sustainable investment choices.

- Diverse financial mechanisms can help provide farmers with the capital and risk management needed to adopt and sustain climate-smart practices. These include innovative, stackable finance and insurance products; private sector procurement guidelines and long-term purchase agreements; and carbon credits and other forms of ecosystem service payments.
- Expertise and knowledge transfer has always been a critical component of the food system. Service providers will continue to play a crucial role in spreading leading practices and socializing innovations, particularly where they are fit-for-purpose, across diverse landscapes.[91]

4.4 The importance of acting now

This modeling has shown that feeding the world sustainably could mean, by 2070, feeding around 10 billion people by producing 40% more calories than it does today while limiting warming to well below 2°C and reducing the number of undernourished people by approximately 300 million.

The recent worsening of hunger rates and increases in global food prices are an early indicator of the food system heading toward an unsustainable path.

There are also several challenges to the food system that were not modeled as part of this analysis (e.g., the impact of changing water availability and quality, invasive species and disease, geopolitical disruption) (Appendix B). These may require additional and separate solutions but, nevertheless, will likely impact the world's capacity to feed itself–further motivating action today.

Appendix A
Glossary

Abbreviation	Description
CGE	Computable general equilibrium
CO_2	Carbon dioxide
COP	Conference of Parties
DAE-RGEM	Deloitte Access Economics Regional General Equilibrium Model
EO	Earth observation
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
IAM	Integrated Assessment Model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
NBSAPs	National Biodiversity Strategies and Action Plans
NDC	Nationally determined contributions
NPV	Net present value
NGFS	Network for Greening the Financial System
RD&E	Research, development and extension (RD&E)
SDG	Sustainable development goal
SSP	Shared Socioeconomic Pathway
TFP	Total factor productivity
UNFCCC	United Nations Framework Convention on Climate Change

Abbreviation	Unit	Conversion
kcal	kilocalorie	1 kcal = 1 Calorie = 1,000 cal
kWh	kilowatt-hour	1 kWh = 1,000 Wh
Mha	millions of hectares	1 Mha = 1,000,000 ha
Mt CO_2-e	million tonnes of carbon dioxide equivalent	1 Mt = 1,000,000 t

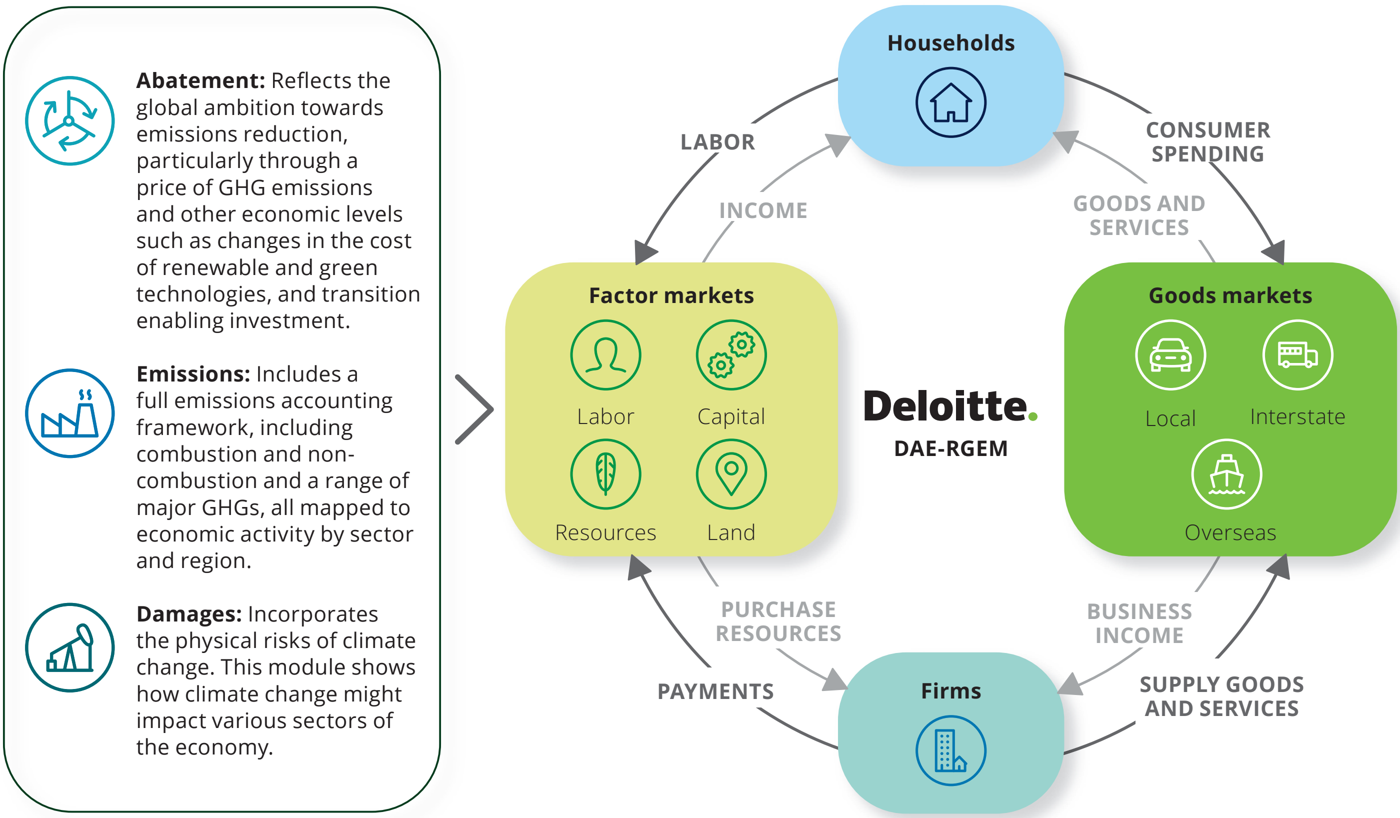
All currency values are in 2023 USD.

Appendix B.
D.Climate modeling approach

D.Climate model

Deloitte has adopted a framework that integrates the economic impacts of physical climate change into a baseline economic trajectory. Factoring in the costs of climate change reveals the economic harms of inaction – or inadequate action – and the significant opportunities that present themselves in remaking the global economy to grow without emissions. This analysis is undertaken using D.Climate, Deloitte Economics Institute's in-house climate-integrated computable general equilibrium (CGE) and integrated assessment model (IAM). D.Climate combines emissions, abatement, and climate damages with an economic model (DAE-RGEM) to represent the implications of the latest climate science and climate policy for economic activity (Figure B.1). In doing so, D.Climate captures the national and global picture of climate change, accounting for global trends in emissions reduction, technological development and changes in public policy to reflect the physical and transitional costs associated with different abatement pathways.

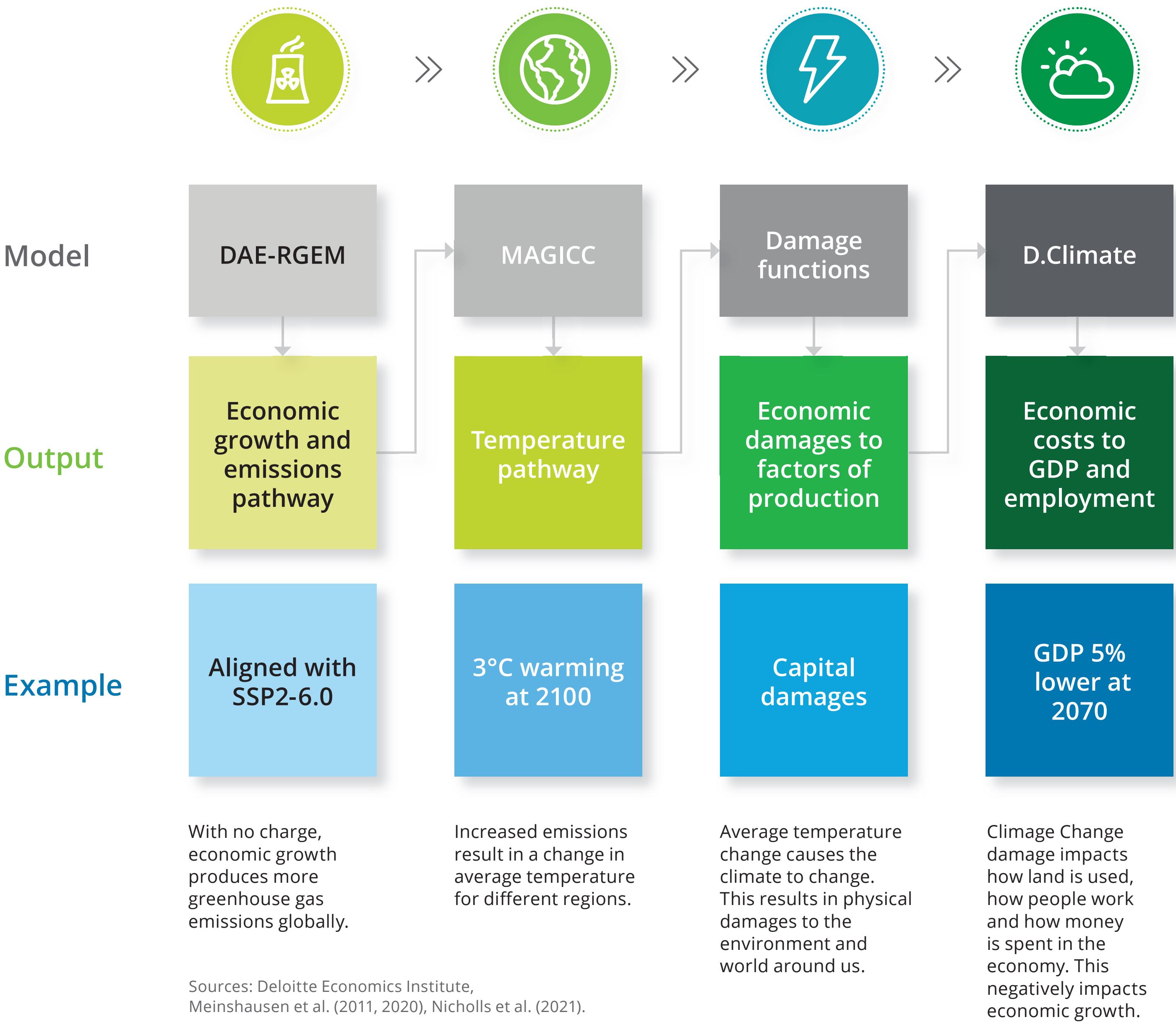
Figure B.1 Climate model



Source: Deloitte Economics Institute

A climate-economy link is established by defining a climate-affected economic baseline (Figure B.2). Scenarios with alternative emissions pathways are analyzed with reference to this baseline. Further information on D.Climate's framework and methodology can be found online as part of a detailed, publicly available technical appendix.

Figure B.2 D.Climate climate-economy link



Sources: Deloitte Economics Institute, Meinshausen et al. (2011, 2020), Nicholls et al. (2021).

Food systems specific considerations in D.Climate

- **Impact of climate change on agricultural productivity:** Climate change will see rising temperatures, higher concentrations of CO_2 in the atmosphere, and different regional patterns of precipitation which affect agricultural production.[92]

In this report, the impact of climate change on the agriculture sector is studied through changes in total factor productivity (TFP) of agriculture using the empirical relationship between TFP, temperature and precipitation identified in Oritz-Bobea et al. (2021).[93] By focusing on TFP, the authors offers a broader reflection of the effects of climate change on the agricultural sector, than previous studies that have focused mainly on crop yields.[94] The relationship between agricultural productivity and temperature and precipitation is also defined by modeling a counter-factual trend, with greater methodological transparency and specification tests that empirically justify the baseline model utilized in this report. In previous versions of D. Climate, the approach used to estimate the impact of climate change on the agricultural sector was based on Mendelsohn and Schlesinger (1999) and Cline (2007), where the variation in output of cereal crops per hectare was expressed as a function of temperature, precipitation, and CO_2 concentration.[95]

- **Nutritional impacts of changes in food supply:** To analyze how change in food supply affects the prevalence of hunger, undernourishment, food balance sheets and nutritional indicators such as calories, fats, proteins and carbohydrates from the FAO were integrated into the D.Climate database.[96] Nutritional accounts were linked to primary and derived food commodities to trace nutrients across different sectors supplying food including, primary production (agriculture), food processing, and food services sectors.

Interpreting results from D.Climate

Results from D.Climate provide a 'top down' order-of-magnitude estimate of the impact of climate change on economic outcomes such as GDP, employment, industry value added (at the industry and regional level), investment and trade. These outputs can be used to provide insights into which industries, jobs and economic activity have the most to lose—or gain—from different decarbonization trajectories. Further insights involve which local economies are impacted the most by the choices being made, the costs and benefits of different options for decarbonization, and by how much any degree of climate change will impact the economy and organizations. To this end, the core function of D.Climate is to provide an economic analysis tool that can be used to help answer a variety of questions relating to the economic impacts of a changing climate and evolving policy landscape.

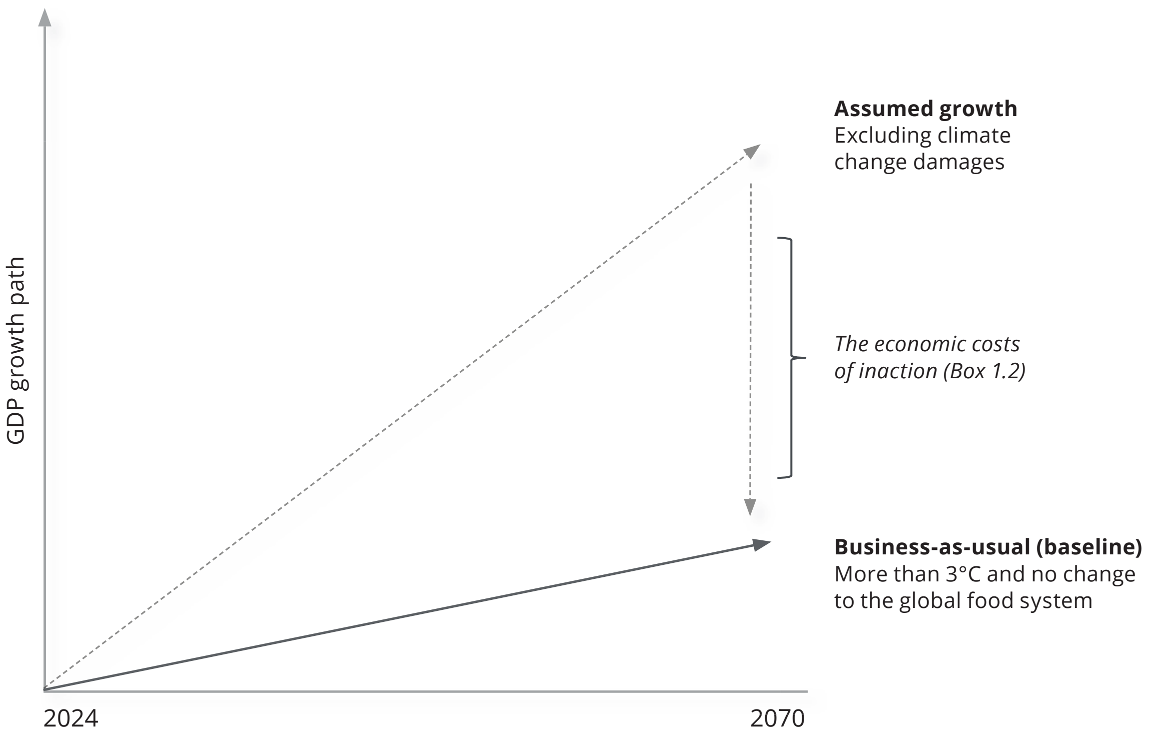
The 'impacts' presented in the scenario analysis are comparisons between possible future worlds.

The discussion of the modelling results usually describe the state of the economy in reference to an alternative future – as a deviation in a variable (like GDP) from one scenario to another.

Accounting for climate change impacts

This report analyses two scenarios: ' feeding the world sustainably' compared to the 'business-as-usual' baseline. The 'business-as-usual' scenario was first derived by adjusting a growth path that does not account for climate change by the extent of damage driven by more than 3°C of warming. This process is described by Box 1.1, Figure B.2 and is illustrated in Figure B.3 below. The economic costs of inaction described in Box 1.2 are calculated by comparing the 'business-as-usual' scenario to the 'assumed growth' path, one that does not account for climate change.

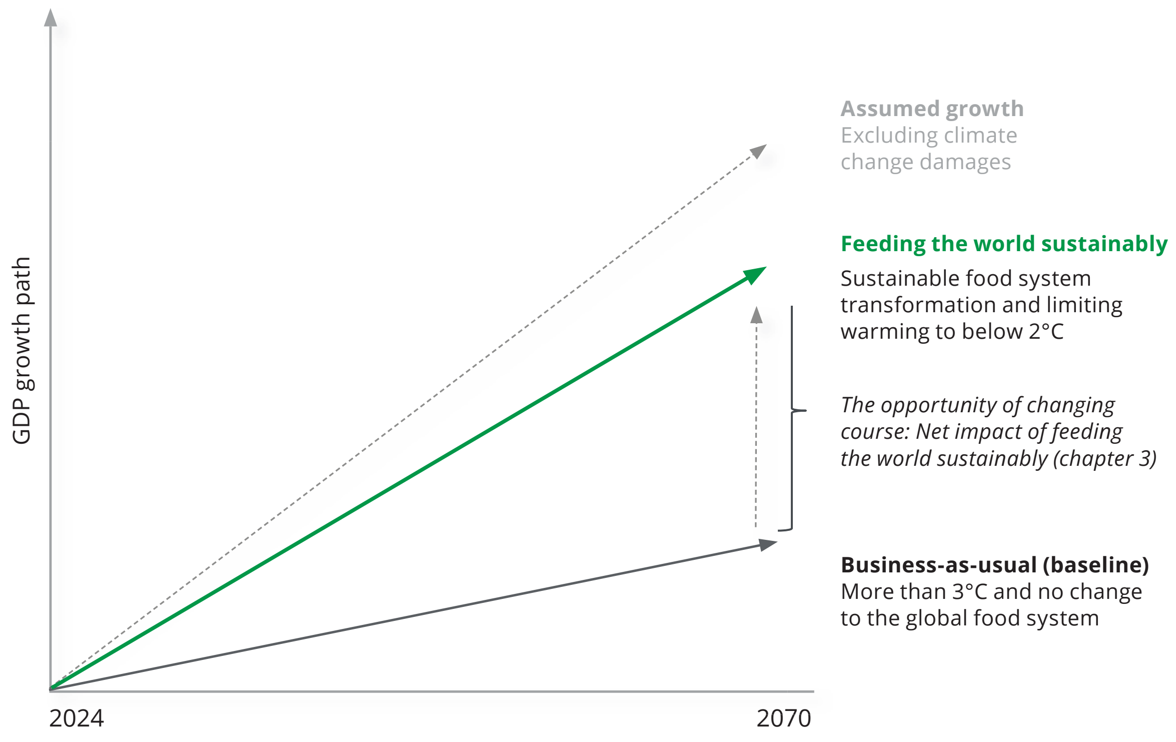
Figure B.3 Illustrative adjustment of an assumed growth path to account for the economic costs of inaction



Feeding the world sustainably scenario compared to the climate-damaged business-as-usual

Once the 'business-as-usual' baseline was defined, accounting for the impact of climate change, the 'feeding the world sustainably' scenario was compared to this. The deviations and impacts of variables throughout the report are comparisons of the 'feeding the world sustainably' scenario to the 'business-as-usual' scenario.

Figure B.4 Illustrative net impact of 'feeding the world sustainably' compared to the 'business-as-usual' scenario



Region and Industry definitions

D.Climate is a global model and can be tailored to a specified regional concordance in line with the Global Trade Analysis Project (GTAP) database. The following principles were considered in defining the proposed regional structure:

- **Socio economic considerations:** countries were initially grouped based on their income per person and undernourishment rates.
- **Climate zones:** consideration was given to climate zones.
- **Alignment with existing regional groupings:** comparisons were made to existing FAO and World Bank groupings.

From this set of regions, eight countries were disaggregated.

This resulted in a total of 23 regions modeled as part of this analysis (Table B.1). Income groupings are based on World Bank 2023 income classifications.[97] Due to the aggregations, individual countries may be grouped in different segments to their current country-level status.

Table B.1 Regional definitions

Income groupings	Model regions	Country mapping
High income	Australia & New Zealand	Australia, New Zealand
	European Union + EFTA + UK	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
	High income Middle East	Bahrain, Israel, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates
	Japan & South Korea	Japan, South Korea
	North America	Canada, Rest of North America, Bermuda, Greenland, Saint Pierre and Miquelon
	Russia	Russian Federation
	Rest of Europe	Aland Islands, Albania, Andorra, Belarus, Bosnia and Herzegovina, Faroe Islands, Gibraltar, Guadeloupe, Guernsey, Holy See (Vatican City State), Isle of Man, Jersey, Martinique, Moldova, Monaco, Montenegro, North Macedonia, Rest of Eastern Europe, Rest of EFTA, Rest of Europe, Réunion, Romania, San Marino, Serbia, Ukraine
	Singapore & Brunei Darussalam	Brunei Darussalam, Singapore
	USA	United States
Upper-middle income	Brazil	Brazil
	China	China, Hong Kong, Taiwan, Macao, Special Administrative Region of China
	Mexico	Mexico
	Middle/High income Latin America	Argentina, Chile, Uruguay, Rest of South America, Costa Rica, Puerto Rico, Caribbean

Income groupings	Model regions	Country mapping
	Rest of Asia	Mongolia, Rest of South Asia, Kazakhstan, Kyrgyzstan, Tajikistan, Armenia, Azerbaijan, Georgia, Turkey, Rest of East Asia, Antarctica, Bouvet Island, Rest of Former Soviet Union, British Indian Ocean Territory, French Southern Territories, Korea, Democratic People's Republic of, Afghanistan, Maldives, Turkmenistan, Rest of the World, Uzbekistan
Lower-middle income	India	India
	Indonesia	Indonesia
	Low-income Latin America	Bolivia, Colombia, Ecuador, Paraguay, Peru, Venezuela, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Dominican Republic, Jamaica, Trinidad and Tobago, Falkland Islands (Malvinas), French Guiana, Guyana, South Georgia and the South Sandwich Islands, Suriname, Belize, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, British Virgin Islands, Cayman Islands, Cuba, Dominica, Grenada, Haiti, Montserrat, Netherlands Antilles, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Turks and Caicos Islands, Virgin Islands, US
	Low- and Middle-income Middle East & North Africa	Iran, Jordan, Rest of Western Asia, Egypt, Morocco, Tunisia, Rest of North Africa, Iraq, Lebanon, Palestinian Territory, Occupied, Syria, Yemen, Algeria, Libya, Western Sahara
	Nigeria	Nigeria
	Rest of South Asia	Nepal, Bangladesh, Sri Lanka, Pakistan, Bhutan
	South-eastern Asia (and Oceania)	Rest of Oceania, Cambodia, Lao PDR, Malaysia, Philippines, Thailand, Vietnam, Rest of Southeast Asia, American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, United States Minor Outlying Islands, Vanuatu, Wallis and Futuna Islands, Myanmar, Timor-Leste
	Southern Africa	Botswana, Namibia, South Africa, Eswatini, Lesotho
Low income	Sub-Saharan Africa	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Senegal, Togo, Rest of Western Africa, Central Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa, Rest of South African Customs Union, Cape Verde, Gambia, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Saint Helena, Sierra Leone, Central African Republic, Chad, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe, Angola, Congo, Democratic Republic of the, Burundi, Comoros, Djibouti, Eritrea, Mayotte, Seychelles, Somalia, Sudan, South Sudan

Source: Deloitte Economics Institute

Understanding the potential pathways to solving global hunger sustainably requires an analytical approach which can capture the interlinkages between the macroeconomy, global food markets and trade, and agrifood systems. The agricultural and food system has been disaggregated into its sub-sectors to reflect the position of agrifood systems across different sectors and within value chains. The industries reported on in this report are defined in Table B.2. These industry aggregations are specified in line with the GTAP database.

Table B.2 Industry definitions

Industry name	Description
Paddy rice	Primary production of rice
Wheat and other grains	Primary production of wheat and other grains (i.e., maize, sorghum, oats)
Vegetables, fruit, nuts & seeds	Primary production of vegetables, fruits and nuts
Oil seeds	Primary production of oil seeds and oleaginous fruits
Sugar cane, sugar beet	Primary production of sugar crops, including sugar cane and beet
Bovine cattle, sheep and goats, horses	Cattle, including bovine animals and horses
Raw milk	Raw milk production
Other animal products	Other livestock, including swine, poultry and eggs
Other agriculture	Production of non-food agricultural products, including spices, aromatics, fiber crops, wool and forestry
Fishing	Fish production
Coal, oil, gas + gas manufacturing and distribution	Coal, oil and gas mining + gas manufacturing and distribution
Other mining	All other mining extraction, including metals ores, other minerals and quarrying
Cattle Meat manufacturing	Production of processed cattle meat
Other meat manufacturing	Production of processed chicken, pork and other meats
Dairy	Dairy products including processed milk, cheese and yoghurt

Industry name	Description
Rice	Processed rice
Sugar and molasses	Processed sugar products
Vegetable oils	Processed vegetable oils
Other food	All other processed foods not elsewhere classified
Beverages & tobacco products	Beverage and tobacco products
Other manufacturing	All non-food manufacturing
Clean electricity	Clean electricity (e.g., renewables)
Conventional electricity	Conventional electricity
Utilities	Electricity transmission and distribution, and water distribution
Construction	Residential and commercial construction
Accommodation, Food and service activities	Accommodation, food and service activities, including restaurants, bars hotels and cafes
Trade	Wholesale and retail trade
Transport	Air, water, road and rail transport services + warehousing and support activities
Services	All private sector services including administrative, scientific, technical and legal services
Government services	Services provided by the government, including public administration, safety, health and education

Source: Deloitte Economics Institute based on GTAP 11.

Scenario descriptions

Several key variables and assumptions describe the scenarios analyzed in this study. The outlook for the food system is analyzed under two different scenarios: 'business-as-usual' and 'feeding the world sustainably'. The economic narrative and underlying assumptions that define each scenario are summarized in Table B.3.

Table B.3 Scenario descriptions

	Business-as-usual	Feeding the world sustainably
Scenario narrative	The business-as-usual scenario reflects a continuation of historical social, economic, and technological trends and slow progress towards sustainability. **No significant action is taken to reduce emissions and temperatures increase to just above 3.9°C by 2100.** In this scenario, the agrifood system evolves slowly. Meanwhile, the cost of climate change inaction is high and materially impact food production. Environmental degradation from unsustainable farming practices also continue to undermine food production. Together, these **growing supply-side and demand-side pressures exacerbate hunger and food insecurity in vulnerable countries.**	This scenario reflects **a step change in what, where and how food is grown. Countries invest in agriculture-related innovation and technology, drive changes in diets, address environmental problems that undermine** food production (such as land degradation and biodiversity loss) and implement policies that deliver a more equitable food systems transition. Meanwhile, a rapid and coordinated decarbonization also **limits the physical impacts of climate change on agricultural productivity** in line with the Below 2°C scenario. Together these interventions highlight the economic dividend associated with investing in the agrifood systems transition.
Population	Global population reaches 9.5 billion in 2070, with a steadily growing middle class.	
Temperatures	Temperatures increase to 3.9°C by 2100.	Decarbonization efforts make it possible to limit warming to well below 2°C by 2100. Temperatures increase to 1.7°C by 2100.
Emissions	Gross emissions reach 95,000 Mt CO_2–e in 2070. This is equivalent to a 133% increase in global emissions relative to 2005 levels. [98] There is no negative emissions sink in this scenario. Emissions from the land use, land use change, and forestry sector increase gradually between now and 2070.	After peaking in this decade, global emissions decline rapidly to limit warming to well below 2°C. Global net emissions are 73% lower than 2005 levels by 2070, declining to 11,000 Mt CO_2–e. There is a gradual expansion of negative emission sinks from 2040. In 2070, negative emissions are approximately -2,500 Mt CO_2–e.
Technology learning rates	Average annual $/kWh in capital costs for renewables decline at approximately 1.8% per year between 2024 and 2074.	Average annual $/kWh in capital costs for renewables decline at approximately 2.0% per year between 2024 and 2074.
Subsidies for the clean electricity sector	With no significant action taken to reduce emissions, at a global level, there is little additional public involvement to encourage the deployment of clean electricity.	Analysis from the International Energy Agency (IEA) suggests that public sector investment in the clean energy sector is anticipated to increase rapidly this decade to support the global decarbonization efforts. This investment is modelled as a subsidy to the clean energy sector which peaks in 2060, reaching approximately 0.2% of global GDP. This subsidy supports the deployment of clean energy and lowers transition costs for energy-intensive industries.

Source: Deloitte Economics Institute based on Riahi et al (2017), IEA (2021).

Feeding the world sustainably scenario

Several agriculture-specific shocks were introduced to model the solution framework outlined in the 'feeding the world sustainably' scenario. These assumptions have been summarized.

Table B.4 Summary of assumptions in the 'feeding the world sustainably' scenario

Agriculture sector interventions	Descriptions	Sources and information used to develop assumptions
Investment in agricultural research and development and technology adoption	Investment in agricultural RD&E drives innovation and diffusion of new and emerging technologies in the agricultural sector. For example, this could include further developments in precision agriculture and Earth observation technologies. These technological advancements boost total factor productivity by increasing the efficiency of inputs.	• The R&D cost of climate mitigation in agriculture[99] • International Agricultural Productivity[100] • R&D Capital, R&D Spillovers, and Productivity Growth in World Agriculture[101] • Climate-Induced Yield Changes and TFP: How Much R&D Is Necessary to Maintain the Food Supply?[102]
Land restoration impacts on agricultural productivity	Investment in on-farm and off-farm land restoration practices such as conservation agriculture, agroforestry, grazing management, grassland management, and assisted natural regeneration contribute to both short- and long-term improvements in agricultural productivity by safeguarding critical ecosystem services on otherwise degraded landscapes. Sustainable land management improves soil health by enhancing nutrient cycling, water retention, and erosion control, which has a direct effect on crop yields. Restoring and protecting natural capital also promotes biodiversity, supporting vital ecosystem services like pollination and pest control, while enhancing water regulation, carbon storage, and reducing soil erosion, all of which contribute to increased agricultural yields.	• Nature's Frontiers: Achieving Sustainability, Efficiency, and Prosperity with Natural Capital[103] • Creating a Sustainable Food Future[104] • The global potential for land restoration: Scenarios for the Global Land Outlook 2[105]
Change in dietary preferences	A modest shift towards healthier and more sustainable diets globally reduces demand for red meat,[o] which is substituted with other sources of proteins (poultry, legumes, and seeds).	• Creating a Sustainable Food Future [106] • The global and regional costs of healthy and sustainable dietary patterns: a modeling study[107] • An exploration into diets around the world [108]
Improvements in waste utilization in a circular economy	Improvements in utilization of waste in a circular economy framework reduces demand for virgin materials, increasing the efficiency of intermediate inputs.	• The Circularity Gap Report, 2023 [109] • Creating a Sustainable Food Future [110]

o The 'red meat' industry in the model includes all major red meat categories other than pork.

Limitations and notes on interpretation

Sensitivity to discount rate

Deloitte Economics Institute utilizes a 2% discount rate for economic analysis pertaining to the impacts of climate change. A lower discount rate recognizes the long-term impacts of climate change and the role of action (or inaction) today and its impact on the wellbeing of future generations. This rate also reflects a consistent view on social discounting in climate change economic analysis, based on the results of a survey of economists in the American Economic Journal: Economic Policy (the sample contains over 200 academics who are defined as experts on social discounting by virtue of their publications) which indicates that most favor a low discount rate, with more than three-quarters arguing for a median discount rate of 2%.[111]

More recently, Bauer and Rudebusch (2023) have analyzed trends in interest rates in the bond market to posit that lower interest rates since 1990's also provide a rationale to utilize a lower social discount rate in climate policy analysis. Their analysis suggests real discount rates should range between 0.5% and 2%.[112] The US government, for the first time in 20 years, has also recently updated its guidance to a 2% discount rate, and suggested a lower discount rate for analysis longer than 30 years.[113] This discount rate is utilized in their calculation of the social cost of carbon.

Interpreting the "costs" of net-zero transition

To reduce emissions, many parts of the economy much change and shift their production processes. Most emissions reduction will take place by switching the source of energy from fossil fuels to a range of lower emissions alternatives, particularly renewable electricity. For other activities, this will require more substantial process changes or new technologies. All of these changes will require economic resources that are not able to be used to produce other new goods and services – this is treated as an economic cost. While the benefits of avoided the impacts of climate change are larger, there is a cost in the short- to medium term to make this change (Figure ii and 3.1). This "cost" should not be conflated with the financial investment cost required to enable the food system transformation described in section 4.2.

Limitations

- **Duration of analysis:** The benefits of limiting warming accumulate in each period relative to the baseline, so would continue to grow beyond 2070. The transition impacts peak and decline, meaning new green industries formed as part of the transition continue to mature post-2070 in a net-zero economy.
- **Wider socio-economic impacts and distributional impacts:** Global emissions reductions and investment in agriculture may drive several wider socio-economic impacts, such as improving environmental (e.g., air pollution, water quality, biodiversity), health and social outcomes. Economic models, such as D.Climate, are designed to analyze production, trade and employment outcomes that take place in markets. Such models do not necessarily capture broader impacts on welfare.
- **Negative emissions:** Result from technologies that capture or remove carbon dioxide and either use or store it. Storage may be biological (in vegetation and soils, see previous section), geological (such as underground storage in oil and gas reservoirs), and in mineral form (such as through mineral carbonation, which accelerates weathering of rocks to sequester carbon dioxide).

There is significant uncertainty around the future development of negative emissions technologies, with many today on a path to commercialization.[114] Although negative emissions technologies and associated sectors are not directly modeled in D.Climate, the net emissions pathway is adjusted to reflect the contribution of negative emissions technologies on the global emissions budget. Assumptions regarding global and regional negative emissions are derived from the International Institute for Applied Systems Analysis (IIASA) database and the Network for Greening the Financial System (NGFS) framework.

- **Representation of environment-economy feedbacks:** The D.Climate model is based on an economic modeling framework. It represents a link between emissions, warming and economic activity. Other environmental impacts and feedbacks, such as the impact of reduced populations of pollinators, which play an economically significant role in agriculture production in many parts of the world, are not represented. As a result, it is possible that solutions developed to support increased production in the "feeding the world sustainably" scenario could result in some negative impacts to the environment, which could in turn have negative effects on production. These impacts and feedbacks have not been explicitly captured.

Going beyond the modeling and areas of further research

The food system's sustainability transition will be complex and involve many aspects which have not been quantified through the D.Climate modeling. Some of these include:

- **Water:** Climate change is set to significantly alter the current water cycle patterns globally. At the same time, continuing to feed the world will mean demands on water resources will continue to increase. While potential outcomes at a local level are highly uncertain, water availability (and quality) will nevertheless be dominant long run trends influencing the future sustainability of the food system.
- **Fishing:** Over 6% of the world's protein is currently supplied by fish.[115] Although the modeling captures the physical impacts of climate change on the seafood industry, detailed climate-fisheries modeling has not been completed.
- **Invasive species and disease:** Changing temperatures and precipitation patterns will alter where and how invasive species and diseases spread across the landscape. Expansion of existing invasive species and diseases, and the introduction of new pests' regions could disrupt local ecosystem function, with ramifications for crop yields and livestock health.[116] The impact of climate change on the distribution of invasive species and associated impacts on food production are not explicitly modelled in this report.
- **Health impacts of over- and undernourishment:** Inadequate access to food (undernutrition), imbalances in consumption of key vitamins and minerals (micro-nutrient related malnutrition) or overconsumption of others (overweight and obesity) poses a significant health risk to individuals and societies. The direct and indirect economic costs associated with adverse health impacts of malnutrition by continuing business as usual and benefits associated with feeding the world sustainably are not quantified in this report.
- **Competition for land:** While land is an input to production in the modeling, it is homogenous in D.Climate. The Deloitte Economics Institute have nevertheless benchmarked our results to other research which has found that it is possible to significantly expand land-based natural solutions without compromising food production. Nevertheless, at particular locations in particular countries, further analysis would be required to resolve the potential for land use competition.
- **Circularity beyond the food system:** The analysis of the impact that circularity could have on the food system has been limited to food waste, particularly around the food manufacturing system.
- **Social safety net:** feeding the world and ending hunger will involve reform and institutional change, beyond the capacity of the economic modeling implemented here.[117]

Appendix C
Reduction in undernourishment

Estimating a decrease in global hunger

Two approaches were used to estimate the reduction of the number of the undernourished population and both draw on outputs of the D.Climate modeling but are calculated separately from the model. These approaches yielded similar results, showing that the "feeding the world sustainably" scenario could fully support around 300 million people who would otherwise be undernourished in 2070.

1. The first approach uses FAO data on the minimum dietary energy requirement and applies a simple average calculation. In this method, the total additional calories produced by region in 2070 in the "feeding the world sustainably" scenario were divided by the regional minimum calories required per person in the same year.
2. The second approach leverages the FAO's depth of food deficit indicator.[118] The depth of food deficit indicator can be reduced by the additional calories produced under the "feeding the world sustainably" scenario. To estimate the number of people who could be fully supported with additional calories, the baseline undernourished population by 2070 was projected using the FAO's database on the number of undernourished people and projected numbers of the undernourished population in 2030.[119,120]

Data Sources

The number of undernourished people from 2001 to 2022, and the projected number of undernourished people by 2030 was obtained from the FAO *The State of Food Security and Nutrition in the World 2023* report.

The minimum dietary energy requirement indicator (FAOSTAT database, 2023).

The depth of food deficit indicator (FAO *The State of Food Insecurity in the World 2000* report

Baseline undernourished population in 2070

The FAO projects the number of undernourished people, by region, from 2022 to 2030. The baseline assumes the same growth rates implied by these projections, by region between 2022 and 2030, continue over the long term (to 2070). This implies that undernourishment persists, but falls as a share of the global population to around 6%.

Calculation of the number of people supported by additional calories

The "feeding the world sustainably" scenario provided estimated improvements in the calories available for consumption by region compared to the baseline.

$$Si = \frac{\textit{Total annual additional calories}_{2070,i}}{\textit{Min dietary energy requirements}_i} \quad i=\textit{region}$$

This calculation provided an estimation for the number of people that could be supported by additional calories produced in each region in 2070. Each region's additional calories are used to support the undernourished population within that region. No additional assumptions are made about the distribution of calories within or between countries, simply a comparison of total production to the need within each region.

$$Si = \frac{\textit{Additional calories per person per day}_{2070,i}}{\textit{Depth of food deficit}_i} \quad i=\textit{region}$$

To calculate the number of undernourished people fully supported by additional calories, the proportion of the caloric gain being filled by additional calories (*Si*) was multiplied by the baseline undernourished population projection. For certain regions, the modeled improvement in calories per person was insufficient to close the undernourished calorie deficit. In these regions, a proportional reduction in the undernourished population was assumed.

Results

The modeling suggests 18% of those extra calories will occur in regions with undernourished populations, enough calories to support an additional 283 million of otherwise undernourished people from those regions.

The modeling suggests nine regions will have their caloric deficit gap fully closed, and enough calories will be available to support an additional 296 million of otherwise undernourished people.

Population in 2070	Number of people
Population in state of undernourishment (baseline)	~550 million
Estimated *reduction* in population in state of undernourishment ("feeding the world sustainably" scenario)	~300 million

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