The Future of Food

IMPACT ROADMAP

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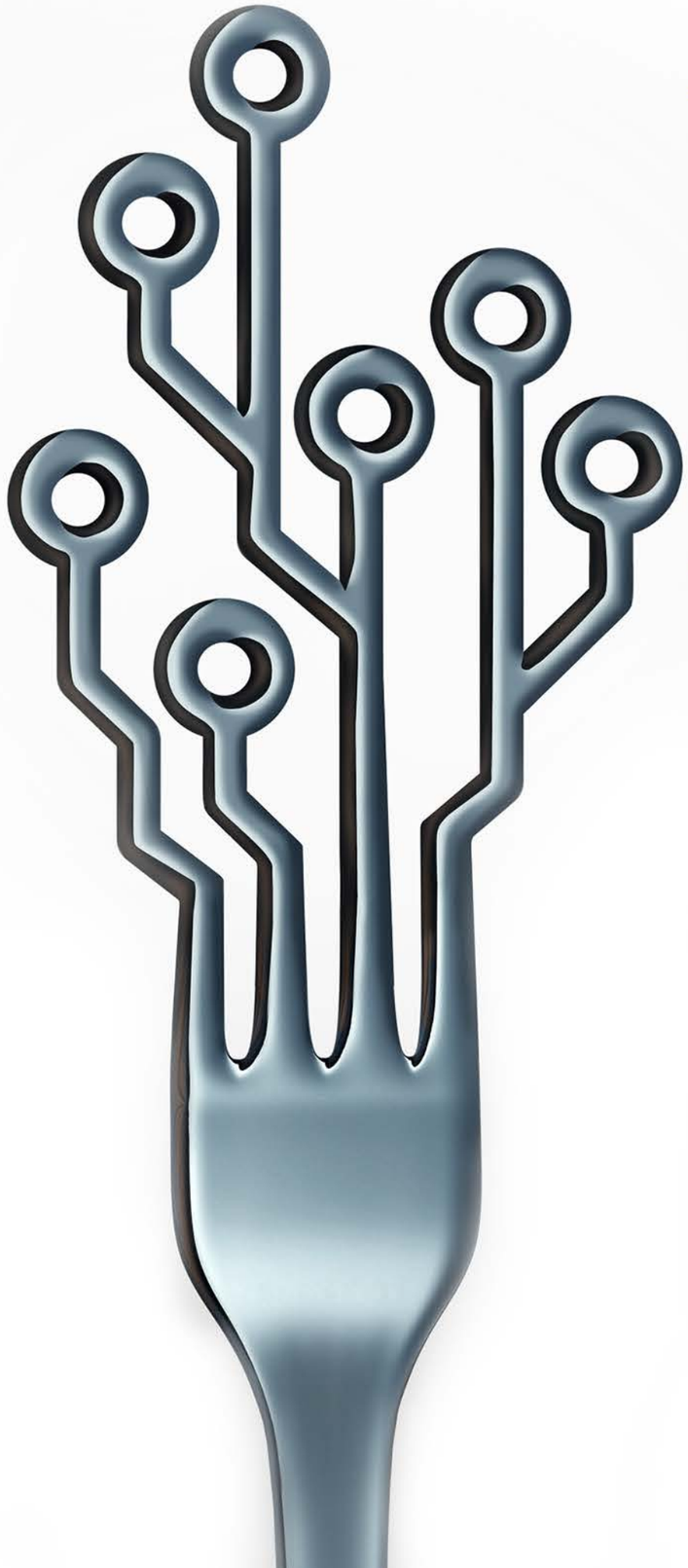

"Abundance is not about providing everyone on this planet with a life of luxury—rather it's about providing all with a life of possibility."

Dr. Peter Diamandis

The Future of Food Team

TIM SILMAN
PRODUCT MANAGER, IMPACT & DESIGN

SEVAG KECHICHIAN
LEAD ANALYST, IMPACT & DESIGN

CAROLINE KOLTA
SENIOR ASSOCIATE, IMPACT & DESIGN

NICK OTTENS
COMMUNITY MANAGER, IMPACT & DESIGN

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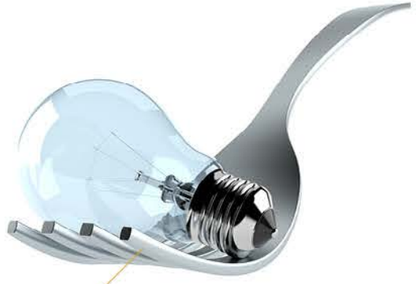

FOREWORD

Food System 'Grand Challenges': The Call for Disruptive Innovations

ONE OF THE great human achievements over the last half century is that advances in food production have largely kept pace with demand on a global basis. Billons fewer people are hungry today than in the world 50 years ago. But we should not be complacent; despite these successes, the scope of all types of malnutrition is massive: over 800 million people are still hungry, at least 2 billion more lack sufficient micronutrients, and at least 2.5 billion people consume excess calories for their needs. Stunting and wasting due to insufficient nutrients and calories, and especially in early years, have lasting impacts on an individual's potential. Meanwhile, cardiovascular disease and Type 2 diabetes are already major – and very expensive – health sector issues afflicting many of the ever-increasing numbers of people over-consuming calories and are the leading cause of death in many countries.

In addition to concerns about the health outcomes of poor diets, there are also major concerns about the environmental footprint of food systems. Current methods of producing, processing, packaging, transporting, retailing, and consuming food are significantly degrading the natural resource base and are a major source of greenhouse gases. The environmental cost of satisfying increasing demand for food without radically changed food systems will be enormous, and it is this factor that is equally worrisome: the prospect of collapse of the natural resource base upon which food security for us all depends.

The array of activities in food systems are however major sources of livelihood for many people around the world. Agriculture and fishing are still the major livelihood strategies in many developing countries especially for small-holders, while food processing and food service dominate in more industrialized countries. The myriad interacting enterprises that constitute the food system need to be economically viable if they are to continue feeding our global population.

One of the greatest societal challenges therefore is to achieve food security for a growing, wealthier, urbanizing population while minimizing further environmental degradation and diet-related diseases, but while also boosting and maintaining vibrant enterprises. This is made the more challenging as this needs to be achieved against a background of climate change, natural resource depletion, many stagnating rural economies, and changes in social, socio-cultural, economic, and political conditions.

Innovations are urgently needed in how to provide better diets for all; how to produce sufficient food with reduced emissions and lower impacts on terrestrial, freshwater and marine ecosystems; how to better manage demand; and how to enhance livelihood opportunities along the whole supply chain, noting especially the enormous potential in growing urban markets. How then can innovative technologies, policies, and practices help mitigate negative food system outcomes while enhancing positive ones, and how can food literacy among policy makers, practitioners, and consumers be enhanced to help them make better informed decisions?

Many ideas to address these challenges are already being implemented in the fields of agriculture, fisheries, and the other food system activities. While individually these are beneficial, each is usually aimed at a specific area such as agricultural productivity or consumer behavior and are incremental in nature. Truly addressing these issues requires a grander solution. We need a "Great Food Transformation," and this calls for systems change. Such a transformation can be inspired by questions such as: How can we both produce and consume healthier food? How can we create more inclusive food supply chains that provide fairer outcomes for all involved? How can we better manage food demands within environmental limits?

These questions, "Grand Challenges," set the agenda for this Impact Roadmap. Game-changing, highly innovative, disruptive interventions which can help bring about systems change are needed, supported by enabling social, economic, and political conditions. The array of possible 'breakthroughs' outlined in this report, and identifying and rewarding creative innovations that underpin them, will help address the major challenges we face and will have substantial and wide-ranging benefits for us all.

DR. JOHN INGRAM

FOOD SYSTEMS PROGRAMME LEADER

ENVIRONMENTAL CHANGE INSTITUTE, UNIVERSITY OF OXFORD

Who We Are

AT XPRIZE, OUR mission is to inspire and empower a global community of problem-solvers to positively impact our world. We believe solutions to the world's problems can come from anyone, anywhere.

Our role is to define the problems, set the targets, and crowdsource solutions through global competitions to incentivize the development of technological breakthroughs that accelerate humanity toward a better future. We provide the opportunity and the platform for people to take risks that ultimately lead to solutions that seemed out of reach or impossible. Instead of simply celebrating great ideas, we reward innovators who follow through on their vision and create tangible solutions that are validated through extensive testing and judging.

The first-ever XPRIZE competition, the $10 Million Ansari XPRIZE for sub-orbital spaceflight, captured the world's imagination and catalyzed a multi-billion-dollar commercial space industry, representing a massively leveraged initial philanthropic investment. Since then, we have launched seventeen competitions in the areas of Energy, the Environment, Civil Society, Human Health & Longevity, Learning, Exploration, and Mobility.

What is an Impact Roadmap?

AN IMPACT ROADMAP is an analytical tool for understanding persistent problems and barriers that make up grand challenges in various domains, as well as the actions that key stakeholders can take to overcome them and achieve a preferred future state. Grand challenges comprise a combination of complex and overlapping social, technological, economic, environmental and policy issues. An Impact Roadmap will highlight the most effective actions to address these issues and accelerate progress toward a more positive future.

XPRIZE is using Impact Roadmaps to help identify potential XPRIZE competitions and other actions that can accelerate a bridge to abundance for all across domains, including Energy, the Environment, Civil Society, Human Health & Longevity, Learning, Exploration, and Mobility.

Emerging, exponential technologies and other innovations in policy and financing have the potential to address grand challenges in these areas, but they require new action by key stakeholders and innovators from around the globe. By promoting the use of exponential technologies in disruptive new ways, XPRIZE is aiming to help create a better world – today.

A Word from Our Sponsors

Australian Centre for International Agricultural Research

ACIAR

ENSURING FOOD AND nutritional security within planetary boundaries is humankind's greatest challenge for the coming decades. Business as usual is not a viable option.

ACIAR is a global leader in developing and delivering agricultural research partnerships in developing countries. We seek to enhance agricultural productivity, sustainability, and food system resilience to climate change through agricultural research for development.

We are excited to partner with IDRC, FFAR and XPRIZE in addressing this most important challenge - the future of food. This Impact Roadmap will identify innovative research opportunities that will help us achieve our preferred future. The knowledge base it provides will shape the creative, collaborative, interdisciplinary research needed to transform our farming and food systems to ensure future sustainable food and nutrition security.

We thank its many contributors.

FFAR

FFAR

TO SUSTAINABLY FEED a growing global population, agriculture must produce more food with fewer resources. Achieving this goal requires partnerships and scientific breakthroughs. The Foundation for Food and Agriculture Research (FFAR) builds public-private partnerships to fund innovative research. FFAR has funded over 100 grants to conduct actionable research that protects the environment, increases health, and supports thriving farms.

Identifying critical research areas where investment can lead to the transformation of the global food system is vital to FFAR's success. This Impact Roadmap can help FFAR plan for the future of food and determine the most pressing challenges facing food and agriculture. The time is ripe for the next great food revolution.

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IDRC

PROVIDING HEALTHY AND nutritious food for an ever-growing population in a context of climate change is one of the key challenges of the Sustainable Development Goals (SDGs). All people should have access to nutritious and healthy food, and food systems must contribute to the resilience of food production and value chains and to the mitigation of climate changes.

IDRC supports the generation of knowledge and innovation for positive change to improve the lives of people in the developing world, especially women and youth. It works on the nexus between agriculture, economic development, human health, and environmental sustainability to improve the lives of smallholders in the Global South.

This Impact Roadmap contributes to a strategic partnership between IDRC and ACIAR that aims at developing an inspiring, visionary perspective on the future of our food system and on the research required to implement it.

Acknowledgments

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The team would also like to acknowledge the contributions of the many individuals whom they formally interviewed or with whom they informally discussed the contents of the report and its ideas. Thank you also to all those who participated at the Future of Food Lab on 5 and 6 June 2019 at XPRIZE headquarters in Los Angeles. Specific acknowledgements of interview subjects and lab attendees are included in the appendices. A special thank you also goes to the XPRIZE global online community for being a source of input and novel ideas.

Despite significantly benefitting from the guidance and input of the above-mentioned individuals and others, the research team and authors of this report are responsible for its conclusions and errors.

Acronyms and Abbreviations

AR: Augmented reality
ATVET: Agricultural technical and vocational education and training
BAU: Business-as-usual
BMI: Body mass index
CH4: Methane
CITES: Convention on International Trade in Endangered Species
CO2: Carbon dioxide
CRISPR: Clustered regularly interspaced short palindromic repeats
CSA: Climate smart agriculture
DALY: Disability-adjusted life years
DNA: Deoxyribonucleic acid
ENMOD: Environmental Modification Convention
EOSD: Earth Observation for Sustainable Development
EPA: Environmental Protection Agency
ESRI: Environmental Systems Research Institute
EU: European Union
FAO: The Food and Agriculture Organization of the United Nations
FDI: Foreign direct investment
FFAR: Foundation for Food and Agriculture Research
FMI: Food Marketing Institute
GDP: Gross domestic product
GHG: Greenhouse gas
GIS: Geographic Information System
GMA: Grocery Manufacturers Association
GMO: Genetically modified organisms
GPS: Global Positioning System
HA: Hectare
HICS: High-income countries
ICTS: Information and communications technologies
ID: Identity
IDRC: International Development Research Centre
IFAD: International Fund for Agricultural Development
ILM: Integrated landscape management
ILO: International Labour Organization
IP: Intellectual property
IR: Infrared radiation
IPCC: Intergovernmental Panel on Climate Change
IOT: Internet of things
IRM: Integrated Resource Management
ISFM: Integrated soil fertility management
LANDSAT: Land satellite
LICS: Low-income countries
LIDAR: Light detection and ranging
LMICS: Low- and middle-income countries
MICS: Middle-income countries
MIT: Massachusetts Institute of Technology
N2O: Nitrous oxide
NCD: Non-communicable disease
NGO: Non-governmental organization
NIR: Near Infrared
OECD: Organisation for Economic Co-operation and Development
PFS: Preferred Future Statement
PPP: Purchasing power parity
QR: Quick Response Code
R&D: Research & development
REDD+: Reducing emissions from deforestation and forest degradation "plus" conservation
RFID: Radio-frequency identification
RS: Remote sensing
RSPO: Roundtable on Sustainable Palm Oil
RUTF: Ready to use therapeutic foods
SAI: Sustainable agriculture intensification
SAN: Sustainable Agriculture Network
SDGS: Sustainable Development Goals
SFM: Sustainable forest management
SMES: Small- and medium-sized enterprises
SNAP: Supplemental Nutrition Assistance Program
SOC: Soil organic carbon
STEEP: Social, technological, economic, environmental, political
UK: United Kingdom
UN: United Nations
UN-REDD: United Nations UN-REDD Programme
UNCAC: The United Nations Convention Against Corruption
UNCCD: United Nations Convention to Combat Desertification
UNDP: United Nations Development Programme
UNFCCC: United Nations Framework Convention on Climate Change
UNODC: United Nations Office on Drugs and Crime
UNTOC: United Nations Convention against Transnational Organized Crime
US: United States
USD: United Stated dollars
USGS: United States Geological Survey
VGGT: Voluntary Guidelines on the Responsible Governance of Tenure
VR: Virtual reality
WEF: World Economic Forum
WFP: World Food Programme
WHO: World Health Organization
WOCAN: Women Organizing for Change in Agriculture and Natural Resource Management
WSN: Wireless-sensor network
WTO: World Trade Organization
WWF: World Wildlife Fund for Nature

Executive Summary

IN THE YEAR 2050, there are projected to be 10 billion people on earth. Currently, humanity and the planet are ill-equipped to sustain a population of that size. Potential catastrophe awaits without radical change in the trajectory of the future. The scale and urgency of the necessary transformation demands widespread agreement on the end goals, as well as the implementation of audacious and impactful breakthroughs that will help achieve them.

As numerous recent studies argue, feeding 10 billion people requires an approach that looks at the global food system in its entirety, rather than focusing on individual aspects such as increasing production or productivity. The fact is we produce enough food today to feed 10 billion people, yet at least 3 billion people suffer from micro and/or macronutrient deficiencies, 1.2 billion are food insecure, 800 million go to bed hungry,[1] and over 200 million children are either stunted or wasted.[2] Nearly half of all child deaths under the age of five are due to undernutrition.[3]

To establish a food secure world by 2050, it is not enough to increase the production of crops that support healthier diets. Tackling demand for and consumption of unhealthy diets is equally important, as is the need for moving away from a calorie-centered system to one that prioritizes nutritional quality. This will only happen if we implement numerous interventions across food systems, including a substantial increase in nutritional awareness, and production of more nutrient-dense crops. There is tremendous urgency to ushering in these changes: worldwide, all forms of malnutrition cost $3.5 trillion annually, and non-communicable diseases due to obesity, such as cardiovascular disease and Type 2 diabetes, cost an additional $2 trillion.[4]

Transforming our global food system extends beyond the eradication of hunger, undernutrition, and diet-related health risks. The food sector employs more people than any other sector, and is a source of livelihood for over 2.5 billion people—many of whom are the poorest and most food insecure in the world.[5] The changes that food systems are currently undergoing have widespread implications for these billions of farmers and workers, for their food security and for the social stability of large parts of the world. Furthermore, urbanization and food demands from a growing middle class are dramatically reshaping food economies, particularly in developing countries. To improve global food and nutrition security, food systems need to be transformed to better provide for the needs of the billions employed in the food sector, especially small-scale farmers, small and medium enterprises, and workers in its value chain.

Our environment is also in significant jeopardy: food systems are by far the largest contributor to environmental degradation, human-induced climate change and biodiversity loss, and are responsible for up to 35% of global greenhouse gas emissions[6] and 70% of water withdrawal.[7] Furthermore, about a third of all food produced for human consumption goes to waste, thereby unnecessarily exacerbating the environmental impacts of food production due to wasting resources. We must make wholesale changes if we are to achieve environmental sustainability and regenerate the natural resource base upon which agriculture, and the rest of humanity, depends.

01.

Preferred Future Statement

ADDRESSING THESE CHALLENGES begins with an articulation of the desired future we wish to achieve. The end goals associated with the transformation of our global food system must be clearly articulated so we can identify the changes that must take place to usher in this transformative future. The following preferred future statement establishes the aspirational goals and values of this desired future, against which remedies, trade-offs, and potential breakthroughs are assessed.

02.

Megatrends

OVER THE NEXT three decades, food systems and the world will be shaped by a number of global megatrends that have emerged in recent years or over prior decades. Summarized below is a list of megatrends identified as part of our analysis; this list is not intended to be an exhaustive list of all potentially transformative global patterns, but ones we consider most relevant in terms of shaping the future of food and food systems. We organized the list according to the STEEP framework that distinguishes between social, technological, economic, environmental, and political factors. The specific implications of these megatrends for the future of food are embedded within our analysis of the challenges in food systems and relied upon to understand and depict the potential future scenarios.

03.

Grand Challenges in Food & Food Systems

OUR ANALYSIS OF the current landscape and trends pertaining to food and food systems identified a set of grand challenges that must be addressed to transform our global food system—each of which is comprised of several critical, underlying challenges. These insights are derived from an examination of the state of research and knowledge on food and food systems, together with our analysis of how some of the aforementioned megatrends may impact food systems in the future.

GRAND CHALLENGE 1: CONSUMING AND PRODUCING HEALTHIER FOOD

Across the world, poor diets are a leading cause of death and health-related diseases, and their negative impacts on health systems and economies are rapidly becoming unsustainable. Almost a billion people consume too few calories, over two-and-a-half billion consume too many, and at least three billion do not have sufficient nutrients.[8] In 2017, poor diets were responsible for 11 million deaths and 255 million disability-adjusted life years (DALYs)[9], the measure of overall burden of disease.[10]

To ensure we produce and consume healthier foods on a global scale, four key challenges must be overcome:

CHALLENGE 1: INCREASING THE CONSUMPTION OF HEALTHY DIETS

Globally, over 800 million people go hungry, 1.2 billion are food insecure, over two billion suffer from micro-nutrient deficiencies, and over 200 million children are either stunted or wasted. Addressing these issues will require people to double on average their consumption of healthy foods, those that are essential to human health, social well-being, and economic productivity.[11,12,13]

CHALLENGE 2: REDUCING THE OVER-CONSUMPTION OF FOODS THAT LEAD TO DIET-RELATED HEALTH IMPACTS

Impacts the world is experiencing an unprecedented rise in diet-related diseases and deaths, driven in large part by increasing consumption of unhealthy ultra-processed foods, along with over-consumption of animal protein in some parts of the world. To enjoy healthier lives, humans on average need to cut their consumption of unhealthy foods by more than half.[14,15]

CHALLENGE 3: IMPROVING FOOD LITERACY

Awareness of healthy diets has been on the rise, but uneven across societies and socioeconomic classes. Changes in lifestyles, effects of marketing, prices and social habits are among the many factors preventing people from making healthier food choices and improving food literacy, without which demand for unhealthy foods and their production are difficult to change.[16,17,18]

CHALLENGE 4: INCENTIVIZING THE PRODUCTION OF HEALTHIER CROPS

For decades, policies incentivized the production of large volumes of a small number of commodity crops, leading to the availability of more calories but oftentimes lower nutritional quality. To produce and consume healthier food, these policies need to be realigned to support a transition towards healthier diets.[19,20]

GRAND CHALLENGE 2: CREATING INCLUSIVE FOOD SUPPLY CHAINS

Food is a vast economic sector employing billions of people across the globe. In many developing countries up to 70% of employment is in the food and agriculture sectors, mostly on an informal basis,[21] including around 500 million smallholder farmers. In total, around 2.5 billion people depend on agriculture for their livelihoods.[22] Many of these households are extremely poor: agriculture is the sector that has the highest incidence of workers living with their families below the poverty line.[23] At the same time, poorer people spend a much greater proportion of their income on food than wealthier people, creating a perverse trap for low-income food system actors.

Urbanization and food demands from a growing middle class are dramatically reshaping food markets and the food economy in most developing countries. To improve global food and nutrition security, food systems need to be transformed to better provide for the needs of the billions employed in the food sector, especially small-scale farmers, small- and medium-enterprises and workers in its value chain. Enabling this transformation to be more rather than less inclusive is key to achieving many of the United Nations Sustainable Development Goals (SDGs).

To help create inclusive supply chains, two critical food system challenges must be resolved:

CHALLENGE 1: ENHANCING LIVELIHOODS OF SMALLER-SCALE FAMILY FARMS

Farmers globally, especially small-scale family farms, face critical challenges from changing food systems, an aging workforce, and climate change. Their survival is at risk, and so is their role in providing livelihoods for billions of people in developing countries, and for food security, economic growth, and social stability. It is imperative to secure a "just transition" for small-scale farmers to maximize equity and economic opportunity within the context of rapid and large-scale changes occurring to local, regional, and global systems.[24]

CHALLENGE 2: OPTIMIZING FAIR ECONOMIC OPPORTUNITIES ALONG THE FOOD VALUE CHAIN

Food supply chains and activities in manufacturing and services beyond primary production are undergoing deep changes and are becoming increasingly significant economic sectors and employers. The food value chain most countries has traditionally favored highly consolidated, vertically integrated actors; re-aligning these systems to provide fair economic opportunities is crucial for inclusive food economies, social and economic equity, and development.

GRAND CHALLENGE 3: MANAGING FOOD SYSTEMS WITHIN ENVIRONMENTAL LIMITS

Current food system practices are not environmentally sustainable. Food systems are responsible for over a third of greenhouse gas emissions globally. Agriculture is the main reason a third of soil on Earth is highly degraded. It accounts for 70% of water withdrawal and causes significant biodiversity loss.[25] Furthermore, about a third of all food produced for human consumption goes to waste, thereby unnecessarily exacerbating the environmental impacts of food production due to wasting resources.

To manage food systems within environmental limits, and to in-turn increase their resilience to the impacts of climate change, five key food system challenges must be resolved:

CHALLENGE 1: ADDRESSING SOIL DEGRADATION AND EROSION

Soil degradation and erosion take many forms and cause further significant environmental damage. Degraded soil is also unproductive soil that reduces the nutritional quality of crops.

CHALLENGE 2: REVERSING GROUND AND SURFACE WATER DEPLETION AND POLLUTION

Water is essential to all life and is becoming scarcer in some parts of the world. Some agricultural practices are responsible for depleting ground and surface water across many regions and are a leading cause of water pollution.

CHALLENGE 3: REDUCING BIODIVERSITY LOSS

The survival of many species – soil microbes, plants, insects, fish, and other animals – is at risk due to the agricultural practices that predominate in most parts of the world. Beyond their intrinsic value, many of these species play crucial roles in the ecosystem and for human food security.

CHALLENGE 4: RADICALLY DECREASING GREENHOUSE GAS EMISSIONS

Food systems significantly contribute to global warming and human-induced climate change. In particular, they are a leading cause of deforestation and forest degradation, primarily through land-use changes as forest lands are converted for agricultural uses, which damages the Earth's ability to sequester carbon from the air.

CHALLENGE 5: CURTAILING AND REPURPOSING FOOD LOSS AND WASTE

Food loss and waste have major negative environmental impacts, as wasted food is wasted natural and other resources. Food waste and loss also have further implications for productivity and efficiency, as well as greenhouse gas emissions.

04.

Breakthroughs for the Future of Food

WE IDENTIFIED 12 breakthroughs critical for overcoming the aforementioned three grand challenges and shifting the trajectory of humanity towards a more preferred future of food. A breakthrough is a discovery or disruption that causes significant, sometimes sudden or dramatic change of the trajectory of the future.

It is important to note that all of the breakthroughs outlined below include components that require political, social, or cultural changes in some form or another – while technological innovation can help catalyze or support change in these areas, it cannot be the sole driving force to do so. Additionally, in some cases a breakthrough may involve the mass scaling of an existing idea or emerging technology, or the adoption of multiple, related innovations together in a manner that exponentially increases their impact. All of these factors highlight how breakthroughs, however audacious, build upon our existing reality and circumstances in important ways.

BREAKTHROUGH 1: FOOD SYSTEM DATA TRUST

A system or platform that ensures protected, democratized access to massive amounts of data on agri-food activities and consumption. This equitably owned and shared information can be used to create actionable intelligence that is leveraged for better health, livelihoods, and environmental outcomes.

BREAKTHROUGH 2: LAND USE REVOLUTION

Methods of optimizing natural resources and inputs such as water, soil, seeds, and fertilizer to maximize efficiency and minimize waste and contamination, dramatically improve overall agricultural production efficiency, and regenerate ecosystems and the natural resource base.

BREAKTHROUGH 3: RENEWABLE ENERGY FOR ALL

Low-cost and accessible grid and off-grid renewable energy sources that regularly supply and store reliable energy for rural and peri-urban households and farms, transforming efficiencies and opportunities along the food value chain while reducing resource dependencies and greenhouse gas emissions.

BREAKTHROUGH 4: ACCESSIBLE PRECISION AGRICULTURE

Precision agriculture tools that are affordable, accessible across the digital divide, context specific, and widely available for smallholder farmers to help them make optimal growing and harvesting decisions.

BREAKTHROUGH 5: OCEAN AND LAND BIODIVERSITY STEWARDSHIP

A system for analyzing, tracking, and valuing biodiversity and ecosystem services, recognizing the vast benefits of biodiversity – from the pollination activities of bees, to the carbon sequestration of trees and beyond – in a manner that influences market activity at scale.

BREAKTHROUGH 6: FOOD PRODUCTION IN URBAN NETWORKS

Expanding food production from crop farming, livestock rearing, and fisheries to encompass a range of new modalities in urban and peri-urban areas. Such innovations would de-couple some food production from land and sea and create connected, sustainable, circular value chains with holistic, systemic connections between consumer demand and food producers, primary processors, manufacturers, distributors, and waste resource managers.

BREAKTHROUGH 7: UNLEASHING LOCAL KNOWLEDGE: ENABLING SMALL AND MEDIUM ENTERPRISE INNOVATION

Accelerating the creation, scale, and efficacy of enabling environments that unleash small and medium-sized enterprises' (SMEs') potential, focused on strengthening access to assets, markets, and investment - especially among women - to encourage and de-risk grassroots value chain innovation.

BREAKTHROUGH 8: EXTENDING FOOD LIFETIMES: REDUCED FRESH FOOD PERISHABILITY

Novel, affordable, and accessible methods to dramatically extend the life of fresh food by monitoring crop and food quality, reducing spoilage along the value chain, and educating consumers on usage options, while preserving food's nutrition value, freshness, safety, taste, and texture.

BREAKTHROUGH 9: ALTERNATIVE AND NOVEL PROTEINS AT SCALE

An unprecedented scale-up in consumption of protein sources that are not drawn from wild or farmed animals. This will require significant technological advances in an already-healthy industry, coupled with decreased price points, alongside significant changes in eaters' preferences in diverse contexts – all while maintaining positive health and environmental benefits as compared to animal-based proteins.

BREAKTHROUGH 10: FOOD AS MEDICINE

A comprehensive shift in our understanding and use of food as a cornerstone of human health, utilizing technological advances such as in personalized nutrition, human genetics, and the gut microbiome to optimize nutrition, manage consumption, and inform medical decisions.

BREAKTHROUGH 11: TRUE COST OF FOOD

An open source and universally standardized evaluation framework to monetize the external costs of food systems, translated into adjusted price points, that incentivizes the consumption of "good" food. Costs to be internalized include diet-related health impacts, effects on worker productivity, harsh labor conditions, and environmental degradation and natural resource depletion.

BREAKTHROUGH 12: ACTIONABLE FOOD EXPERIENCES: CRAFTING NEW FOOD NORMS

A range of tools to influence consumers, powered by cutting-edge emerging technologies and behavioral science, to shift consumption toward food choices that are healthier and more environmentally sustainable.

05.

Imagining Three Future Scenarios

WE IMAGINE THREE future scenarios based on the progression of global megatrends and their impact on the global food system. The first conveys Dark Times, or a dystopian future; the second: an age of successes and tremendous failures characterized by The Paradox of Plenty; and a utopian scenario that represents A Nourished Planet.

DARK TIMES

Countries and large corporations fail to agree on common goals and cooperate. The world becomes divided between two social classes: the haves and the have-nots. Failure to keep global warming 2°C under pre-industrial levels accelerates a downward climate spiral. Natural resources are scarce and less productive. Large swaths of the world are uninhabitable. Billions suffer from hunger and malnutrition. Natural ecosystems are collapsing—devoid of nutrients and microorganisms. Any land containing nutrient-rich soil is commandeered by government agencies or private corporations. Self-sustaining environmental mechanisms disintegrate, and nature is unable to bounce back.

The new currency of power and wealth is food. For most, food is anything pseudo edible that isn't immediately fatal. Real, nutritious food is only accessible to the rich, and becomes the singular socio-economic class indicator, and in turn, creates an atmosphere where food discrimination is commonplace.

THE PARADOX OF PLENTY

In 2050, people around the world face a food paradox. Plenty of food is available to the many, and although our global calorie needs are met, very little food contains adequate nutritional quality. The number of people suffering from hunger continues to fall as a result of advances in science and medicine. But obesity and malnutrition are on the rise, and the health and economic impact of diet-related diseases skyrockets. In the developing world, handfuls of small-scale family farms managed to commercialize, while more than a third of smallholder farmers lost their farms and were forced to relocate to urban centers. Technological advances and breakthroughs improved overall productivity, but not in ways optimal to nutritious diets, improved livelihoods, and long-term environmental sustainability. Science helps limit the ecological footprint of global food systems, but negative impacts continue to be externalized to both the healthcare and environmental sectors. Climate change has intensified as a driver of havoc and instability on global food systems and the planet at large.

A NOURISHED PLANET

In 2050, people around the world consume healthy and nutritious foods that are affordable, sufficient, and diverse—further incentivizing the production of healthy crops in both small and large-scale agriculture. Policies across the food sector are redesigned to move from calorie-maximization to nutritional quality. Food literacy improves; with more access to nutritious foods, people are able to make educated, and in turn, healthy dietary choices.

Both smallholder farming and large-scale industrial agricultural production systems are empowered and incentivized to grow healthier and more productive crops in inclusive food systems that improve the livelihoods and quality of life of workers. These inclusive food systems provide fair economic opportunities along the entire food value chain and allow small and medium enterprises to thrive.

This success is partially a result of transforming food systems to regenerate environmental systems, enrich our natural resource base, minimize the production of greenhouse gases, and achieve nutritional abundance and economic equity. Soil, water, and biodiversity are replenished and revitalized, in part due to efforts made to curtail and repurpose food loss and waste.

01.

INTRODUCTION

01

Why an Impact Roadmap on the Future of Food in 2050?

A Preferred Future: Values and Assumptions

What is Included and Left Out

Research Methodology

Why an Impact Roadmap on the Future of Food in 2050?

FOOD SYSTEMS HAVE witnessed transformative changes over the past century and are currently undergoing changes with profound significance for the future of humanity. As the next chapters illustrate, these changes have precipitated numerous challenges that must be addressed to successfully halt and reverse a wide range of harmful and pervasive issues related to human health, social and economic stability, and environmental sustainability. Audacious actions need to be taken today to avert potential catastrophe.

The scope of global food systems, the scale of their impacts, and their pervasive complexity are staggering. Over 25% of humanity fails to receive adequate nutrients,[26] yet obesity alone costs $2 trillion dollars annually, or 2.8% of global GDP.[27] Food production and consumption create tremendous environmental impacts,[28] and yet around 2.5 billion people depend on agriculture for their livelihoods,[29] with up to 70% of employment in developing countries in the food and agriculture sectors, mostly on an informal basis.[30] Surmounting these overlapping, interconnected, and systemic issues must be accomplished against the backdrop of continuing to provide food for billions of people and ensuring the survival of our planet.

This Impact Roadmap outlines these issues and the future of food at a global level. The approach is designed to focus on entire food systems rather than concentrating on food production. As a result, the report pays close attention to the consumption and demand side of the system, while also considering relevant aspects of midstream segments, including storage, processing, distribution, and retail.

Transformative changes in food systems demand not only persistent and serious efforts, but audacious and impactful disruptions that can change the trajectory of the future. This Roadmap and its 12 breakthroughs are part of XPRIZE's contribution to this transformation.

A Preferred Future: Values and Assumptions

OUTLINING THE DESIRED end-state for any transformative endeavor is critical for assessing how any new efforts and initiatives may usher in such a future. The Preferred Future Statement establishes the aspirational goals and values of this desired future, against which remedies, trade-offs, and potential breakthroughs are assessed. Starting with the end goal allows us to better chart a course for its achievement.

Our Preferred Future Statement centers around the year 2050, three decades in the future when the world's population is projected to reach 10 billion people, as the aspired timeframe for these transformations. The year 2050 in our Preferred Future Statement is not fixed or rigid but is meant to represent a point in time far enough into the future for breakthrough interventions to be implemented, and their impacts given enough time to cause meaningful transformation.

The Preferred Future Statement emerging from our work exploring the current state of food systems, and the desired trajectory for humanity within this domain, is comprised of three key sets of outcomes.

THE PREFERRED FUTURE STATEMENT

IN THE YEAR 2050,

People around the world consume healthy and nutritious foods that are affordable, sufficient, and diverse. Improved food literacy supports healthier dietary choices, thereby further increasing demand for such food. Food system policies incentivize the production of healthier crops in both small- and large-scale agriculture.

Inclusive food systems enable enhanced livelihoods for small- and medium-sized enterprises through increased productivity and accessible commercialization and support the growth of fair economic opportunities along the entire food value chain.

Food systems mitigate environmental decline, regenerate environmental systems, and ensure resiliency in the face of climate change by addressing soil degradation and erosion, reversing water depletion and pollution, reducing biodiversity loss, radically decreasing greenhouse gas emissions, and curtailing and repurposing food loss and waste.

VALUES AND ASSUMPTIONS

THE PREFERRED FUTURE Statement prioritizes certain values and makes several assumptions—some of which are clearly articulated and others that require more detail. In terms of values, it helps to look at the three components of the statement as three sets of value-driven outcomes or goals informed by rights-based approaches and United Nations frameworks.

The first value set is comprised of health and nutrition outcomes for all consumers. Emphasis is placed on the nutritional quality of food and its accessibility, which also includes eradicating all forms of hunger and diet-related health issues—especially obesity, undernourishment, and other forms of malnutrition, in particular those affecting children.

The second set of outcomes relates to the economic and social impact of the food industry on the billions of people who are dependent on food economies for their livelihood. Of particular emphasis are the most needy and vulnerable of these in the developing world, such as smaller-scale family farmers, small- and medium-sized enterprises, and laborers throughout the food value chain. Food systems provide a unique opportunity to alleviate poverty, elevate rural development, and advance core values related to inclusivity and equity.

The third set of outcomes pertains to environmental sustainability, which includes not only preserving the natural environment, but enhancing its regenerative capacity and resiliency in the face of climate change. Food systems must promote the environment's intrinsic value along with the instrumental components that affect all aspects of life, including agricultural productivity and food systems. Soil health, water availability and quality, all forms of biodiversity, and reduced greenhouse gas emissions are of crucial importance.

It should be noted that the above are not exclusive of other values, such as increasing agricultural productivity, for example. We also realize that no single outcome will be equally preferred by all stakeholders and that achieving these objectives in practice will require trade-offs and difficult decisions. Therefore, any intervention will need to be carefully assessed in relation to other food system components and within specific contexts.

Our articulation of a desired future is also based on our analysis of the trajectory of our current reality. An assessment of global megatrends is a key element of this understanding, helping us explore and remain mindful of the trajectory of future change. Importantly, we do not assume substantial changes in individual and social value systems, as a future of three decades is an insufficient period over which to expect such deep transformation. We therefore assume that no major disruptions will radically alter current trajectories and megatrends.. We describe those megatrends we believe will play a significant role in humanity's future, as well as the future of our global food system.

What is Included and Left Out

FOOD SYSTEMS ARE vast and complex. It is difficult to imagine an aspect of life, nature or any other human-made system that is not affected by food systems. As such, any study dealing with the topic will need to make difficult decisions regarding its scope.

The scope of this Impact Roadmap is global, and its focus is on the most significant global challenges. The report covers most core food systems topics, but not every aspect of these topics. The global scope of this Impact Roadmap does not preclude us from reviewing key dynamics that pertain to specific regions. The most visible example is the attention we pay to smallholder farming in sub-Saharan Africa and south Asia. This is primarily due to the high concentration of smallholder farming in those regions, as well as their projected large-scale demographic changes over the next several decades, with profound importance to food security both in those regions and globally.

Considering food systems from a human-centered viewpoint, using the perspective of different actors and groups, can help illuminate important nuances and components not otherwise apparent from traditional research methods. The following table presents the important lenses and groups utilized when constructing this report and its analysis. The categorizations are designed to provide clarity around the groups and geographies that drive change in food systems, and those that will be impacted by its transformation. In particular, these categorizations are used as a component of evaluating the impact of potential breakthroughs later in this report. It should be noted that these groupings are not mutually exclusive, in part reflecting the myriad impacts and stakeholders involved in modern food systems.

It is important to emphasize that this Impact Roadmap does not provide an exhaustively comprehensive analysis or assessment of global food systems or any of the specific topics within it. Instead, it represents our distillation of the plethora of academic and expert publications that do exactly that. Our work utilizes the findings and conclusions of such works as the basis for our analysis. Those interested in learning more about the research underlying our analysis may examine the references cited in the endnotes to this report.

Generally, anything not directly related to the three aforementioned outcomes is not included in this report. This is easier said than done given the interdependencies, feedback loops, synergies, and trade-offs between so many of the factors within food systems. A number of topics are excluded from this report, such as food cultures, ideologies, and histories. Other topics are underrepresented, such as specific food safety considerations, animal welfare, and specialized dietary and nutritional needs.

Perhaps the biggest exclusion is local context itself. Many of the challenges, concepts, and issues presented herein play out and are experienced differently in different parts of the world. Some of the core concepts themselves, such as smallholder farming or small and medium enterprises (SMEs), have different meanings in different parts of the world, and many countries have diverse landscapes and farming systems that share more with similar landscapes and systems across borders than within the borders of the country itself.

Any system-level analysis will necessitate generalizing about these relationships to identify overall patterns. The key is to look through the prism of local conditions when working to operationalize any resulting insights. Being mindful of inter- and intra-country variation, local context, and the issues surrounding excluded topics is especially critical when thinking about or operationalizing the breakthroughs outlined in this report. The extent to which a breakthrough achieves the desired impact is dependent on the interaction between many important factors within a complex setting or context. Carefully assessing these synergies and trade-offs against specific backgrounds and within particular contexts is crucial.

Research Methodology

OUR RESEARCH UTILIZED a food systems approach to identify and frame the different grand challenges, challenges, and breakthroughs presented in this report. This approach is designed as an interdisciplinary framework that analyzes the relationships between different components of the global food system along with their effect on food and nutrition security, at the socio-economic level, and on the environment.

To do this, we distinguished between megatrends on one hand and the immediate drivers creating each challenge on the other. Analyzing global megatrends serves the purposes of both understanding some of the major factors that will shape the future, and of their impact on the core issues and challenges at the center of this report. Immediate drivers refer to proximate or immediate reasons, variables, or factors that cause the outcomes forming any given challenge. These are not meant to be exhaustive, provide in-depth causal narratives or assign exact outcomes or probabilities to each cause, but they are meant to be illustrative of the most important factors. These immediate drivers can help us conceive of possible solutions or interventions that can remove a given cause, sever its link with an effect, or reduce or mitigate its impact.

CHALLENGES, GRAND CHALLENGES AND BREAKTHROUGHS

A **challenge** is the outcome of a set of issues, typically brought about by a number of causes or factors that presents an opportunity for intervention.

A **grand challenge** is a set of complex and overlapping challenges that are commonly multi-dimensional; in that they contain social, technological, economic, environmental, and political dimensions.

A **breakthrough** is a discovery or disruption that causes significant, sometimes sudden or dramatic change of the trajectory of the future. Breakthroughs can be technological, social, political, cultural, economic, or a combination of these.

Beyond analyzing the current landscape of challenges in food systems, we also attempted to illustrate the cohort of existing remedies capable of addressing these issues. These listings are not exhaustive but are instead designed to showcase some of the major existing strategies, programs, or interventions that are attempting to deal with some of the important factors or causes that form these challenges. The potential success of these remedies, and their trajectory over time, helps us understand the degree to which current efforts may or may not be sufficient, and was used to inform and validate our choice of food system breakthroughs.

Each of these breakthroughs was assessed against the challenges it is intended to address, its impact and audacity, the groups and users most impacted by it, the need for the breakthrough and its potential impact, its potential trade-offs and unintended consequences, promising technologies and innovations to best attain it, and specific pathways for impact. These breakthroughs are further illuminated by an articulation of three futures or scenarios: a worst-case dystopian scenario, a business-as-usual, and a preferred future scenario. These scenarios are based on an analysis and an interpretation of the direction of the megatrends and challenges outlined in the report, and in the case of the preferred future scenario, on the impact of the breakthroughs.

The information presented in this report is drawn from open sources, interviews, and crowdsourced activities. We used public databases and reviewed publications and reports from leading international and academic institutions and used multiple sources to corroborate our analysis and test the synthesis of our arguments.

We carried out interviews with over 30 experts in the areas of food systems, agriculture, nutrition, and behavioral economics, as well as farmers, entrepreneurs, innovators, and futurists. In addition to these formal interviews, we spent hours discussing core issues with experts, colleagues, and professionals within the XPRIZE network.

We benefitted from the insights and input of a number of participants on XPRIZE's Future of Food online community platform, using various online activities, including surveys both on the platform and via emails, to assess some of our findings and assumptions, and prioritize issues and interventions.

In addition to conducting numerous ideation sessions, we organized internal XPRIZE workshops to discuss, imagine and draft short descriptions of several core issues and aspects of challenges, and how they might evolve under different scenarios.

At our two-day Future of Food Lab held at the XPRIZE offices, we discussed and invited criticism of our framework, grand challenges, challenges, and value assumptions. The vast majority of this time was spent ideating breakthroughs with the assembled experts, practitioners, and entrepreneurs.

What follows is our synthesis and analysis of the core issues in food systems, the radical transformations needed to change the trajectory of these issues, and potential futures in which the world has been unsuccessful or successful (in part or in whole) in addressing these challenges.

02.

MEGATRENDS

Introduction

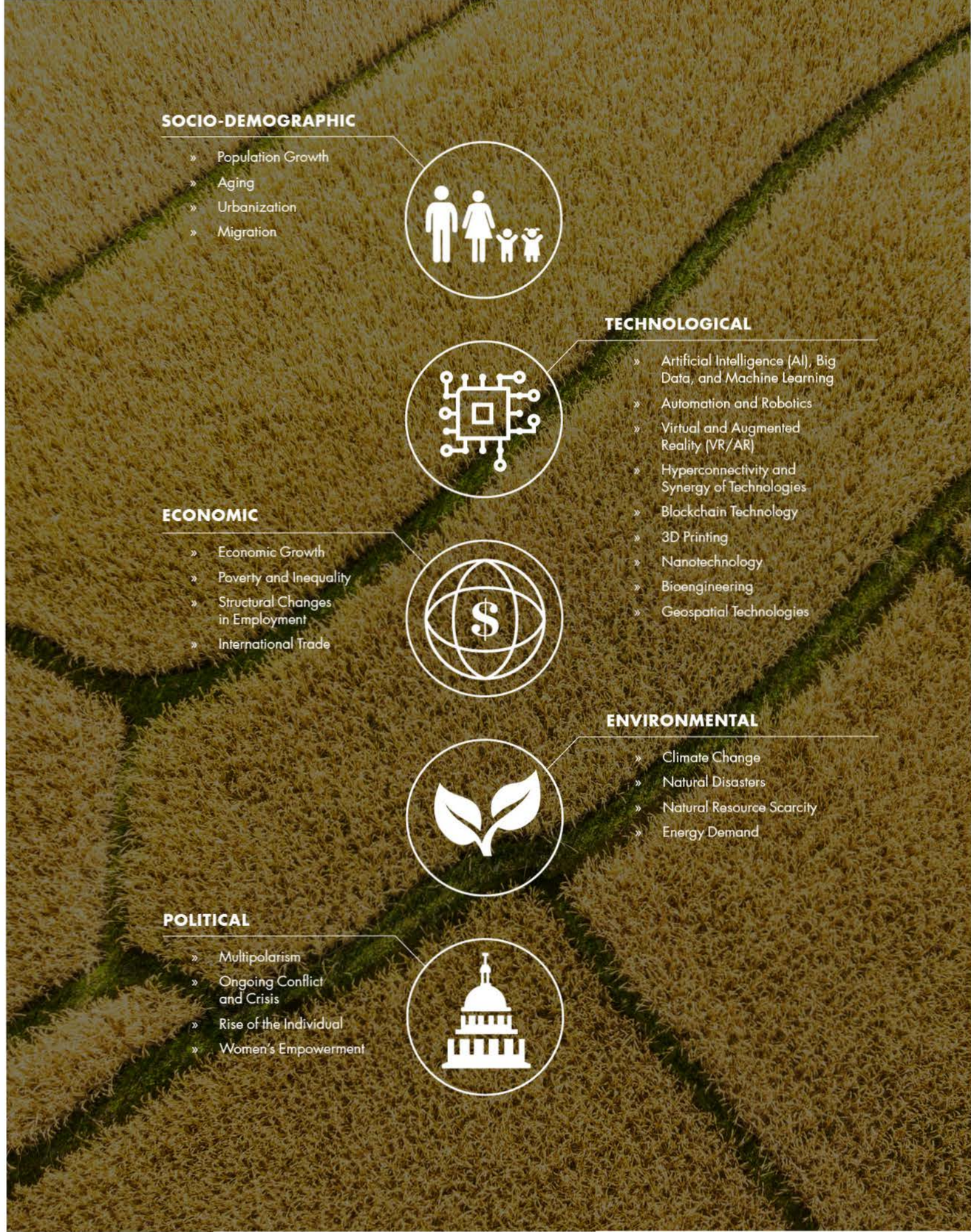
MEGATRENDS ARE POTENTIALLY transformative global forces that shape the future, with far-reaching implications for industries, economies, societies, cultures, and individuals.

The purpose of presenting these megatrends is to help us understand some of the broader factors shaping and characterizing the future as it unfolds over the next years and decades. It is not to suggest that we can use them to precisely predict the future. However, in later chapters we describe a set of possible futures in food systems, including a business-as-usual scenario drawn heavily from our understanding of the potential direction and implications of the megatrends presented below.

Megatrends in this report are organized according to the STEEP framework – socio-demographic, technological, economic, environmental, and political. Megatrends in all categories involve certain degrees of uncertainty with regards to the direction and magnitude of their impact over the coming decades, further compounded by the interdependent nature of trends and forces at the global and regional level.

The below megatrends were selected after a thorough analysis and review of the literature, together with expert feedback on the Future of Food online community and at XPRIZE's internal workshops. It should be noted that the below list is not exhaustive, as there are an endless number of forces that shape the direction of humanity at a macro level. Instead, the chapter that follows represents our synthesis of those megatrends we feel will be most important in shaping the future of food and food systems.

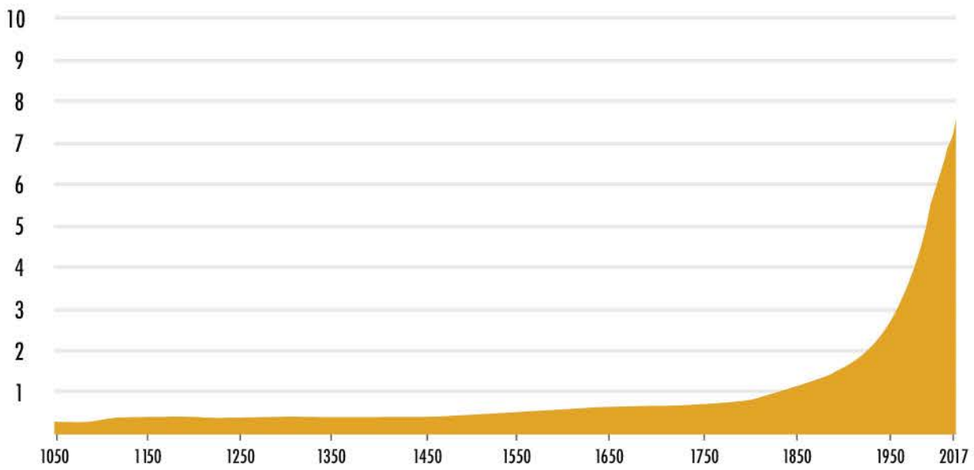
The analysis below focuses on describing the general nature and direction of each megatrend; the specific implications of these megatrends for the future of food are primarily embedded in subsequent chapters outlining our analysis of the challenges in food systems.



MEGATRENDS

Socio-Demographic

HUMAN POPULATION GROWTH
(Billions)



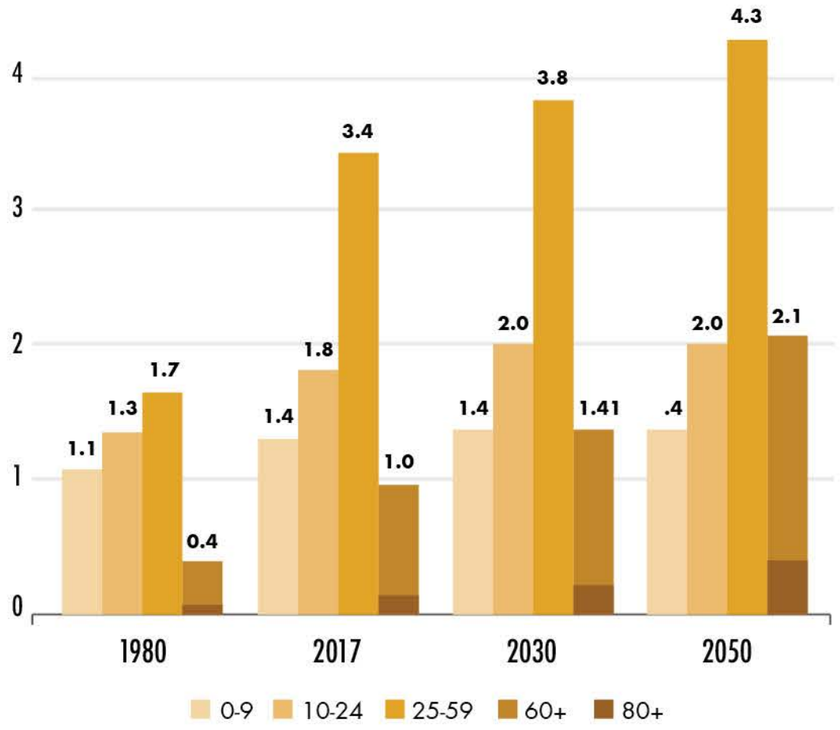
Source Link: https://populationmatters.org/the-facts/the-numbers

POPULATION GROWTH

The world population is expected to grow by more than 2 billion people by 2050, reaching approximately 10 billion. This global trend, however, is not the same across regions. Populations of high-income countries are expected to reach their peak by 2040, while low- and middle-income countries are expected to reach their maximum later in this century and into the next.[31]

Half of all population growth in the coming decades is expected to occur in sub-Saharan Africa, where the population is expected to double, while Asia's population is expected to grow by 41%. Arable land per person in these regions is currently only three-quarters of an acre and one-third of an acre, respectively. Countries in these regions will need to substantially increase their agricultural productivity, increase the amount of arable land, or import a larger portion of their food needs to feed these growing populations.[32]

GLOBAL POPULATION BY AGE GROUP
(Billions)



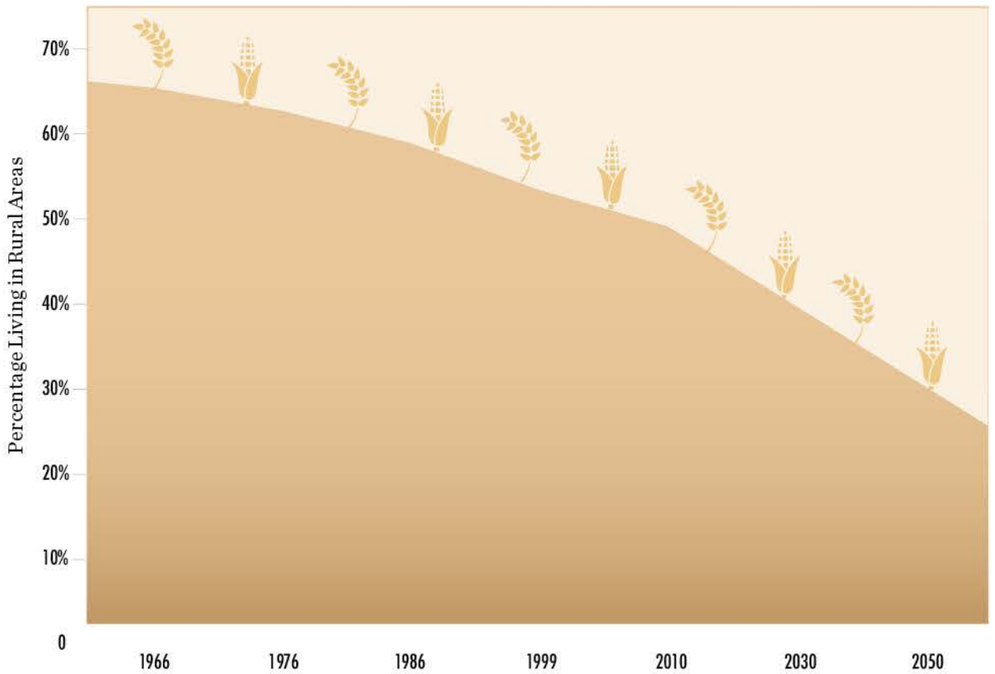
Source Link: http://www.chinadaily.com.cn/a/201904/09/WS5cabe02da3104842260b50cb.html

AGING

The proportion of the population aged 65 and above is expected to sharply increase by 2050. This growth is expected to be fastest in Latin America and the Caribbean, with a projected 71% increase in this demographic group, followed by Asia (66%), Africa (64%), Oceania (47%), North America (41%), and Europe (23%).[33]

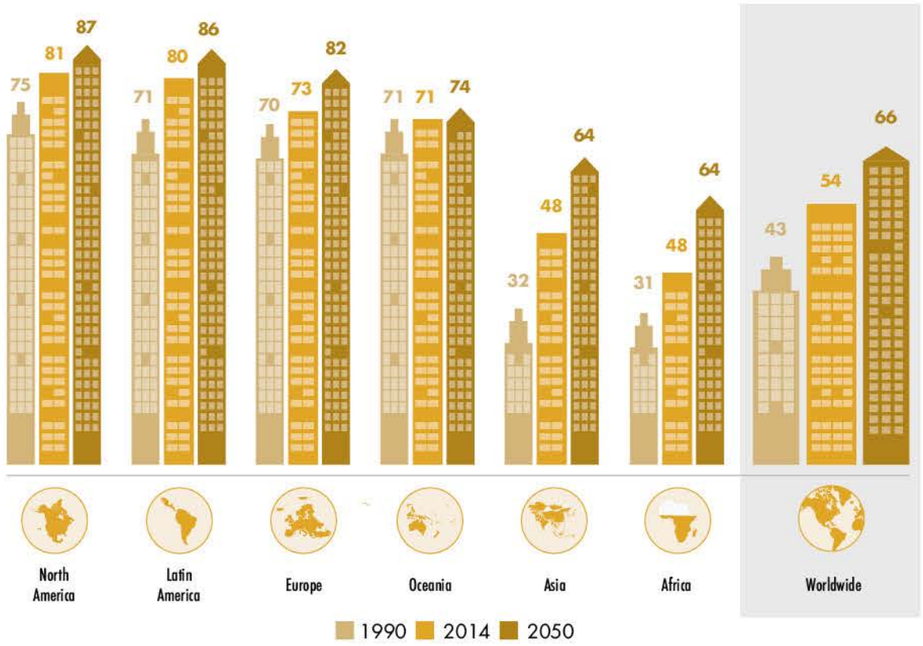
Around 80% of the increase will occur in developing countries,[34] leading to slowing economic growth and strained social safety net and healthcare systems. Aging, particularly in rural areas, has major implications on labor supply and productivity, especially with rural out-migration of younger age groups, leading to a wider gap between rural and urban areas, among other effects.[35]

POPULATION LIVING IN RURAL AREAS



Source Link: https://www.researchgate.net/figure/World-population-growth-million- people-and-urbanization-percentage-living-in-rural_fig7_283455459

POPULATION LIVING IN CITIES
(Percent of 100)



Source Link: http://populationeducation.org/sites/default/files/urbanization_chart.jpg

URBANIZATION

By 2050, almost 70% of people in the world will be living in urban areas, compared to less than 54% currently and 40% thirty-five years ago. In absolute terms, global urbanization could lead to a net addition of 2.4 billion people to towns and cities by 2050, which is more than the 2.2 billion people of projected population growth. This means that rural populations may see a net reduction of nearly 200 million people.[36]

With this increased urbanization, the number of megacities (population of more than 10 million people) and other urban centers will rise, leading to potentially severe consequences. Even with proper sanitation and housing, the concentration of millions of people in limited space will allow infectious diseases to spread faster. Cities account for more than 70% of global greenhouse gas (GHG) emissions and use two-thirds of the world's energy.[37] These numbers will also go up, and air pollution will have a larger negative effect on human health. Urbanization will stretch food supply chains and increase the distance between food production and consumption, but it will also create opportunities to shape demand.

MIGRATION

Both international and internal migration are expected to increase over the next decades. Currently, there are around 244 million international migrants, and 740 million internal migrants.[38] While more than one-third of international migration is from the global "South" to "North", the larger proportion is "South" to "South". Part of this is and will remain rural out-migration.[39]

Root causes of migration include conflicts, poverty, food insecurity, lack of employment opportunities, limited access to social protection, natural resource depletion and the adverse effects of climate change. Population movement disrupts normal patterns of food consumption, exacerbating the impact of food system challenges, in particular food insecurity. The main cause of rural out-migration is unemployment, of which agriculture is a major component, being associated with low and insecure incomes, poor occupational safety and health conditions, gender inequality in pay and opportunities, and limited access to social protection.[40]

MEGATRENDS

Technological

ARTIFICIAL INTELLIGENCE (AI), BIG DATA, AND MACHINE LEARNING

AI is arguably the most significant technology megatrend and is rapidly reshaping almost every component of our lives and our global institutions. It is being used to augment the processing capabilities of machines, and, through machine learning, to perform human-like intelligence functions.[41] This megatrend is being further strengthened by the dramatic increases in computing power and the storage and availability of big data.

AI is expected to cause significant disruption to numerous industries. It can substantially enhance accuracy and efficiency of performing tasks through automation, providing new insights and predictions. In food systems, AI can be used to create precise nutrient content for specific consumers; improve soil health; detect pests and diseases; and increase efficiency and safety in primary production, supply chains, and retail; among other functions.[42] AI will also create serious risks to individuals and their privacy, and will empower corporations and governments with unprecedented access to data that could be used to influence human behavior.

AUTOMATION AND ROBOTICS

Automation and robotics have become increasingly common in traditional manufacturing industries, such as automobiles and electronics. They are now spreading to other industries such as retail, healthcare, supply chains, and distribution, as well as agriculture and food production,[43] as these systems become faster, more efficient, more intelligent, and agile.[44]

The impact of automation and robotics cannot be overstated. Workplace automation is expected to disrupt employment and labor markets and change the nature of work. While the increasing prevalence of automation and robots can reduce errors significantly, enable work in harsh conditions, and improve efficiency, it is also causing anxiety in labor markets. According to one study, 30% of "work activities" could be automated by 2030, thereby replacing 375 million workers worldwide.[45] In agriculture, robots are increasingly used in various ways, such as drones to monitor crop growth, autonomous tractors for harvesting, and robotic arms for sorting and packing.[46] Automation and robotics also present opportunities for addressing acute labor shortages in certain industries, agriculture among them.

VIRTUAL AND AUGMENTED REALITY (VR/AR)

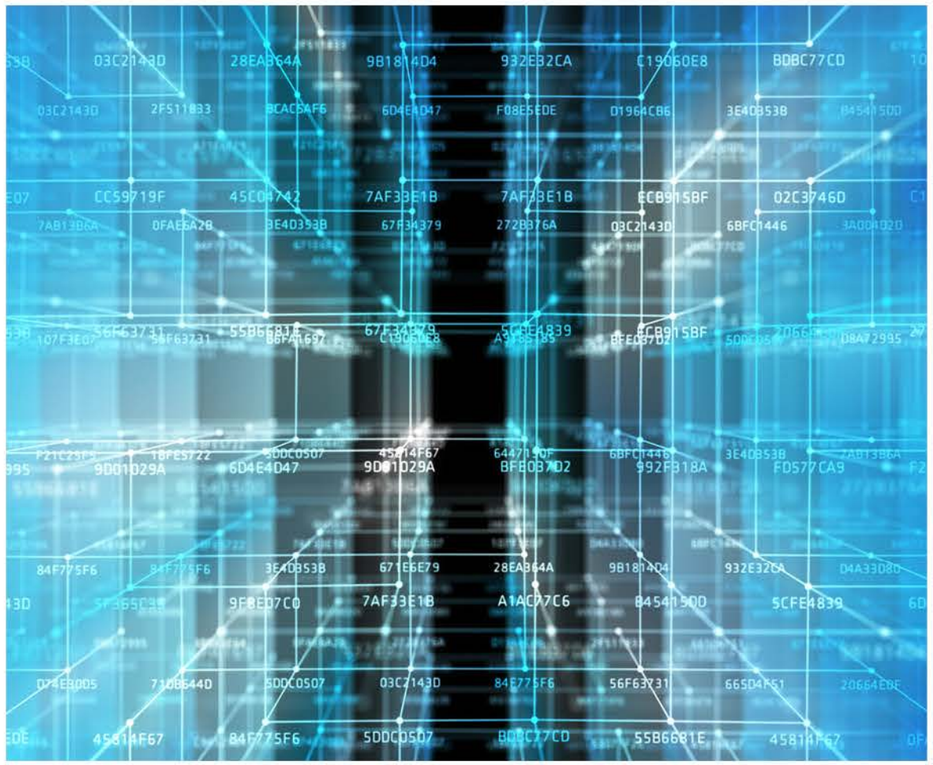
VR/AR can be used for numerous purposes, including as means to activate consumer senses and experiences through immersion, or simulate real-life settings for training. Both can become powerful tools to increase knowledge and awareness, including of healthy and nutritious foods in the food industry.

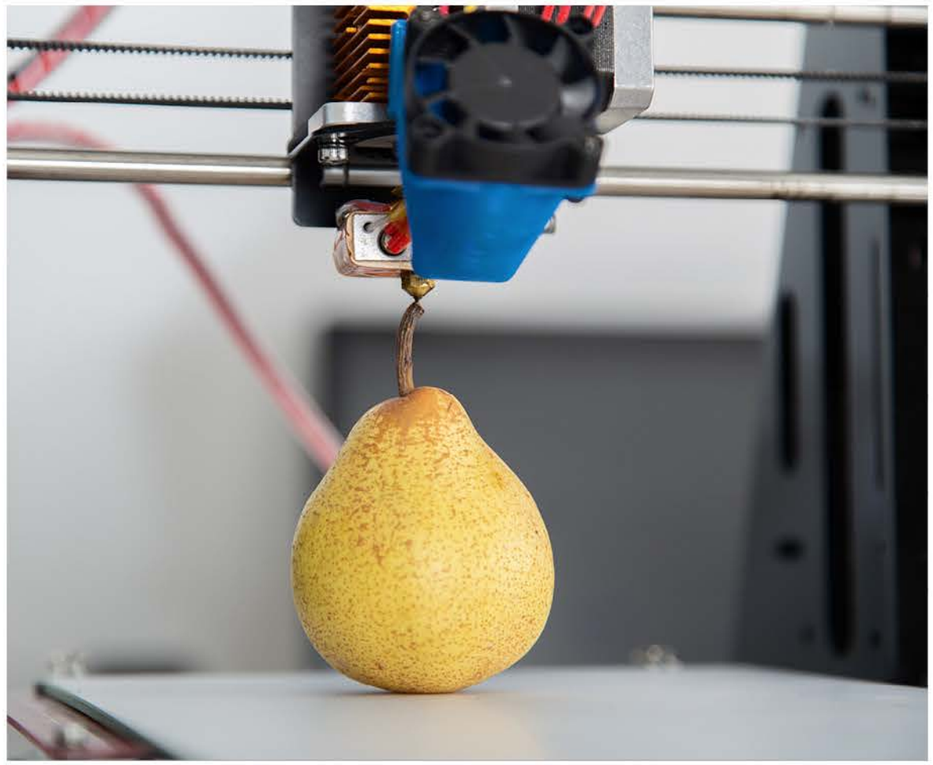
VR/AR technologies are expected to become an integral part of the future of marketing, work and entertainment.[47] In the food industry, human resources and customer experiences are the two obvious areas being affected by VR/AR. Beyond these two areas, the technologies have the potential to transform food literacy and bridge the gap between consumers and producers, thereby potentially increasing empathy and encouraging responsible sourcing.[48] VR/AR may also generate social disruption if people retreat into digital worlds that lack the ability to effectively replicate the interpersonal interaction seen in the physical world.

HYPERCONNECTIVITY AND SYNERGY OF TECHNOLOGIES

Over four billion people around the world are currently using the internet, and five billion have a mobile phone. With the next generation of communication infrastructure (5G) and the decreasing cost of devices, the hyperconnectivity of increasingly powerful devices will have profound impacts across numerous industries and human activities by connecting more people to services and enabling efficient, precise, and smart processes and decisions.[49]

Increased connectivity will further rely on other advances in technology, and especially data and storage. The Internet of Things (IoT), cloud and geospatial technologies, satellite and imagery, and the proliferation of sensors will generate invaluable information that people can use to improve their lives and business, but not necessarily to benefit everyone or without trade-offs; for example, there is the question of who controls such data and for what purposes.[50] Additionally, hyperconnectivity enables the rapid spread of misinformation and may be leveraged by bad actors to sow political or social instability.





BLOCKCHAIN TECHNOLOGY

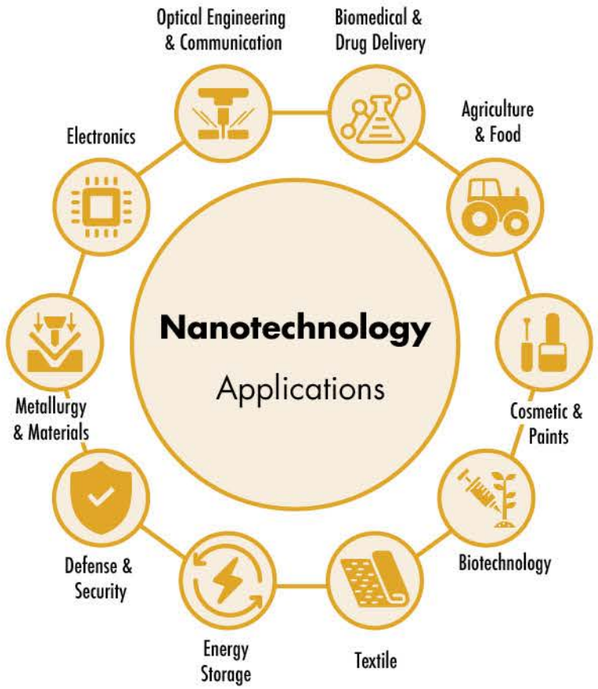
Blockchain systems use a decentralized platform to promote transparency and validation among members and end users. Using a single publicly available digital ledger helps detect hacking attempts, while reducing the messiness associated with systems containing multiple ledgers and data systems.[51] Blockchain is already disrupting industries such as banking and financial services, stock markets, and others, including through cryptocurrencies. Over the next five years blockchain is expected to grow by 75.2% and 87% in the financial technology and supply chain markets, respectively.[52]

Blockchain can have a significant impact on numerous industries and human activities in the future. It can provide individuals with secure digital IDs, enable safe and swift contracts and transactions between individuals and with governments, protect property rights, improve efficiency by removing middlemen, and enable seamless and automated transactions between billions of devices through the Internet of Things (IoT).[53] These can significantly enhance efficiency, reduce cost and time, and further democratize industries and empower individuals.[54]

3D PRINTING

3D printing is a manufacturing method that creates three-dimensional products using a computerized or digital process. It is currently being used to create industrial and automotive products, medical devices, consumer goods, and in the architecture, aerospace, and defense industries. Such technology is expected to become prevalent in households and additional industries[55] and is projected to grow by 18% by 2025.[56]

3D printing can improve a product's value by increasing the efficiency and effectiveness of the design process, including through reducing waste, time, and cost of production. It provides ordinary people with the means to produce or manufacture goods. In the food industry, 3D printing is already being used for automated cooking and in restaurants, to create personalized meals, and for mass manufacturing.[57]



Source Link: http://vtu.ac.in/wp-content/uploads/2013/12/nano3.jpg

NANOTECHNOLOGY

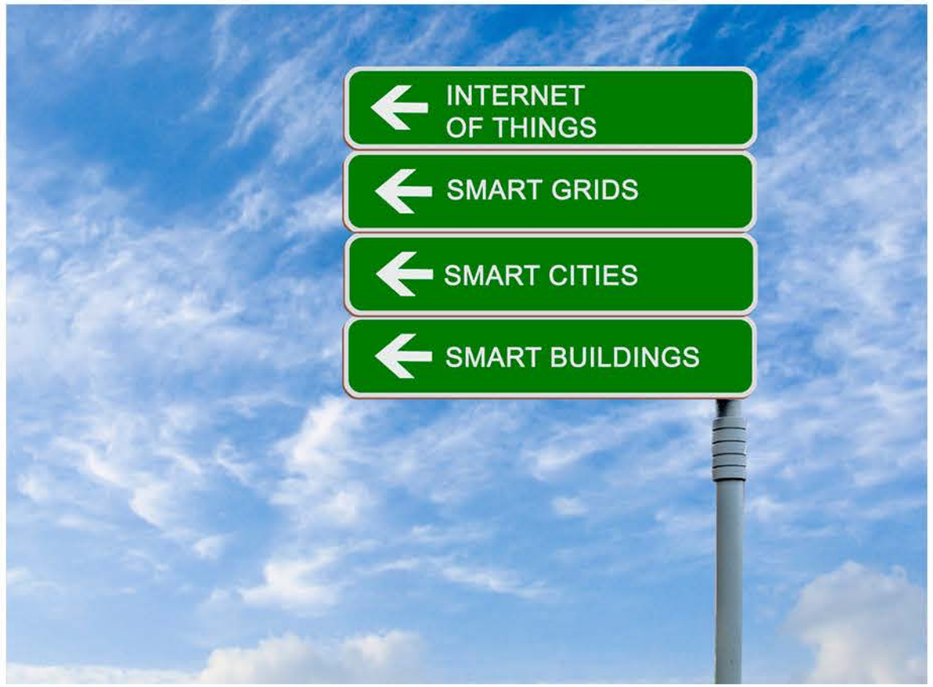
Nanotechnology is the branch of technology that deals with the manipulation of individual atoms and molecules to create functional material, devices, and systems that possess unique properties and capabilities.[58] The technology can be found in many industries, such as sports equipment, electronics, biomedicine, automotive, aerospace, agriculture and food. Between 2014 and 2019, the global nanotechnology market grew by 20%[59], and is expected to grow by more than 17% by 2024.[60]

Nanotechnology is expected to become increasingly common in products and impact all aspects of human life. It can make materials more resilient and durable, vastly improve health monitoring and solar energy capture and harvesting. In agriculture and food systems, nanotechnology can become commonplace in the form of nanosensor applications to monitor plant and animal health, detect diseases, improve crop yield and efficiency, provide alternatives to chemical pesticides, and reduce food loss.[61] Nanotechnology can also transform consumer experiences with food through nanoencapsulated flavor enhancers, or nanoparticles for better availability and dispersion of nutrients.[62] One issue with the utilization of nanotechnology is the lack of studies analyzing its long-term impacts, particularly with regards to environmental systems.

BIOENGINEERING

Bioengineering, or the use of technology and science to manipulate, redesign, and create organic material, is becoming increasingly advanced and available. Genetic engineering, including DNA editing and stem cell research, has been used to create genetically modified organisms and for biomedical purposes.[63]

Over the next decades bioengineering is expected to further blur the boundaries between organic and non-organic matter, and increasingly find its way into our daily lives through various mediums, such as using bioengineering with biomimicry to create new bionic products and technologies, or with 3D printing to produce human organs. Bioengineering has had a significant influence on the agriculture and food sectors, enabling scientists to imbue products with desirable traits such as increased yields, pest resistance, and improved nutrition. This is occurring not only through genetically modified seeds, but also through the rising industry of cultured meat.[64] Bioengineering also has applications with regards to water and soil management, designed to achieve comparable results.



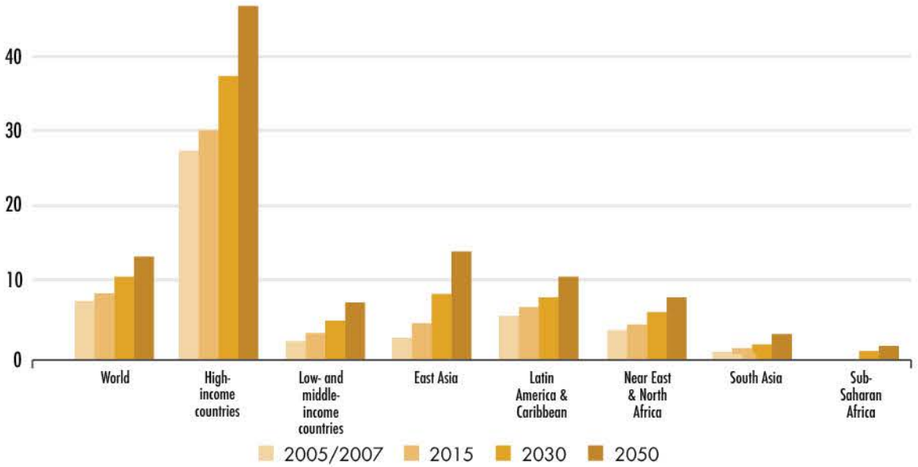
GEOSPATIAL TECHNOLOGIES

Geospatial technologies are tools such as satellites and imaging systems that are used for mapping features on the surface of the earth. These systems are able to collect and analyze data from specific locations, as well as store, process, display, and disseminate it.[65] The most notable geospatial technologies include GPS (global positioning systems), GIS (geographical information systems), and RS (remote sensing). These technologies are used in a variety of activities and disciplines including meteorology, commercial and recreational navigation, archaeology, seismic and tectonic analysis, climate studies, and in agriculture.[66]

MEGATRENDS

Economic

BOTTOM 50% AVERAGE ANNUAL INCOME
(EU€ Thousands per adult)



Source Link: Data for 2015 are based on FAO Global Perspectives Studies (unpublished data), data for 2005-2007, 2030, and 2050 are based on Alexandratos and Bruinsma, 2012

ECONOMIC GROWTH

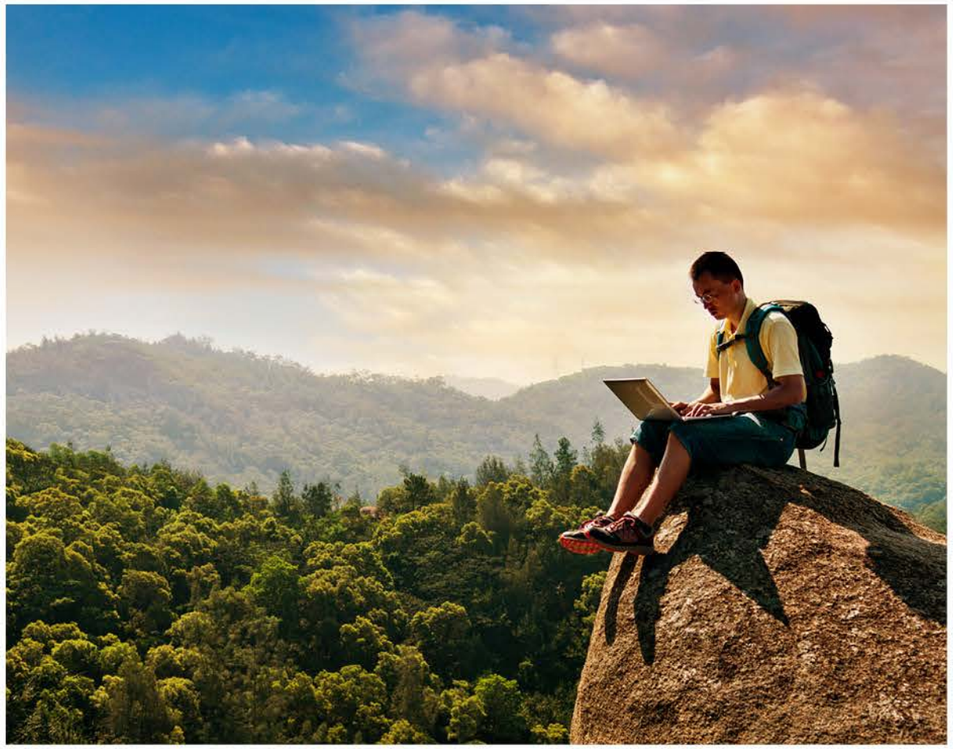
The world economy is expected to expand in the long term, with World Bank baseline projections indicating 2.9% average annual growth of global Gross Domestic Product from 2005 to 2050. High-income countries will only grow at 1.6% but developing countries will grow at 5.2%, narrowing the income gap between these groups. Developing countries' share of global output is expected to increase from 20% to 55% in 2050.[67]

Economic growth in developing countries will have wide implications for energy demand and use, the environment, trade, markets, agriculture, and food. By raising incomes and expanding a growing middle class, it will likely lead to increases in food consumption as well as shifts in demand patterns, most notably significant increases in meat and dairy demand, which will in turn create incentives for more livestock farming with adverse environmental effects. In many cases, economic growth will also be accompanied by increases in population size; changes in demographics, especially more elderly people; urbanization; and structural changes in economies.

POVERTY AND INEQUALITY

Extreme poverty, measured in terms of the number of people living below the poverty line of US $1.90 a day in purchasing power parity, has significantly declined since 1990. Yet, 736 million people were considered extremely poor in 2015.[68] The majority of the global poor are in sub-Saharan Africa and Asia, live in rural areas, are poorly educated, derive their livelihoods from the agricultural sector, and are under 18 years of age.[69]

Despite expected global economic growth and significant improvements and expectations that extreme poverty can be eradicated by 2030, millions of people will continue to live in poverty in 2050. Economic growth will improve the overall living conditions of people in developing countries, but intra-country inequalities will become more pronounced. Moreover, poverty as a multidimensional problem will become more difficult to eradicate as political instability, the effects of climate change, difficulty of reaching remote areas, and other factors will keep the poor vulnerable to shocks.[70]



STRUCTURAL CHANGES IN EMPLOYMENT

Technological developments and structural changes in economies will have a major impact on employment and workspaces. Over the past 50 years, the relative contribution of agriculture to GDP and its share of employment decreased globally. When high-income country economies moved away from primary production towards industry and the services sectors, labor was also reallocated.[71]

In 2050, businesses will likely employ more overseas employees than ever before as both the nature of work and increased globalization will make physical workplaces redundant.[72] Automation and robotization are expected to further disrupt global labor markets.[73] In low- and middle-income countries, a massive transformation is likely to occur away from primary production and towards new industries, mirroring the shifts seen in high-income countries. As these countries develop further, small-scale farmers will face increasing competitive pressures, and will either be forced to diversify their sources of income and employment or leave the agricultural sector entirely.[74]

INTERNATIONAL TRADE

Economic globalization and trade liberalization have made businesses and industries across the world more competitive and interdependent. Supply chains of large manufacturing companies are globalized, and dependent on the orderly flow of goods, services, and capital across borders.[75] While this overall megatrend is bound to endure, it is likely to continue to face setbacks and reversals, especially in the form of trade tariffs and other policies.

The relatively recent reemergence of protectionist policies in the United States and elsewhere, and Brexit in the United Kingdom, have posed questions about the future of free trade. Tariffs on imported goods and similar restrictions on free trade are likely to produce long-term significant consequences for various industries across the globe. If such "trade wars" continue to escalate, their likely implications will impact most aspects of human life, and in particular, the dynamics of food production and availability. Food security will especially be of concern for those countries that are net importers of food under this situation.[76]

MEGATRENDS

Environmental

GLOBAL CLIMATE CHANGE EFFECTS

(Risks from rising temperatures, according to UN)

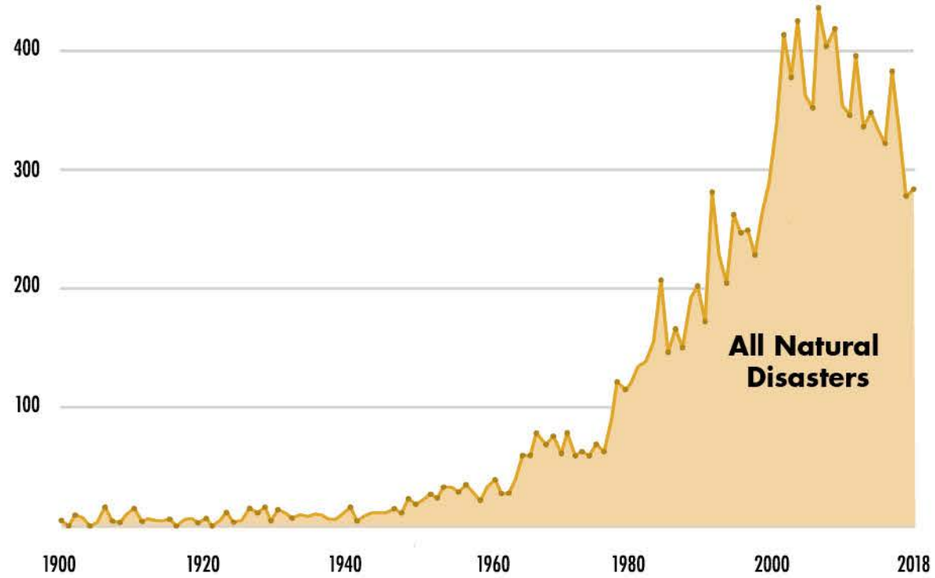
Source Link: http://www.jordantimes.com/sites/default/files/styles/news_inner/public/2Climate_change.jpg?itok=inRuN4nt

CLIMATE CHANGE

As the climate continues to change, humans and all other living organisms on the planet will increasingly suffer from and need to adapt to the adverse effects of higher temperatures, rising sea levels, melting of ice masses, changes in rainfall patterns, increased drought, and extreme weather conditions. The magnitude of climate change's impact in 2050 will largely depend on the scale of human adaptation and mitigation strategies over the next three decades to cap the increase in global mean temperatures at or below 1.5°C above pre-industrial levels.[77]

The impact of global warming has already been observed, and even with an increase of under 1.5°C, climate-related risks will increase to human health, livelihoods, economic growth, water supply, food, and physical security. Climate change is expected to disproportionately affect low-income developing countries, coastal cities and islands, and vulnerable populations and groups, and lead to mass migration. It will disrupt growing and harvesting seasons and will reduce the yield and nutritional quality of major crops such as rice and wheat.[78]

FREQUENCY OF RECORDED NATURAL DISASTERS

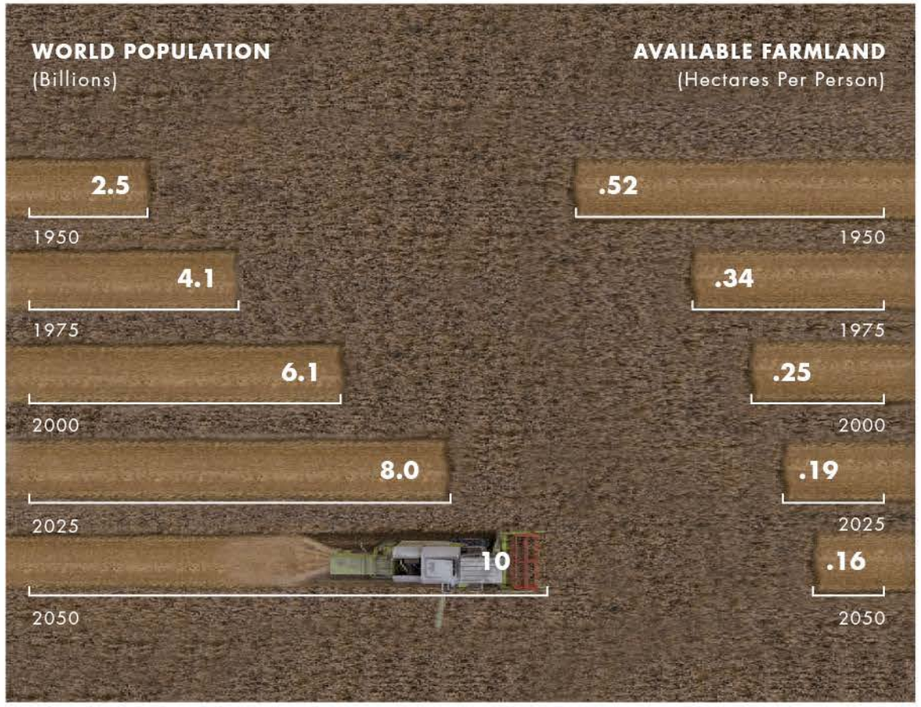


Source Link: https://ourworldindata.org/natural-disasters

NATURAL DISASTERS

The past three decades have seen a rise in the frequency of natural disasters, which are likely to become more intense and devastating in the future, causing significant disruption and damage to natural ecosystems and human habitats. Different parts of the world will witness more frequent and intense floods, storms, and drought periods.[79]

Natural disasters can devastate food production systems, reduce food availability, and inflate food prices. The most vulnerable people in low-income countries, especially women, are particularly exposed to the impact of natural disasters on their physical and food security, and these impacts are likely to continue and intensify in the future.[80]



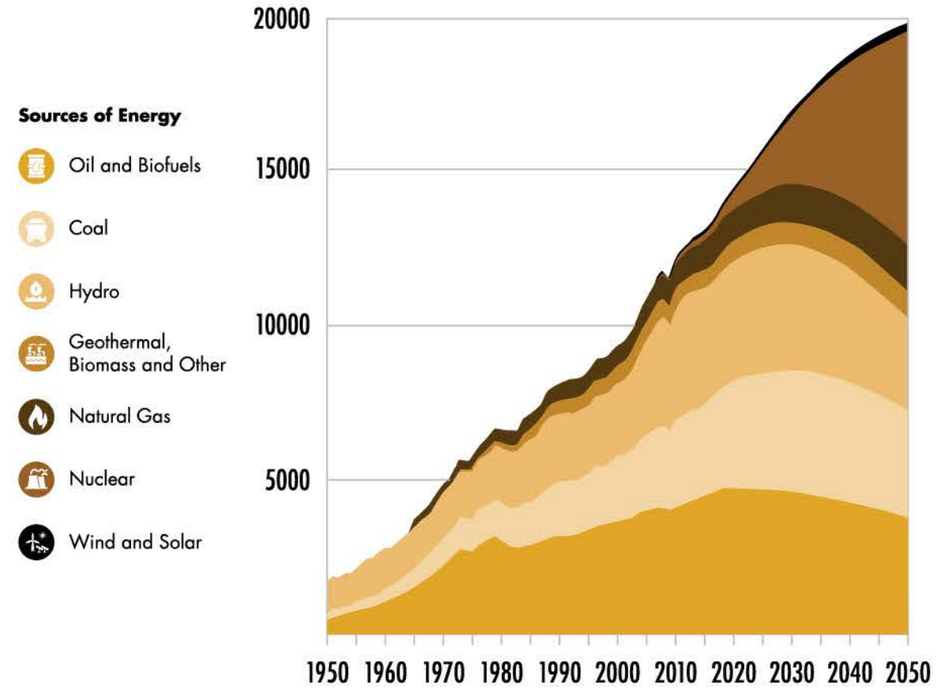
Source Links: http://www.megatrendswatch.com/resources-megatrends.html
https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/900

NATURAL RESOURCE SCARCITY

Natural resource scarcity is expected to increase, as competition for these resources, such as arable land and water, intensifies and leads to their overexploitation and unsustainable use, in turn reducing land available to produce food and animal feed.

Natural resource scarcity will take many forms and impact regions differently. In some parts of the world, water depletion and scarcity are already posing severe crises to people and will increasingly do so in the future. Deforestation and soil degradation will worsen air pollution and atmospheric greenhouse gas concentration, and worsen water quality, while also reducing productivity of agricultural lands and nutritional quality of crops. Without active countermeasures, competition for natural resources will likely increase their overexploitation and combined with other factors such as climate change, lead to food insecurity, more biodiversity loss, and other significant problems.[81]

WORLD ENERGY CONSUMPTION
(Millions of Tons)



Source Link: http://peakoilbarrel.com/world-energy-2018-2050-world-energy-annual-report-part-1/

ENERGY DEMAND

Demand for energy and efficiency in its production will continue to increase as the world witnesses 20% growth in population size and increasing expansion of economies by 2050, especially in developing countries. Despite energy consumption and demand increasing at a slower pace than in previous decades, supply of energy by 2050 is likely to increase anywhere between 27% to 61%, depending on the actions of consumers, markets, and governments.[82]

While renewable energy sources are expected to witness the highest rates of growth, fossil fuels will continue to dominate the global energy mix, projected to meet approximately 66% of the world's total energy needs in 2050, compared to 80% today.[83] This is unless major disruptions shift markets away from such business-as-usual predictions. Electricity generation will be the primary driver of increased energy demand, with an expected increase between 123% to 150% in 2050 compared to 2010.[84] To counter this increasing demand and use of energy, countries will need to impose emissions reductions and mitigation measures to limit the environmental impacts of energy use. This will include reducing emissions from agriculture, particularly through fertilizer application and nitrification inhibitors.[85]

Political

MULTIPOLARISM

The increased global prominence of China, India, Indonesia, and Nigeria, and the increasing regional and global presence of Russia, Europe (especially Germany and France), Asia more broadly, Brazil, and Turkey, will further diffuse international power and lead to a multipolar world in 2050. This world will be further characterized by the potential and relative erosion of international institutions, such as the United Nations, and the weakening of the global role of the United States.[86]

Multipolarism has historically been associated with relative instability. But it is unclear how such instability will play out in an increasingly globalized and interdependent world. Many other factors will play a role in shaping the characteristics of the multipolar world in 2050. These will include the role and status of inward-looking nationalism and populism in developed countries, policies limiting or restricting free trade and movement of people across borders, global and regional alliances between major powers, the role of technology in society and warfare, and within-country tensions between central authorities and local and provincial groups.[87]

ONGOING CONFLICT & CRISIS

According to the United Nations Secretary General, the number of countries in violent conflict in 2017 was the highest in 30 years, while the number of people killed in them has risen tenfold since 2005.[88] In 2017, a record 68.5 million people worldwide were forcibly displaced because of violent conflict. The overall economic costs of such violence reached $14.8 trillion in 2017.[89] The disruptive effects of climate change will exacerbate this trend, as extreme weather and food insecurity create competition for scarce resources and create social and political upheaval. For example, the incidence of armed conflict in sub-Saharan Africa is projected to increase by 60% by 2030 given projected trends in global warming.[90]

Violent political conflicts are closely associated with hunger and food insecurity. They disrupt farming activities and access to resources needed for agricultural production. In situations of political conflict, it is all too common to witness displacement of people from their homes, farming lands, and fishing grounds, and the destruction of food stocks. As an example, after eight years of violent conflict, 9.4 million Syrians (half of the people remaining in the country) were deemed to be food insecure.[91]

TRENDS IMPROVING INDIVIDUAL EMPOWERMENT

Source Link: https://i.ytimg.com/vi/V46MUYE_MGI/maxresdefault.jpg

RISE OF THE INDIVIDUAL

Individual empowerment will likely advance and become more pronounced, driven by advances in education and healthcare, rise in incomes, democratization of technologies, increasing global connectivity, and an increasing awareness of universal human rights, individual self-worth, and dignity.[92]

Individual empowerment will likely impact all aspects of life, leading to increasing transboundary collaboration, provision of services and collaborative consumption models directly based on individuals through the use of technological platforms. This empowerment is also likely to manifest itself in trends and movements that question the validity of science and scientific authority and mobilize itself globally. Transboundary terrorism will likely be amplified by individual empowerment and the processes that enable it.[93]

WOMEN'S EMPOWERMENT TRENDS

Source Link: https://womendeliver.org/wp-content/uploads/2018/09/Thumbnail-Leadership-Infographic.png

WOMEN'S EMPOWERMENT

Across the globe, women have been playing an increasingly significant role in both public and private sectors. The percentage of seats held by women in national parliaments rose from 18% in 2008 to 24% in 2018.[94] The World Economic Forum has found that closing the gender gap in countries is strongly correlated with economic competitiveness.[95] In Nigeria, Africa's largest economy, women are three times more likely to own and run a business than their male counterparts, while Latin American women are 20% more likely to participate in the workforce.[96]

Despite some reversals and this megatrend not being uniformly manifested in all parts of the world, the impact of women's increasing empowerment is likely to increase in the future as the gender gap is further reduced, especially in science, technology, engineering, and math. Women will remain the primary decision-makers for consumption in their households and female consumer spending is estimated to continue increasing, especially in the food sector,[97] thereby pushing industries in both developed and emerging markets to respond to female consumer dominance. This, together with their increasing workforce ascendancy, is likely to make women a powerful force for economic growth and change.

03.

GRAND CHALLENGE 1: CONSUMING AND PRODUCING HEALTHIER FOOD

Increasing the Consumption of Healthy Diets

Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts

Improving Food Literacy

Incentivizing the Production of Healthier Crops

CHAPTER 3.

Grand Challenge 1: Consuming and Producing Healthier Food

ACROSS THE WORLD, poor diets are a leading cause of death and health-related diseases, and their negative impacts on health systems and economies are rapidly becoming unsustainable. Almost a billion people consume too few calories, over two-and-a-half billion consume too many, and at least three billion do not have sufficient micro- and/or macronutrients.[98] In 2017, poor diets were responsible for 11 million deaths and 255 million (DALYs)[99], the measure of overall burden of disease[100]. Furthermore, worldwide, all forms of malnutrition cost $3.5 trillion, and non-communicable diseases due to obesity, such as cardiovascular disease and Type 2 diabetes, cost an additional $2 trillion.[101]

Addressing these issues requires increases in the consumption of healthier diets, especially among children. This is achieved in part by tackling the increasing demand for unhealthy foods by shifting from a calorie-centered system to one that prioritizes nutritional quality. Improvements in food literacy will also be critical in changing food consumption patterns.

In commercial agriculture, incentives continue to drive production towards high-calorie, low-nutrient staple crops at the expense of diversified systems that can be healthier for people and the environment. Food system policies, and especially subsidies, need to be realigned to best serve the goal of advancing nutritional security.

To ensure we produce and consume healthier foods on a global scale, four key challenges must be overcome:

INCREASING THE CONSUMPTION OF HEALTHY DIETS

Globally, over 800 million people go hungry, 1.2 billion are food insecure, over two billion suffer from micronutrient deficiencies, and over 200 million children are either stunted or wasted. Addressing these issues will require people to double on average their consumption of healthy foods, those that are essential to human health, social well-being, and economic productivity.[102,103,104,105]

REDUCING THE OVER-CONSUMPTION OF FOODS THAT LEAD TO DIET-RELATED HEALTH IMPACTS

The world is experiencing an unprecedented rise in diet-related diseases and deaths, driven in large part by increasing consumption of unhealthy ultra-processed foods, along with over-consumption of animal protein in some parts of the world. To enjoy healthier lives, humans on average need to cut their consumption of unhealthy foods by more than half.[106,107]

IMPROVING FOOD LITERACY

Awareness of healthy diets has been on the rise, but uneven across societies and socio-economic classes. Changes in lifestyles, effects of marketing, prices and social habits are among the many factors preventing people from making healthier food choices and improving food literacy, without which demand for unhealthy foods and their production are difficult to change.[108,109,110]

INCENTIVIZING THE PRODUCTION OF HEALTHIER CROPS

For decades, policies incentivized the production of large volumes of a small number of commodity crops, leading to the availability of more calories but oftentimes lower nutritional quality. To produce and consume healthier food, these policies need to be realigned to support a transition towards healthier diets.[111,112]

CHALLENGE 1.1

INCREASING THE CONSUMPTION OF HEALTHY DIETS

ACROSS THE WORLD, over 800 million people (11% of world population) still go hungry, and an additional 1.2 billion people are also food insecure.[113] Due to lack of consumption of healthy foods, approximately one billion people suffer from protein deficiency and more than two billion suffer from micronutrient deficiencies (also known as "hidden hunger.")[114,115]

Without increasing the consumption of healthy foods, and reducing the overconsumption of "empty calories," food-related non-communicable diseases, and particularly obesity, will continue to increase. Healthy foods contain vitamins and minerals which, although consumed in small quantities, are essential for physical and mental development, especially of children.[116] According to the EAT Lancet Commission Report, people globally need to double their consumption of healthy foods, such as fruits, vegetables, legumes, and nuts, and reduce by more than half their consumption of less healthy foods such as added sugars and red meat,[117] with those suffering from hunger and food insecurity needing to simultaneously increase their overall caloric intake.

WHAT IS A HEALTHY DIET?

According to the World Health Organization[118] (WHO), a healthy diet is a balanced, diverse and appropriate selection of foods eaten over a period of time that ensure a person's needs for macronutrients (proteins, fats and carbohydrates including dietary fibers) and essential micronutrients (vitamins, minerals and trace elements) are met. The exact make-up of a healthy diet depends on a number of factors such as the person's gender, age, physical activity level and physiological state, but the basic principles include: sufficient consumption of fruits, vegetables, legumes, nuts, and whole grains; minimal intake of free sugars; less than 30% of total calories derived from fats, with an emphasis on so-called "good fats" (i.e. unsaturated fats); and minimal intake of salt. For children, optimal nutrition during the first two years is critical for a child's growth, development and health later in life. The WHO recommends breastfeeding for young children, and after 6 months of age, the introduction of a variety of nutrient-dense foods, in addition to the above guidance for adults.[119]

The recent EAT Lancet Commission report on what constitutes a "planetary health diet" recommends a similar composition as the WHO, outlining a diet that compared to current food composition averages represents a significant increase in consumption of vegetables, fruits, whole grains, legumes and nuts, and a 60% decrease in red meat and starchy vegetable consumption worldwide.[120] The report breaks down macronutrients in detail and provides a "reference diet" (see citation) that is tailored to achieve both human and environmental health outcomes.

IMMEDIATE DRIVERS[121]

VARIOUS FACTORS DIRECTLY AFFECT THE CONSUMPTION, OR LACK THEREOF, OF NUTRITIOUS FOODS; HOWEVER, POVERTY IS THE PRINCIPAL CAUSE OF HUNGER. IN ADDITION TO THE ONES HERE, OTHERS ARE LISTED UNDER THE CHALLENGE OF "REDUCING THE OVER-CONSUMPTION OF FOODS THAT LEAD TO DIET-RELATED HEALTH IMPACTS."

- HIGH PRICES OF NUTRITIOUS AND FRESH FOODS MAKE THEM LESS ACCESSIBLE TO LOW-INCOME HOUSEHOLDS.
- LOW-INCOME NEIGHBORHOODS LACK GROCERY STORES AND FARMERS' MARKETS THAT CONTAIN SUFFICIENT HEALTHY FOODS SUCH AS FRESH FRUITS AND VEGETABLES, WHOLE GRAINS, AND LOW-FAT DAIRY PRODUCTS.
- LOW-INCOME HOUSEHOLDS DO NOT HAVE THEIR OWN VEHICLES OR CONVENIENT TRANSPORTATION MEANS TO GET TO SUPERMARKETS OR STORES WITH FRESH PRODUCE.
- LACK OF COLD STORAGE TO PRESERVE OR EXTEND FRESH PRODUCT SHELF LIFE, SUCH AS FOR VEGETABLES AND FRUITS, INCREASE THESE PRODUCTS' PERISHABILITY AND THEREFORE UNAVAILABILITY.
- FOOD ADULTERATION, OR ADDITIVES TO INCREASE QUANTITY, TASTE, TEXTURE OR APPEARANCE OF FOOD, COULD RESULT IN LOSS OF QUALITY AND NUTRIENTS.
- INSUFFICIENT FOOD LITERACY AND POOR AWARENESS OF WHAT CONSTITUTES HEALTHY AND NUTRITIOUS FOODS REDUCES THE LIKELIHOOD OF CONSUMING HEALTHY FOODS.
- CHANGES IN CLIMATE ALSO HEAVILY IMPACT NUTRITION THROUGH IMPAIRED NUTRIENT QUALITY AND DIETARY DIVERSITY OF FOODS PRODUCED AND CONSUMED.[122,123,124]

IMPACT AND SIGNIFICANCE

The lack of access to healthy and nutritious foods is a key factor contributing to hunger, obesity and micronutrient deficiency, which are responsible for the huge rise in diet-related diseases globally. Poor access to healthy food increases the risk of low birth weight, childhood stunting and anemia in women of reproductive age, and it impedes child growth and development.[125] These have further significant implications for health costs, labor productivity, and economies of countries.

Maternal and child undernutrition contributes to 45% of deaths in children under five, and even when non-fatal, contributes to negative physiological outcomes (such as stunting) as well as increased longer-term health and developmental risks. Furthermore, low birth weight due to undernutrition is related to increased risks of coronary heart disease, stroke, diabetes, and abdominal obesity in later stages of life.[126],[127]

Hunger and other forms of undernutrition have significant impact on societies and economies, including in causing or determining poverty and severely reducing labor productivity. The economic costs of undernutrition, measured both in reduced national productivity and economic growth, are significant and range from 2% to 3% of GDP in some countries and up to 11% of GDP in Africa and Asia each year.[128],[129] Globally, undernutrition and micronutrient deficiencies cost over $2.1 trillion per year.[130]

Micronutrient deficiencies also have severe health implications. For example: anemia, which results from iron and vitamin B12 deficiency, contributes to 20% of all maternal deaths, according to the WHO, and deficiencies in other micronutrients such as iodine, vitamin A, and iron cause impaired cognitive development, blindness, weakened immune systems, and impaired growth, among other effects.[131]

EXISTING REMEDIES

Various remedies are being used to tackle hunger, and nutrient and micronutrient deficiencies. These include poverty alleviation interventions, nutrition-sensitive programs, nutritional supplement aid, women's economic empowerment, taxes, and policy instruments to improve availability of nutritious foods, better food regulations and inspection to reduce loss of nutritional quality from adulteration or in food processing, and many others. Below is a sample of some of these interventions that are directly related to foods and food systems; other relevant ones are also listed under other challenges. It should be noted that not all of these remedies are appropriate for all populations and contexts, given regional variations in how the issues around consumption of healthy diets are expressed within specific communities.

MICRONUTRIENT FORTIFICATION

Food fortification is the process of adding nutrients, such as vitamins and minerals, to foods.[132] It is commonly carried out by private sector companies, such as local and global producers. Micronutrient fortification is helpful for targeting specific population groups, but on its own it is not a viable long-term strategy for a whole population or country (except in rare cases, as in the case of iodized table salt), as it faces the challenge of becoming physically and economically accessible to rural populations, and its consumption depends on other products in the market.[133] There are numerous examples of micronutrient fortification, including by global companies such as Nestle, which in 2016 delivered 64 billion servings of fortified food and beverages in Central and West Africa.[134]

BIOFORTIFICATION

Biofortification is the process of enhancing the nutritional quality of food crops during plant growth through agronomic practices, conventional plant breeding, or modern biotechnology.[135] While biofortification has many advantages, it could lead to poor diets by increasing dependence on a few market-based crops at the expense of nutritional diversity.[136] Some biofortification methods, such as bioengineering, are not accepted by many people. Furthermore, some biofortified seeds are owned by companies and are not affordable or available to farmers. One of the recent examples of biofortification is "Golden Rice," which is rice enriched with beta-carotene, a source of Vitamin A.[137]

INNOVATIVE FOOD PRODUCTS

New innovative food products are being increasingly made available to treat severe malnutrition. While their accessibility and incorporation into daily diets remains a challenge, such products have helped reduce malnutrition. An example of this is the Ready to Use Therapeutic Foods (RUTF), which have been developed in the form of peanut-butter-based pastes and biscuits that are nutrient-rich and packed with high concentrations of protein and energy. RUTFs reduce exposure to water-borne bacteria, as they contain no water. They require no refrigeration and are ready to serve, ensuring that essential nutrients are not lost by the time the products are consumed. With no water, heating or preparation required, RUTFs avoid all of the major inconveniences of therapeutic milk-based products, which are the standard treatment in inpatient care of severe acute malnutrition.[138]

APPS FOR HEALTHY DIETS

In recent years, a large number of mobile phone apps that help improve healthy diets have become available across the world. While many of these are free to use, these apps depend on mobile phone technologies and some level of technological literacy to be used, in addition to physical access and affordability. This limits their reach and usefulness to many of those who need to consume healthier diets. Examples include MyFitnessPal, Lifesum, MyDietCoach, etc.[139]

INITIATIVES TO INCREASE PROTEIN CONSUMPTION IN THE DEVELOPING WORLD

Increasing the consumption of protein can help address issues of undernutrition and macro- and micronutrient deficiencies. Animal proteins such as eggs have high amounts of bioavailable micro- and macronutrients.[140] Initiatives such as OneEgg[141] and First 1000 Days[142] focus on providing eggs as a protein source during early childhood. Recent research supports the impacts of providing protein to young children to prevent stunting and encourage healthy brain development. For example, a randomized controlled trial in Ecuador that provided eggs to children aged 6 to 9 months for a six-month period reduced stunting by 47%, and showed significant improvements in the presence of biomarkers associated with cognitive development.[143] Related benefits are obtained by providing eggs to lactating women.[144]

CHALLENGE 1.2

REDUCING THE OVER-CONSUMPTION OF FOODS THAT LEAD TO DIET-RELATED HEALTH IMPACTS

SINCE THE 1980S, ultra-processed, packaged, branded, affordable, ready to eat/drink/heat "fast" or "convenient" products have dominated the food industries of high-income countries. In middle- and low-income countries, these products are rapidly displacing traditional dietary patterns based on minimally processed foods and freshly prepared dishes and meals, with severe health outcomes.[145]

Ultra-processed foods are often characterized by lower nutritional quality and the presence of additive ingredients.[146] Replacing the consumption of more nutrient-rich foods with increased consumption of ultra-processed foods leads to micronutrient deficiencies, and is linked to higher incidences of being overweight or obese, which can lead to hypertension, cancer, type 2 diabetes, cardiovascular and other non-communicable diseases.[147] In addition to ultra-processed foods, there is evidence that the long-term consumption of increasing amounts of red meat, particularly processed meat, can lead to an increased risk of total mortality, cardiovascular disease, colorectal cancer and type 2 diabetes, in both men and women,[148] although studies quantifying these associations suffer from some methodological challenges given the difficulties in conducting nutritional research.[149]

WHAT ARE ULTRA-PROCESSED FOODS?

According to the NOVA food classification system, ultra-processed food products are "industrial formulations typically with five or more and usually many ingredients. Such ingredients often include… sugar, oils, fats, salt, anti-oxidants, stabilizers, and preservatives." Other substances in ultra-processed food include "additives whose purpose is to imitate sensory qualities…" of unprocessed food.[150]

IMMEDIATE DRIVERS[151]

ECONOMIC

- LOWER-INCOME CONSUMERS ARE MORE LIKELY TO CHOOSE LOW-PRICED FOOD, MUCH OF WHICH IS HIGH IN FAT, SUGAR, AND SALT.
- ULTRA-PROCESSED, MASS-PRODUCED AND GLOBALLY DISTRIBUTED FOOD IS CHEAPER AND INCREASINGLY MORE AVAILABLE AND CONVENIENT THAN ITS HEALTHIER AND MORE NUTRITIOUS COUNTERPARTS, GIVEN INNOVATIONS IN PRODUCTION, PROCESSING, PACKAGING, AND DISTRIBUTION TECHNOLOGIES.
- FREE TRADE, MODERN SUPERMARKETS, FOOD DISTRIBUTION AND MARKETING ARE CHANGING DIETS IN LOW- AND MIDDLE-INCOME COUNTRIES, IN WHICH OBESITY APPEARS TO BE RISING.

SOCIAL

- INSUFFICIENT FOOD LITERACY AND POOR AWARENESS OF HEALTHY AND NUTRITIOUS FOODS INCREASES THE LIKELIHOOD OF CONSUMING UNHEALTHY FOODS.
- CHANGES IN LIFESTYLE, IN PARTICULAR THE INCREASED SHARE OF WORKING WOMEN AND THE CONSEQUENT TIME CONSTRAINTS ON COOKING ACTIVITIES, ENCOURAGE CONSUMPTION OF CONVENIENT FOODS.
- CHANGES IN SOCIETY, SPECIFICALLY THE PREVALENCE OF SINGLE-PERSON HOUSEHOLDS, CREATE DEMAND FOR PORTIONED AND CONVENIENTLY PACKAGED FOOD, WHERE THE FAST FOOD INDUSTRIES HAVE DEVELOPED CAPACITIES.
- ULTRA-PROCESSED FOOD IS CONVENIENT AND REPRESENTS THE "STATUS SYMBOL OF WESTERN FOOD," WHICH MAKES IT HIGHLY ATTRACTIVE, AND HEAVILY MARKETED, IN DEVELOPING COUNTRIES.

MARKETING AND PSYCHOLOGICAL

- MARKETING UNHEALTHY FOOD AND DRINK TO CHILDREN, PARTICULARLY THOSE CONTAINING HIGH SUGAR, IS A LEADING CAUSE OF DIET-RELATED DISEASES AMONG CHILDREN.
- IN-STORE MARKETING TOOLS AFFECT CHOICES CONSUMERS MAKE IN BUYING DIFFERENT TYPES OF FOOD.
- CONVENIENT, ULTRA-PROCESSED COMFORT FOOD RICH IN SUGAR, FAT, AND SALT HAS BEEN ASSOCIATED WITH DECREASING ANXIETY AND STRESS IN THE SHORT TERM, LEADING TO ITS OVERCONSUMPTION.
- THE HUMAN BODY DESIRES SUGARY AND FATTY FOODS, AND HUMAN BRAINS RESPOND TO THESE FOODS BY RELEASING DOPAMINE AND THEREFORE CREATING INTENSE FEELINGS OF PLEASURE.[152]

THE DOUBLE BURDEN OF MALNUTRITION[153]

The double burden of malnutrition refers to the coexistence of undernutrition along with overweight and obesity, or diet-related noncommunicable diseases, within individuals, households and populations, and across the life-course.

In 2016, more than 1.9 billion adults worldwide were overweight while 462 million were underweight. More than 650 million were obese. In the same year, 41 million children under the age of five were overweight or obese,[154] yet in 2014 156 million were affected by stunting and 50 million by wasting.[155] While poor nutrition causes nearly half of deaths in children under five, low- and middle-income countries now witness a simultaneous rise in childhood overweight and obesity.

IMPACT AND SIGNIFICANCE

Poor diets are the second-leading risk factor for deaths and DALYs globally, accounting for 18.8% of all deaths, of which 50% are due to cardiovascular disease.[156] The economic cost of obesity is a staggering $2 trillion annually, through loss of economic productivity and health care costs.[157]

Recent evidence supports the conclusion that ultra-processed foods are a key driver of these outcomes. Two recent large-sample, longitudinal studies have associated ultra-processed foods with mortality and cardiovascular diseases.[158] Increased consumption of ultra-processed foods is linked with higher incidences in overweight, obesity, hypertension, cancer, and other non-communicable diseases. Consumption of this type of food is also responsible for micronutrient deficiencies.[159]

OBESITY AND ITS HEALTH AND ECONOMIC BURDENS

ACCORDING TO THE WORLD HEALTH ORGANIZATION,[160]

- **THE GLOBAL PREVALENCE OF OBESITY ALMOST TRIPLED BETWEEN 1975 AND 2016.**
- **OF THE MORE THAN 1.9 BILLION ADULTS (39% OF MEN, 40% OF WOMEN) WORLDWIDE WHO WERE OVERWEIGHT IN 2016, 650 MILLION (11% OF MEN, 15% OF WOMEN) WERE OBESE.**
- **41 MILLION CHILDREN UNDER THE AGE OF FIVE WERE OVERWEIGHT OR OBESE IN 2016.**

HEALTH BURDEN

- **AROUND 3.4 MILLION ADULTS DIE EACH YEAR AS A RESULT OF BEING OVERWEIGHT OR OBESE. OVERWEIGHT AND OBESITY ARE RESPONSIBLE FOR 44% OF THE DIABETES BURDEN, 23% OF THE ISCHEMIC HEART DISEASE BURDEN AND BETWEEN 7% AND 41% OF CERTAIN CANCER BURDENS.[161]**

ECONOMIC BURDEN

- **OBESITY DRIVES BETWEEN 2% AND 7% OF GLOBAL HEALTH CARE SPENDING.[162]**
- **OBESITY HAS THE SAME IMPACT ON THE GLOBAL ECONOMY AS ARMED CONFLICT OR SMOKING. THESE THREE ARE BY FAR THE LARGEST GLOBAL ECONOMIC IMPACT AREAS DRIVEN BY HUMAN BEHAVIOR.[163]**

The consumption of ultra-processed food also can lead to food and other waste, both because of large portion sizes and wasteful packaging. Ultra-processed foods also reduce consumers' food literacy skills, constraining knowledge about food, its ingredients, and nutrition.[164]

EXISTING REMEDIES

Remedies to reduce overconsumption of unhealthy foods can take different forms. Many of these are discussed under the previous challenge of "Increasing the Consumption of Healthy Diets" and in "Improving Food Literacy." Subsidies and taxes are discussed further below under "Incentivizing the Production of Healthier Crops." Others, such as extending the shelf-life of fruits and vegetables or shortening the distance between their production and consumption, are discussed under the challenges of "Curtailing and Repurposing Food Loss and Waste" and "Optimizing Fair Economic Opportunities Along the Food Chain." Here we discuss other remedies, including alternatives to animal-based proteins.

EMERGING TRENDS IN DIET

There is an increasing number of dietary trends in many parts of the world that are based on healthier choices than the Western-style diets that have been globalized. Overall, there has been a trend towards more informed, often health-focused, eating habits among affluent consumers, primarily in developed countries. Three of the most significant of these are Vegetarian, Vegan, and Flexitarian. Vegetarian diets come in different forms but share the common attributes of abstaining from eating meat, fish and poultry. A vegan diet is a type of vegetarian diet that excludes meat, eggs, dairy products, and all other animal ingredients.[165] "Flexitarian" is a combination of "flexible" and "vegetarian." It is primarily a vegetarian diet with the occasional inclusion of meat or fish.[166] There are a range of other diet types and new products designed around them.

PLANT-BASED ALTERNATIVES TO ANIMAL PROTEIN

Plant-based meat alternatives have recently been introduced to markets in North America and elsewhere by companies such as Impossible Burger and Beyond Meat. A challenge with some plant-based alternatives is that they could cause harm to the environment and human health by encouraging monoculture. Additionally, current plant-based meat alternatives are highly processed and may not be an improvement nutritionally versus animal-based protein, although that is projected to change in the future.[167]

INSECT-BASED PROTEIN ALTERNATIVES

Insect-based protein alternatives are also being proposed as an alternative to mammal-based protein products. There are over 2000 types of edible insects, and up to 80% of the world's population already eat bugs,[168] with cricket powder being one common example. Insect protein has a much higher protein-to-weight ratio than animal protein (for example, crickets are 69% protein while beef is only 29%), and also has a much higher feed-conversion efficiency rate, measured as the ratio between the weight of input feed and resulting weight gain.[169] Unlike plant-based animal protein alternatives, insects are not as widely accepted due to the "yuck factor" and they are mostly produced for animal feed rather than human consumption.

CULTURED OR LAB-GROWN MEAT

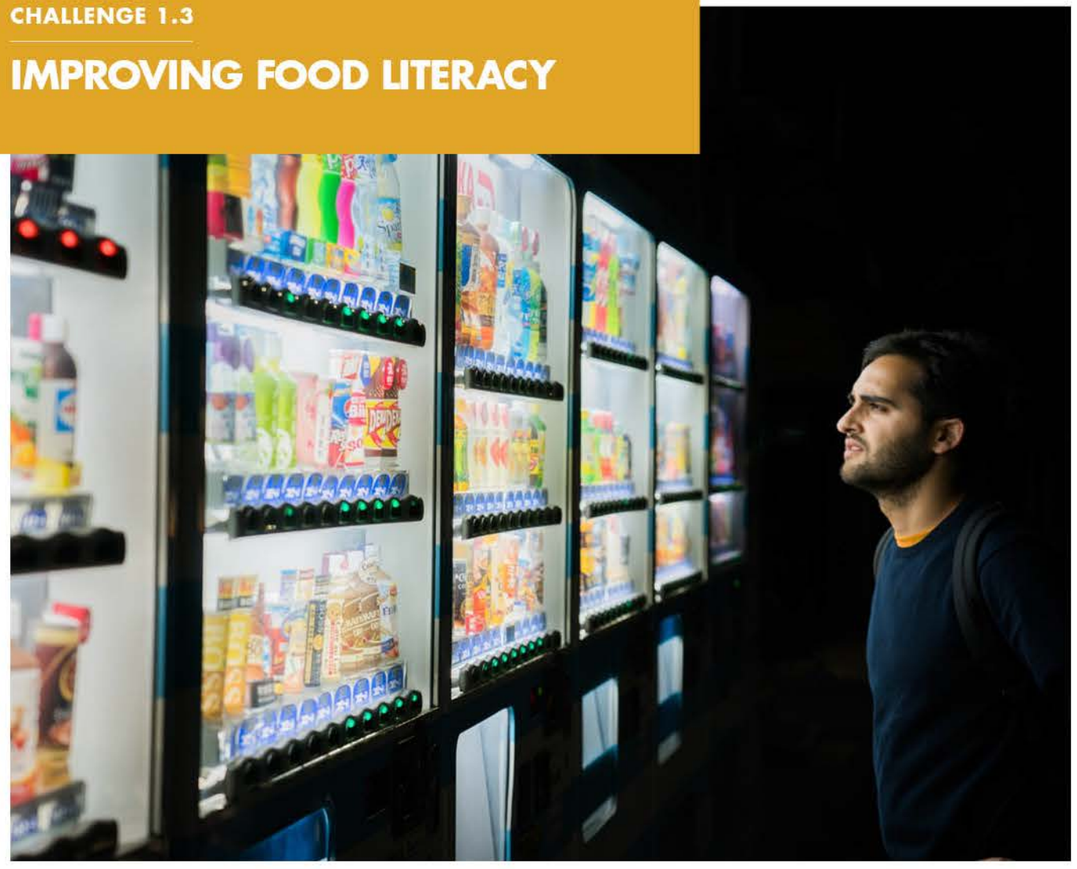
Cultured or lab-grown meat from animal cells is currently being developed at an increasing pace and is expected to be introduced to markets in the coming years. An example of laboratory-grown meat: Tokyo-based Integriculture is developing cellular agriculture and clean meat, winning the Singularity University's Global Impact Challenge in 2017. Its founder, Yuki Hanyu, also runs Shojinmeat, a non-profit that provides microwave-sized heated boxes that enable school children to culture cells at home. Currently, lab-grown meat is still expensive and unavailable to the public, and the extent to which consumers will accept it remains unclear.[170]

PORTION CONTROL INNOVATIONS

Various food portion control innovations have been introduced to food markets in recent years. These include pre-prepared meals, portioned ingredients for at-home meal preparation, or portion control serving tools.[171] An example of this is Blue Apron in the United States, that delivers carefully portioned fresh ingredients to subscribers who can make their meals from these with little or no waste.[172] The reach and accessibility of these innovations are however limited both geographically and economically.

CHALLENGE 1.3

IMPROVING FOOD LITERACY



FOOD LITERACY IS about people understanding the consequences of what they eat for their health, the environment, and the economy. It means having the knowledge and skills to makes healthy food choices and to prepare healthy meals.[173]

While there has been an increase in awareness of healthy and nutritious foods, this has been uneven within and across countries. Food literacy is shaped both by broader institutional and social factors, as well as individual values and preferences. Food supply and accessibility to diverse, nutritious products is a key determinant of one's ability to become food literate.[174]

Food literacy is profoundly impacted by marketing and communication, as well as social habits, behaviors and tastes of consumers. Without food literacy or increased awareness, consumer choices are led by marketing that promotes food not necessarily in the best interest of the consumer. These choices subsequently motivate demand for unhealthy food and reinforce their supply.[175]

FOOD LITERACY[176]

There is not a single, universally agreed upon definition of food literacy. Most definitions use a combination of the below attributes, and some emphasize that the concept, or relevant components of it, should be used relative to particular individual needs within specific larger contexts (e.g. socio-cultural, etc.).

- Food and nutrition knowledge, from experience or education, about the variety of foods that exist, where they come from, how food is produced, basic ingredients, nutritional composition, and function of nutrients in the human body.
- Food skills, including techniques of food purchasing, preparation, handling and storage. This also includes use of cooking equipment and food safety best practices.
- Capacity or self-efficacy in distinguishing between scientific and evidence-based information of foods and nutrition, and non-factual knowledge.
- Understanding of the larger forces and factors (e.g. socioeconomic, environmental, etc.) of food systems.
- Applying knowledge, information, and skills to actively choose healthier and more nutritious foods within the larger context and in relation to the other factors mentioned above.

IMMEDIATE DRIVERS[177]

- POVERTY AND THE PHYSICAL AVAILABILITY OF HEALTHY FOODS PLAY A ROLE IN SHAPING FOOD LITERACY, AND PARTICULARLY IN LIMITING AN INDIVIDUAL'S CAPACITY TO EXERCISE IT.
- SOME CULTURES PUT MUCH MORE EMPHASIS ON FOOD LITERACY THAN OTHERS, ASCRIBING A MUCH MORE PROMINENT PLACE REGARDING RELATED KNOWLEDGE, TECHNIQUES, AND SKILLS.
- LEVELS OF FOOD LITERACY, PARTICULARLY OF WOMEN AND MOTHERS, CAN DETERMINE HOW NOURISHED OR UNDERNOURISHED CHILDREN ARE. CHILDREN WHOSE PARENTS HAVE LOW LEVELS OF FOOD LITERACY ARE LIKELY THEMSELVES TO END UP WITH POOR FOOD LITERACY.
- INCREASING TIME CONSTRAINTS, CHANGES IN LIFESTYLES AND MEAL HABITS CAUSE INCREASED RELIANCE ON CONVENIENT FOODS AND DECREASED TIME SPENT COOKING MEALS FROM WHOLE OR MORE BASIC INGREDIENTS, THEREBY REDUCING FOOD LITERACY.
- MARKETING HAS SIGNIFICANT IMPACTS ON CONSUMER CHOICES AND LEVELS OF FOOD LITERACY. THIS INCLUDES INCENTIVES FOR THE PRIVATE SECTOR TO MARKET UNHEALTHY FOODS.
- LACK OF PUBLIC EDUCATION ABOUT FOOD AND HEALTH REDUCES FOOD LITERACY.
- EDUCATION SYSTEMS THAT PROVIDE COURSES ON COOKING TO CHILDREN INCLUDE LITTLE OR NO NUTRITION EDUCATION.
- MEDICAL SYSTEMS THAT DO NOT FOCUS ON NUTRITION AND PREVENTIVE CARE ARE DETRIMENTAL TO FOOD LITERACY.

IMPORTANCE OF CHILDHOOD AND ADOLESCENCE IN FOOD LITERACY

Most researchers argue that dietary habits and food preferences develop in childhood, are established by age 15, and become habitual in due course. Adolescence is thus still a key formative period in the development of eating habits.[178]

IMPACT AND SIGNIFICANCE

Food literacy can improve consumption of healthy and nutritious diets by giving individuals a better understanding of food ingredients, production processes, and their impact on the natural environment, thereby making their choices less restricted by their immediate environment or other factors such as cheap prices.[179]

Food literacy can also improve nutritional intake by making healthy foods more valuable to the individual, more pleasurable and more likely to be consumed. It can add to an individual's ability to stay resilient to economic and social changes that negatively affect healthy eating choices.[180] Food literacy is especially important for individuals responsible for making dietary choices for others, such as those responsible for school meals, hospital cafeterias, airlines, and others.

A lack of food literacy creates difficulties for an individual to engage in a healthy lifestyle as they are unable to take control of their own food consumption. Consumers are more likely to be misled by marketing and misinformation and end up making unhealthy and less nutritious food choices.[181]

Weak or absent food literacy not only affects consumer choices and their health; demand for unhealthy foods increases their availability for other consumers, exacerbating the effect of poor food literacy, and creates incentives for both large and small food producers alike to develop unhealthy foods and produce the types of crops of which they are comprised.[182]

Through its impact on individual consumer's choices and demand, weak food literacy contributes to mass malnutrition problems globally and as such is a factor of the other challenges presented previously.[183]

EXISTING REMEDIES

MASS MEDIA CAMPAIGNS

Mass media campaigns focused on preventing weight gain have been successful in a number of countries. A three-year mass media campaign ('Maak je niet dik!' or "Don't get fat") implemented in the Netherlands resulted in high campaign awareness, more positive attitudes, greater social support, and positive intentions to prevent weight gain. Similarly, the 2009 Western Australian "Draw the Line" campaign, which aimed at maintaining a healthy weight, was effective in achieving high campaign awareness, understanding of campaign messages, and confidence in the target group's ability to implement and sustain weight-related behaviors.[184]

NUTRITION EDUCATION PROGRAMS

Nutrition education programs help people make better conscious choices about their food intake. These programs are typically combined with physical exercise interventions in community health promotion programs. Dietary behavior however is not only the outcome of conscious choices, but also unconscious processes, such as habits, and broader environmental factors affecting those choices. Increasingly, multi-behavior programs are taking a whole-of-community approach to target obesity (e.g., Victorian-based Health Promoting Communities: Being Active Eating Well initiative).[185]

SETTINGS APPROACHES

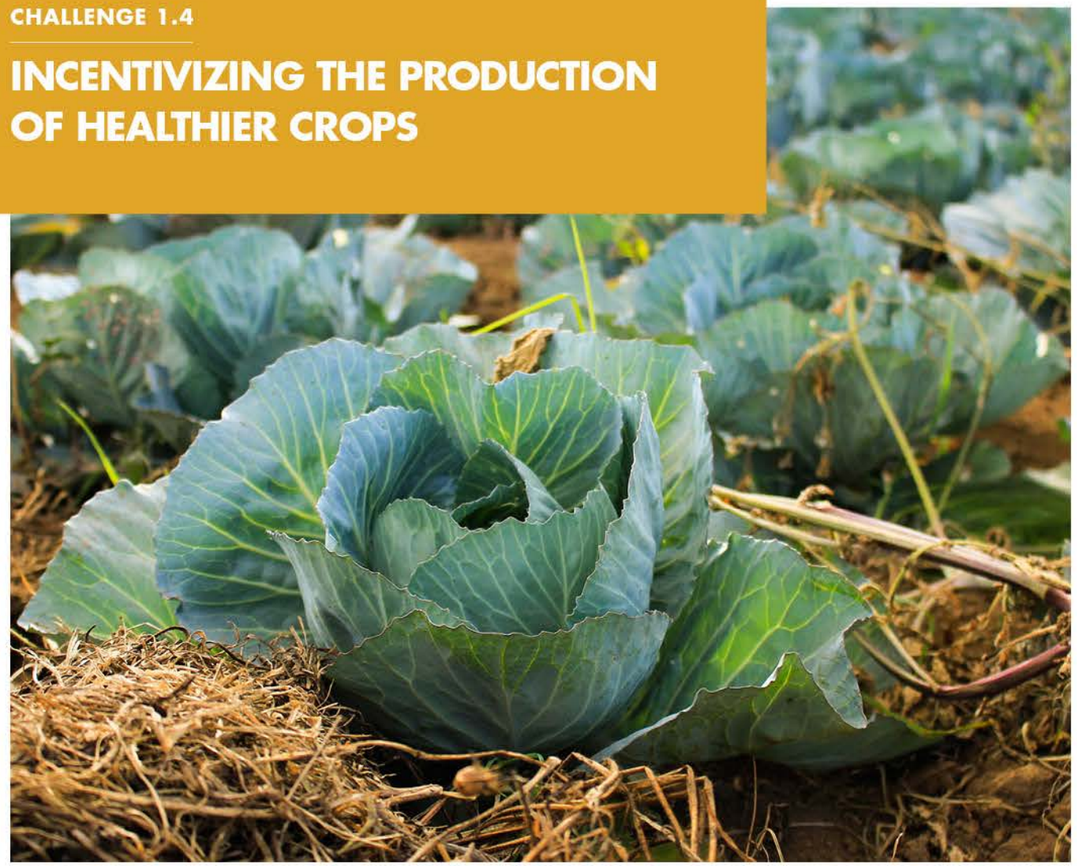
Settings approaches are targeted interventions to increase food literacy and nutritional awareness in specific populations. The two most common settings or target populations for interventions are schools and workplaces. These approaches have shown mixed results in improving overall nutritional intake and physical health of their targeted populations. See the endnotes for details on examples of these two approaches.[186,187]

IMPROVED FOOD LABELLING FOR NUTRITION

Accurate and easy-to-understand nutrition labeling is an important strategy to improve food literacy and help consumers make healthier choices. The existing nutrition labels on packaged foods are inconsistent and not uniform, and not all food vendors or restaurants provide nutrition information for the food they serve. Examples of improved nutrition labelling of food include clearer visual representation of key information, such as using the multiple traffic lights system on packaged foods in the United Kingdom and using the single "Choices" logo in the Netherlands.[188]

CHALLENGE 1.4

INCENTIVIZING THE PRODUCTION OF HEALTHIER CROPS



CONSUMING HEATHIER DIETS requires greater availability and affordability of more nutrient-dense food crops. This entails realignment of policies to incentivize their production by both smaller- and larger-scale food producers and a stronger market to encourage their production.[189]

Across the world, many policies that impact food systems are not designed to produce more nutrient-rich crops or improve diet quality. The most common food policies aim to promote profitability, support livelihoods, and increase food production to generate more calories and meet demand, meaning that just a handful of foods now account for most of the calories we consume.[190] In particular, the role of supply side subsidies remains most controversial and has significant impact on other incentives, such as market-based ones.

Incentivizing the production of healthier crops requires the appropriate mix of policies and their instruments of implementation to be aligned in the service of improving healthy diets. The appropriate mix of such policies and their tools is in turn best determined by specific country contexts (see 'Policies and Instruments,' following page).

POLICIES AND INSTRUMENTS

Policies can be categorized in different ways or take different forms. One common way of categorizing policies is to distinguish between:[191]

- **Distributive policies:** governments distribute goods and services to benefit small groups, specific industries or provide public goods.
- **Regulatory policies:** governments use laws, regulations, and institutions to regulate human behavior, economies and societies.
- **Redistributive policies:** governments redistribute resources in society by moving resources from specific groups to others.

Policies can be implemented using different tools or instruments, all of which vary in terms of their coercive power, ranging from advocacy and communication, monetary policy, legal strategies and court challenges, subsidies, taxes, legislation, and regulatory policy.

IMMEDIATE DRIVERS[192]

VARIOUS POLICIES AND INSTRUMENTS ARE USED BY GOVERNMENTS GLOBALLY TO INFLUENCE ALL ASPECTS OF THEIR COUNTRIES' ECONOMIES AND SOCIETIES. AN EXAMINATION OF THE MYRIAD MECHANISMS THROUGH WHICH POLICY CAN INFLUENCE FOOD SYSTEM DYNAMICS HIGHLIGHTS THE PARTICULAR RELEVANCE OF AGRICULTURAL SUBSIDIES IN SHAPING PRODUCER AND CONSUMER INCENTIVES. THE EXISTING AGRICULTURAL AND FOOD SYSTEM SUBSIDIES ('FORMS OF SUBSIDY,' FOLLOWING PAGE) ARE MOSTLY EXPLAINED BY ECONOMIC AND HISTORIC FACTORS, AND INCLUDE:

- AGRICULTURAL SUBSIDIES HAVE TYPICALLY BEEN USED AS A STATE TOOL TO ALLEVIATE POVERTY OR STABILIZE SOCIETIES AND ECONOMIES, RATHER THAN PRIORITIZING OPTIMAL NUTRITIONAL OUTCOMES.
- GLOBAL DEMAND OF SPECIFIC TYPES OF COMMODITIES, AND FOR THEIR AVAILABILITY THROUGHOUT THE YEAR, ENCOURAGES UNSUSTAINABLE AND CONTINUOUS PRODUCTION OF THESE CROPS THROUGH SUBSIDIES AS THESE GENERATE PROFITS.
- LARGER AND MORE ORGANIZED AGRIBUSINESS INDUSTRIES ARE BETTER ABLE TO INFLUENCE SUBSIDY POLICIES TO SERVE THEIR INTERESTS AT THE EXPENSE OF SMALLHOLDER FARMERS, POORER COUNTRIES, AND THE HEALTH AND NUTRITION REQUIREMENTS OF CONSUMERS.
- PROFIT-DRIVEN VALUES AND INCENTIVES LEAD TO DEPRIORITIZING GROWING HEALTHIER CROPS, AND THEREFORE PRODUCING UNHEALTHY DIETS, AS LONG AS THEIR DEMAND PERSISTS.
- SUBSIDIES MAY INDIRECTLY ALTER AGRICULTURAL PRODUCTION BY TARGETING AGRICULTURAL INPUTS, SUCH AS SUBSIDIES ON ENERGY, FERTILIZERS, OR WATER.[193]

FORMS OF SUBSIDY[194]

STATE SUBSIDIES ARE ONE OF THE MOST COMMON POLICY TOOLS OF INCENTIVIZING PRODUCTION IN AGRICULTURE. SUPPLY-SIDE SUBSIDIES TAKE MANY FORMS; THE MOST COMMON ONES ARE:

- **DIRECT PAYMENTS TO FARMERS**
- **PRICE SUPPORT THROUGH GOVERNMENT PURCHASE**
- **REGULATIONS SETTING MINIMUM PRICE ACCORDING TO SOME CHARACTERISTIC, SUCH AS LOCATION OR END USE**
- **CROP INSURANCE, DISASTER RESPONSE, CREDIT, MARKETING, ETC.**
- **EXPORT SUBSIDIES**
- **IMPORT SUBSIDIES, SUCH AS QUOTAS, TARIFFS, AND OTHERS**

THE HISTORY AND POLITICAL ECONOMY OF SUBSIDIES[195]

Subsidies played a crucial role in the success of the "Green Revolutions" in Asia in the 1960s and '70s. But in the 1980s, economic liberalization led to redirecting of public spending away from subsidies. This change was influenced by a number of factors, including the rise of neo-liberal economics in the US and the UK that led to the rolling back of the state. Some have blamed state subsidies for post-Green Revolution problems in Asia, and ineffective development of agriculture in Africa. Subsidies remain a highly contested ideological and political issue between proponents of state intervention and its opponents calling for free trade and markets.

IMPACT AND SIGNIFICANCE

For decades, various policies and incentives were put in place across the world to promote the production of large volumes of a small number of commodity crops, leading to the availability of more calories but oftentimes lower nutritional quality and diversity. As a result, healthier and more nutritious foods, such as fruits, vegetables, whole grains, legumes, and nuts became either unavailable or prohibitively expensive in many countries around the world, and subsidies ended up contributing to obesity and the increasing cases of non-communicable diseases.[196]

This "cheap food" or "low-cost food system" model guaranteed a stable food supply, especially for urban populations, but it allowed workers to be paid relatively low wages in the manufacturing sector and traded off against environmental contamination. In high-income countries, the share of household income spent on food fell drastically and the expectation of cheap food has become highly embedded, despite its spiraling health and environmental impacts.[197]

Input subsidies, on energy, fertilizers, and water, as well as public purchases of agricultural produce, can cause increasing damage to the environment by encouraging excessive and inefficient use of irrigation, fertilizers and pesticides, which can adversely affect carbon storage and cycling; cause soil degradation, water and air pollution; and weaken water retention and drought resistance. In the fisheries sector, subsidies contribute to overfishing. They may also promote the expansion of agricultural lands.[198]

At the global level, subsidies result in over-production and excess of products on global markets and lead to reduced global prices. Low global prices in turn impact poverty levels, food security, economic growth, and rural infrastructure in developing countries lacking subsidies and importing these products.[199]

SUBSIDIES FOR HEALTHIER FOOD

A study assessing 20 interventions conducted in seven countries – the US, New Zealand, France, Germany, Netherlands, South Africa, and the United Kingdom – found "subsidies on healthier foods to significantly increase the purchase and consumption of promoted products." These subsidies were in the form of price discounts and vouchers for fruits and vegetables, and other healthy foods.[200]

EXISTING REMEDIES

Many do not consider subsidies as a problem per se, but some forms of subsidies have adverse health, environment, and/or livelihood consequences. Short of their complete abolition, which some argue for, remedies for subsidies can take the form of reformed subsidies or additional measures to remove or reduce their adverse effects. Some existing examples of these include the below.

ALTERNATIVES TO AGRICULTURAL INPUT SUBSIDIES

Some of the most contentious subsidies in agriculture concern input subsidies. These help farmers better access inputs, such as fertilizers, provide social protection, and reduce social costs of income disparities between rural and urban areas. Alternative policies that can advance the same goals include investments in public infrastructure, input-supply distribution networks to reduce supply costs, linking rural retailers to large input wholesalers, forms of social safety nets such as cash and food transfers, and others (see remedies under "Enhancing Livelihoods of Smaller-Scale Family Farms").[201]

FRUIT AND VEGETABLE INCENTIVE PROGRAMS

Governments support and subsidize different types of programs to increase the availability and accessibility of fresh foods and nutritious diets. An example from the United States is the Supplemental Nutrition Assistance Program (SNAP) program. Further details on this and other examples of these programs are included in the endnotes.[202,203]

TAXES

Similar to their approaches with regards to products like cigarettes, governments have increasingly been using tax regulations on certain unhealthy product ingredients as a mechanism to decrease their consumption. If the tax rate is high enough, consumers in theory would purchase less of products containing the taxed ingredients. Such regulations have been implemented in the United States, Mexico, and some countries in Europe. Two examples from Europe include Denmark's tax on saturated fats and France's tax on sugar- and artificially-sweetened beverages. Further details on these examples are included in the endnotes.[204,205]

04.

GRAND CHALLENGE 2: CREATING INCLUSIVE FOOD SUPPLY CHAINS

Enhancing Livelihoods of Smaller-Scale Family Farms

Optimizing Fair Economic Opportunities Along the Food Value Chain

CHAPTER 4.

Grand Challenge 2: Creating Inclusive Food Supply Chains

FOOD IS A vast economic sector employing billions of people across the globe. In many developing countries up to 70% of employment is in the food and agriculture sectors, mostly on an informal basis,[206] including around 500 million smallholder farmers. In total, around 2.5 billion people depend on agriculture for their livelihoods.[207] Many of these households are extremely poor: agriculture is the sector that has the highest incidence of workers living with their families below the poverty line.[208] At the same time, poorer people spend a much greater proportion of their income on food than wealthier people, creating a perverse trap for low-income food system actors.

Urbanization and food demands from a growing middle class are dramatically reshaping food markets and the food economy in most developing countries. To improve global food and nutrition security, food systems need to be transformed to better provide for the needs of the billions employed in the food sector, especially small-scale farmers, small and medium enterprises, and workers in its value chain. Enabling this transformation to be more rather than less inclusive is key to achieving many of the United Nations Sustainable Development Goals (SDGs).

To help create inclusive supply chains, two critical food system challenges need to be overcome:

ENHANCING LIVELIHOODS OF SMALLER-SCALE FAMILY FARMS

Farmers globally, especially small-scale family farms, face critical challenges from changing food systems, an aging workforce, and climate change. Their survival is at risk, and so is their role in providing livelihoods for billions of people in developing countries, and for food security, economic growth, and social stability. It is imperative to secure a "just transition" for small-scale farmers to maximize equity and economic opportunity within the context of rapid and large-scale changes occurring to local, regional, and global systems.[209]

OPTIMIZING FAIR ECONOMIC OPPORTUNITIES ALONG THE FOOD VALUE CHAIN

Food supply chains and activities in manufacturing and services beyond primary production are undergoing deep changes and are becoming increasingly significant economic sectors and employers. The food value chain in most countries has traditionally favored highly consolidated, vertically integrated actors; re-aligning these systems to provide fair economic opportunities is crucial for inclusive food economies, social and economic equity, and development.

CHALLENGE 2.1

ENHANCING LIVELIHOODS OF SMALLER-SCALE FAMILY FARMS

SMALLHOLDER FARMERS PROVIDE up to 80% of the food supply in Asia and sub-Saharan Africa and are some of the poorest and most food insecure people in the world.[210] These small family farms are under pressure as population growth creates land competition, prices for their products drop, costs of inputs rise, public services fall away, natural resources degrade, and the impacts of climate change take hold.[211]

The coming decades will require a profound transformation in smallholder agriculture. To improve their livelihoods and food security, transitions to commercialization or alternative sources of employment are needed for these farmers to avoid or escape the poverty trap. Enabling the development of commercially viable smallholders is key to driving wider economic development in rural areas, together with creating off-farm livelihood options for those who are unable to make a living from agriculture.[212]

The transformation of smallholder agriculture must also ensure women's empowerment, protect people's rights and access to land and resources, enable more sustainable approaches to farming and landscape management, support the production of more diversified and nutrient-rich crops, and enable people to protect their cultural identities.

WHO ARE SMALLHOLDERS?

According to the FAO definition, smallholders are small-scale farmers, pastoralists, forest keepers, or fishers who manage areas varying from less than one hectare to 10 hectares; the size of land varies according to different settings, however, the size of two hectares or less is most commonly used to distinguish or define smallholder farming.[213] Smallholders[214] are characterized by family-focused motives such as favoring the stability of the farm household system, using mainly family labor for production and using part of the produce for family consumption.[215]

IMMEDIATE DRIVERS[216]

A VARIETY OF DRIVERS HINDER THE ABILITY OF SMALL-SCALE FAMILY FARMS TO IMPROVE THEIR LIVELIHOODS FROM FARMING ACTIVITIES.

POLICIES, MARKETS, AND SUPPLY CHAINS

- RURAL UNDERDEVELOPMENT AND THE URBAN BIAS IN GOVERNMENT POLICIES AND OPERATIONS RESULT IN A LACK OF BASIC SERVICES IN RURAL COMMUNITIES, PRESENTING MAJOR MARKET CONSTRAINTS FOR FARMERS IN THESE AREAS.
- SMALLHOLDER FARMERS ARE PARTICULARLY VULNERABLE TO THE INSTABILITY OF INTERNATIONAL MARKETS AND HIGH PRICE VOLATILITY, ESPECIALLY AFTER MARKET AND TRADE LIBERALIZATION IN THE 1980S AND 1990S.
- SMALLHOLDER FARMERS FACE DIFFICULTIES INTEGRATING INTO SUPPLY CHAINS AND MEETING PRODUCT CERTIFICATION REQUIREMENTS, WHICH ARE NEEDED TO ACCESS MANY TYPES OF MARKETS AND BUYERS.
- ABSENCE OF COOPERATIVES, AND CHALLENGES ASSOCIATED WITH THEM – SUCH AS BUILDING TRUST AND THE LENGTH OF TIME NEEDED TO FORM ONE – WEAKEN THE BARGAINING POWER OF SMALLHOLDERS VIS-À-VIS OTHER SUPPLY CHAIN ACTORS.
- SMALLHOLDER FARMERS, PARTICULARLY SUBSISTENCE FARMERS, ARE ACUTELY SUSCEPTIBLE TO THE IMPACTS OF EXTREME WEATHER EVENTS, PESTS AND DISEASES, AND OTHER BIOSECURITY CHALLENGES.

TECHNOLOGY AND INFORMATION

- LACK OF THE TECHNOLOGY INFRASTRUCTURE AND INTERNET CONNECTIVITY FOR RURAL SMALLHOLDER FARMERS IS A MAIN FACTOR LIMITING THEIR ACCESS TO INFORMATION AND ADOPTION OF NEW TECHNOLOGIES.
- SMALLHOLDER FARMERS' LACK OF REQUISITE MATERIAL AND EDUCATION, OR KNOWLEDGE, LIMIT THEIR TECHNOLOGY ADOPTION.
- RISKS ASSOCIATED WITH NEW TECHNOLOGIES DISCOURAGE THEIR ADOPTION. FOR EXAMPLE, SMALLHOLDER FARMERS KNOW THAT RADICALLY INCREASING PRODUCTIVITY CAN POTENTIALLY LEAD TO DEPLETION OF SOIL NUTRIENTS.

IMMEDIATE DRIVERS CONT.

- » ABSENCE OF EASY-TO-USE, UP-TO-DATE, AND RELEVANT INFORMATION TAILORED TO MEET THE EXACT NEEDS OF SMALLHOLDERS HINDERS THEIR ABILITY TO MAKE BEST USE OF EXISTING TECHNOLOGIES.
- » ABSENCE OF OR WEAK SERVICES, SUCH AS FINANCE, INSURANCE, AND INFORMATION DISSEMINATION, NEGATIVELY IMPACT TECHNOLOGY ADOPTION BY SMALLHOLDERS.
- » EMBEDDED SOCIETAL NORMS, BEHAVIORS, AND PRACTICES CAN DISCOURAGE ADOPTION OF A PARTICULAR TECHNOLOGY. FOR EXAMPLE, IN PARTS OF SUB-SAHARAN AFRICA, CERTAIN TYPES OF CROPS, SUCH AS THOSE GROWN FOR EXPORT, ARE EXPECTED TO BE ONLY PRODUCED BY MEN.[217] WOMEN SMALLHOLDER FARMERS THEREFORE CANNOT BENEFIT FROM TECHNOLOGIES THAT PROMOTE PRODUCTIVITY OF THOSE CROPS.

INPUTS

- » FERTILIZER USE BY MOST AFRICAN SMALLHOLDER FARMERS HAS BEEN SEVERELY LIMITED BY COSTS AND LACK OF ACCESS TO SAVINGS OR CREDIT FOR PURCHASING THE INPUT.
- » LOCAL SEED COMPANIES ARE EITHER NON-EXISTENT OR HAVE WEAK PRESENCE IN DEVELOPING COUNTRIES. ONLY 10% OF THE WORLD'S 500 MILLION SMALL FARMS HAVE ACCESS TO GLOBAL SEED COMPANIES.
- » CLIMATE CHANGE AND ITS EFFECTS HAVE MADE RAINFALL UNPREDICTABLE AND WATER RESOURCES SCARCER, AND SMALLHOLDER FARMERS GENERALLY HAVE LESS ACCESS TO IRRIGATION.
- » LACK OF SECURE RESOURCE (PRIMARILY LAND) TENURE IS A KEY BARRIER PREVENTING SMALLHOLDER ACCESS TO MARKETS AND FINANCE. IMPORTANTLY, IT DISCOURAGES FARMERS FROM MAKING PRODUCTIVITY INVESTMENTS. WOMEN FARMERS ARE DISPROPORTIONATELY AFFECTED BY LAND TENURE INSECURITY.

SMALLHOLDERS IN DEVELOPED COUNTRIES

Small farms do not exist only in developing countries. Of the 10.3 million farms in the EU, two thirds (65.4%) are less than five hectares in size.[218] Small farms predominate in rich countries such as Japan, Norway, South Korea, and Switzerland.[219]

IMPACT AND SIGNIFICANCE

Improving the livelihoods of smallholders is key to tackling poverty, rural underdevelopment, and food and nutritional security. Over 2.5 billion people depend on agriculture to make a living, and investing in small-scale farms can contribute significantly to poverty reduction. Small-scale farming is not only important as a source of income to many poor and food insecure households, but agricultural development in general is a key strategy for fostering the development of rural economies and eradicating hunger and poverty.[220] Smallholder farmers provide up to 70% of the food calories in sub-Saharan Africa and Asia, where food insecurity is most acute[221] and where the greatest challenges of a growing world population will be felt: approximately two-thirds of the 2.2 billion additional people projected by 2050 will live in sub-Saharan Africa and south Asia.[222,223]

Smallholder agriculture is an important factor supporting social and political stability, not only in rural areas, but also urban centers that rely on these rural areas for food supplies. Disruptions in food supplies and/or higher food prices play significant roles in creating social discontent, and they are a main reason why governments provide input and other subsidies.[224]

Smallholder farming increases food systems' resilience to the multiple impacts of climate change. With only 12 plants and five animal species making up 75% of what the world consumes, food systems are vulnerable to natural disasters and disease outbreak. Smallholder farmers are stewards of natural biodiversity; they grow a broader diversity of crops and are more likely to preserve historical varietals that are not utilized in larger-scale agriculture.[225]

Women are key to small-scale agriculture, particularly in low-income countries: around 43% of smallholder farmers in developing countries are women. Women farmers face far more constraints than men in accessing credit, information, training, and inputs, inequalities which hinder the productivity of women smallholder farms. Smallholder agriculture can therefore become a powerful vehicle to empowering women, which would create numerous other benefits, such as improved incomes, food and nutritional security both for women and children, and increased productivity and yields benefitting economies and societies as a whole.[226]

There is an ongoing debate about the futures of smallholding farmers in light of changing markets and global dynamics. Smallholder farming is becoming unviable as the main source of livelihood for many, and a very large number of smallholders do not want their children to stay as farmers and experience the deprivations they have had to endure.

WOMEN IN AGRICULTURE

THE MILLIONS OF WOMEN ENGAGED IN AGRICULTURAL ACTIVITIES AROUND THE GLOBE DEAL WITH VASTLY DIFFERENT REALITIES AND CHALLENGES IN CONTINUOUSLY EVOLVING CULTURAL, SOCIAL, TECHNOLOGICAL, AND ECONOMIC CONTEXTS. THESE CHALLENGES MEAN THAT WOMEN FARMERS ARE 20-30% LESS PRODUCTIVE THAN MEN IN MOST COUNTRIES, ACCORDING TO THE FAO.[227] THIS GAP NOT ONLY PERPETUATES WOMEN'S POVERTY AND MARGINALIZATION, IT ALSO IMPACTS NATIONAL ECONOMIES AND INCREASES OVERALL HUNGER. CLOSING THE GENDER GAP COULD INCREASE CROP OUTPUT BY 2.5-4% IN DEVELOPING COUNTRIES AND REDUCE GLOBAL UNDERNOURISHMENT BY 17%.[228]

UNEQUAL ACCESS TO RESOURCES

» WOMEN FACE UNEQUAL ACCESS TO RESOURCES SUCH AS CAPITAL, TECHNICAL TRAINING, INPUTS, FINANCE, MARKETS, LAND RIGHTS, AND NEW TECHNOLOGIES. THIS ACCESS CHALLENGE IS OFTEN COMPOUNDED BY SOCIO-CULTURAL NORMS THAT LIMIT WOMEN'S DECISION-MAKING POWER AND MOBILITY.[229]

UNCOUNTED AND UNPAID AGRICULTURAL LABOR

» WOMEN ARE MORE LIKELY TO PERFORM UNPAID WORK IN SUBSISTENCE OR SMALLHOLDER AGRICULTURE, SUCH AS TENDING TO SMALL LIVESTOCK OR POULTRY OR PROCESSING AND PREPARING FOOD FOR IMMEDIATE CONSUMPTION.[230]

EXCLUSION FROM DATA COLLECTION AND RESEARCH

» ESTIMATES OF WOMEN'S PARTICIPATION IN THE AGRICULTURAL LABOR FORCE ALSO EXCLUDE THIS UNPAID WORK IN SUBSISTENCE OR SMALLHOLDER AGRICULTURE,[231] AND WHILE THE UN SDGS INCLUDED SPECIFIC INDICATORS TO MEASURE WOMEN'S OUTCOMES IN AGRICULTURE, ONLY THREE OF THE 14 INDICATORS OF GOAL 5 (ACHIEVE GENDER EQUALITY AND EMPOWER ALL WOMEN AND GIRLS) HAVE INTERNATIONAL STANDARDS OF MEASUREMENT AND ARE BEING MONITORED IN MOST COUNTRIES.[232]

VULNERABILITY TO CLIMATE CHANGE

» WOMEN ARE AT GREATER RISK IN TERMS OF THEIR ABILITY TO ADAPT TO CLIMATE CHANGE GIVEN THEIR UNEQUAL ACCESS TO RESOURCES AND SOCIO-CULTURAL STANDING. WOMEN, BOYS, AND GIRLS ARE 14% MORE LIKELY TO DIE DURING CLIMATE DISASTERS THAN MEN.[233]

EXISTING REMEDIES

Different strategies and hundreds of programs have been developed and are being implemented by states, international organizations, the private sector and local NGOs to enhance smallholder livelihoods. We highlight some of the major strategies or categories of interventions and illustrate them with examples in the endnotes of this report.

RURAL DEVELOPMENT & PUBLIC SERVICES

Development of rural areas can have significant impact on improved smallholder livelihoods and productivity by creating better physical infrastructure that links smallholder farmers to markets and urban areas, by better connecting them to technologies and information, and by enhancing their skills and education.[234,235]

SOCIAL PROTECTION

Social protection policies aim to reduce social and economic risks, vulnerability, extreme poverty, and deprivation. They can help ease credit constraints by providing cash and in-kind support, and enable smallholders to better manage risks and engage in more profitable livelihood and agricultural activities.[236] Not all social protection schemes are equally effective, however, as their impact depends on social and political contexts, policies and other existing programs, and gender.[237]

GOVERNANCE, LAND TENURE, AND PROPERTY RIGHTS

The legal and institutional environment, and regulations and their enforcement, are critical factors enabling a stable, transparent, and supportive environment for smallholders. Governance, not only by central authorities, but also through devolved and inclusive processes, is critical to ensure that existing laws and regulations are enforced. This is particularly important for land tenure and property rights, without which farmers have no incentives to invest or plan for the longer term.

PUBLIC-PRIVATE PARTNERSHIPS

Public-private partnerships are a common means of providing support and services to smallholders, thereby promoting growth and opportunities for small-scale farms.[238,239]

FINANCIAL SERVICES

Financial services are crucial for smallholder productivity and livelihoods. Without them, smallholders cannot invest in their farms or in equipment that can improve their productivity and production.

» **MICROFINANCE**

Microfinance is a form of financial services devised for individuals and small businesses who are unable to access conventional banking and finance. Microfinance includes provisions of loans to poor clients (microcredit), financial services similar to those provided by banks, and microinsurance. The contemporary microfinance movement started in the 1970s with organizations such as Grameen Bank of Bangladesh. It became a widely adopted system in Asia and is becoming increasingly common in Africa.[240,241,242]

RESEARCH, DEVELOPMENT, AND EXTENSION SERVICES

Smallholders typically do not benefit directly or immediately from research and development services, such as technological development. This has been changing in recent years, with investment in agricultural research and extension targeting smallholders.[243,244] Information and communication technologies (ICTs) are critical technological developments that are closing the knowledge gap, helping smallholder farmers access real-time weather, market, and pest data that can help them increase their productivity and access markets and finance.[245]

MARKETS AND VALUE CHAINS

Markets need to cater to smallholder conditions, including integrating small-scale farmers and producers in value chains. This can significantly improve smallholder productivity and ability to enter value chains and markets.[246,247]

LIVESTOCK FOR POVERTY REDUCTION

Livestock are a critical, widely-acknowledged resource for smallholders and subsistence farmers throughout the world.[248,249] According to the FAO, 40% of the global value of agricultural output is attributable to livestock, supporting the livelihoods and food security of almost 1.3 billion people.[250] Furthermore, "about 600 million of the world's poorest households keep livestock as an essential source of income."[251]

CHALLENGE 2.2

OPTIMIZING FAIR ECONOMIC OPPORTUNITIES ALONG THE FOOD VALUE CHAIN

FOOD SUPPLY CHAINS have been undergoing deep transformations across the globe, driven by changes in diet, urbanization, and income growth. While part of this transformation has seen the involvement of large, multinational companies, others have been characterized by the proliferation of local, small- and medium-sized enterprises (SMEs).[252] In either case, changes are required to ensure fair economic opportunities for the tens of millions employed in this growing and increasingly important midstream sector of food economies.

Insecure employment and low compensation are key characteristics of food system employment. Current food systems employ billions of people around the world – over 60% in sub-Saharan Africa, and 70% in low income countries globally[253] – and drive poverty and inequality in many ways.

As per capita incomes increase, food industries grow, and supply chains continue to evolve, food systems jobs, especially in developing countries, will shift further from primary production to food manufacturing and services.[254] This further increases the need to optimize fair economic opportunities along the food value chain to ensure fair income for small-scale producers and laborers, equitable distribution of added value along the food network for small and medium-sized enterprises, reasonable prices for consumers, and accessibility for lower income groups.[255]

WHAT ARE SMALL AND MEDIUM-SIZED ENTERPRISES?[256]

There is no globally agreed upon definition of SMEs. According to the World Bank, an SME is a firm with 99 employees or fewer, whereas for the Asian and African development banks, an SME is a firm with 50 employees or fewer. The European Commission defines SMEs according to a mixture of employee (<250 employees), revenue and asset criteria.

SMEs are the backbone of economies. Globally, formal and informal SMEs make up more than 95% of all firms, accounting for approximately 50% of value added and 65% of total employment. This amounts to between 420 million and 510 million SMEs, 310 million of which are in emerging markets.

IMMEDIATE DRIVERS[257]

INDIVIDUALS AND SMES THROUGHOUT THE FOOD VALUE CHAIN FACE SIMILAR BARRIERS AND OBSTACLES TO THOSE FACED BY SMALLHOLDER FARMERS IN PRIMARY PRODUCTION. AS SUCH, MANY OF THE IMMEDIATE DRIVERS LISTED IN THE PREVIOUS CHALLENGE ON "ENHANCING LIVELIHOODS OF SMALLER-SCALE FAMILY FARMS" ARE MOSTLY APPLICABLE FOR THIS CHALLENGE AS WELL. THESE ARE:

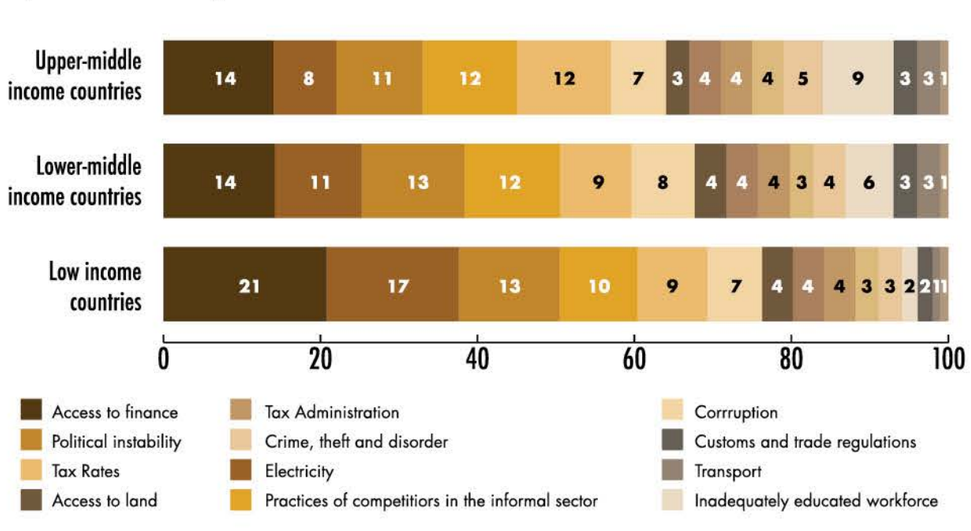
- SEGMENTS OF SOCIETY THAT TRADITIONALLY HAVE LESS ACCESS TO EDUCATION, RESOURCES AND CAPITAL, NAMELY WOMEN, YOUTH, URBAN AND RURAL POOR, AND INDIGENOUS PEOPLES, FACE BARRIERS TO PARTICIPATE IN MODERN VALUE CHAINS.
- INSUFFICIENT KNOWLEDGE OF PROCESSING METHODS, INGREDIENTS, AND PROCESSES PREVENTS FARMERS FROM MAKING USE OF VALUE ADDITION PRIMARY PROCESSING OPPORTUNITIES.
- INCREASED CERTIFICATION AND QUALITY-ASSURANCE STANDARDS MAKE IT DIFFICULT FOR MANY TO ENTER OR GROW IN THIS SECTOR.
- THE INFORMAL NATURE OF LARGE PARTS OF THE FOOD SECTOR IN DEVELOPING COUNTRIES CREATES BARRIERS TO GROWTH AND DEVELOPMENT.
- LIMITED ACCESS TO MARKETS AND INFORMATION ON CONSUMPTION AND FOOD DEMAND TRENDS HINDERS THE ABILITY TO CAPITALIZE ON OPPORTUNITIES THROUGH PROCESSING CROPS AND MANUFACTURING FOOD PRODUCTS.
- SMES ARE GENERALLY HARD TO FINANCE BECAUSE THEY HAVE MODEST NEEDS, LIMITED COLLATERAL, AND UNCERTAIN GROWTH PROSPECTS.

IMMEDIATE DRIVERS CONT.

- SMALL ORGANIZATIONS ARE UNLIKELY TO HAVE IN-HOUSE SUSTAINABILITY KNOWLEDGE AND EXPERTISE, WHICH MEANS THEY MAY HAVE TO RELY ON EXPENSIVE EXTERNAL CONSULTANTS WHICH THEY CANNOT AFFORD.
- COOPERATIVES ARE HELPFUL IN PROVIDING PRIMARY PROCESSING KNOW-HOW AND SERVICES. IN THEIR ABSENCE, ENTREPRENEURS AND START-UPS IN DEVELOPING COUNTRIES ARE OFTEN UNABLE TO LAUNCH OR SUSTAIN THEIR BUSINESSES.
- COST OF PROCESSING, MANUFACTURING, OR LOGISTICS EQUIPMENT PUTS IT OUT OF THE REACH OF MANY ASPIRING ENTREPRENEURS.

BOTTLEKNECKS FACED BY SMALL BUSINESSES IN DEVELOPTING COUNTRIES

(Percent out of 100)



Source Link: SME Competitiveness Outlook, 2019: Big Money for Small Business

IMPACT AND SIGNIFICANCE

As one of the largest employers, food systems have significant impact on workers and on the health and social and economic well-being of all countries. Better income and economic opportunities in the food supply chain are essential for food security, social stability, and economic growth, especially in the developing world.

In the developing world, the ability of food value chains to include women and youth in food labor markets will be a critical determinant of economic equity and social stability. Women constitute 40% of the workforce in the overall food sectors of developing countries and predominate in sub-sectors such as fish, vegetable and fruit processing.[258] In almost all populations of the developing world, the largest age group is below 24, and this age group is at least twice as likely as older adults to be unemployed. This age group is important for entrepreneurship, innovation, and economic growth, and the food sector is the key sector that can provide them with the opportunities for improved incomes and livelihoods.[259]

While most of the food supply in developing countries comes from local producers and small and medium enterprises, large companies are significant employers, posing potential problems to local producers and enterprises in some contexts. The huge bargaining power of large food processing and retail companies not only allows costs to be passed down the chain, it also reduces producer autonomy and increases their vulnerability to risks. Barriers to entry for new food value chain SMEs are high under these conditions and existing SMEs will also face challenges competing. These can engender inequalities and lead to negative social and economic outcomes.[260]

SMEs also face challenges similar to small-scale producers, despite being removed from direct on-farm activities. As food production becomes increasingly standardized, mechanized, and technology-enabled, local SMEs that operate in a mostly informal economy face critical challenges of accessing the right type of resources and knowledge to be able to satisfy regulatory and other standards, as well as consumer expectations.[261] In large parts of the developing world where most of the food consumed is produced locally, the ongoing transformation of food supply chains poses challenges for local businesses to meet increasing requirements of certification and standardization from retailers, governments, and consumers.

EXISTING REMEDIES

Different strategies exist to improve supply chain inclusivity, fairness, and equity. Many of these strategies overlap with those of "Enhancing Livelihoods of Small-Scale Family Farms" challenge, such as investment in infrastructure and development, providing financial services, extension services, and others.

DEVELOPING AN ENTREPRENEURSHIP ECOSYSTEM

Developing an entrepreneurship ecosystem can help facilitate private sector growth and improve the quality of jobs in food value chains through access by entrepreneurs to mentors and advisors; business enablers (such as incubators); improving the ease of doing business; upgrading business, management, and technical skills; as well as new instruments for mobilizing investments. For example, the Africa Agriculture Innovation Network (AAIN) developed a program targeting the establishment of more than 100 business incubators in over 50 African countries to help new and startup agribusiness SMEs.[262,263]

SUSTAINABILITY CERTIFICATION STANDARDS

Voluntary sustainability certification standards focused on increased environmental and/or economic requirements have come to occupy increasing market shares for various (mostly tropical) foodstuffs. As of 2016, more than a quarter of the land devoted to coffee production received at least one voluntary sustainability certification.[264] Another example is Fair Trade, an institutional arrangement that connects disadvantaged producers and workers with consumers, promotes fairer trading conditions and empowers farmers and workers to combat poverty and strengthen their market position.[265]

AGRICULTURAL TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING (ATVET)

Formal education, vocational institutes and other entities have been implementing programs to develop skills beyond agricultural production, including in food storage, grading, processing, and alternative energy.[266,267]

LEGISLATION AND LITIGATION AGAINST UNFAIR PRACTICES IN FOOD SUPPLY CHAINS

Legislative and judicial bodies around the world are showing more interest in tackling excessive power in food supply chains and its impact on workers and consumers alike. We highlight several examples in the endnotes.[268,269]

05.

GRAND CHALLENGE 3: MANAGING FOOD SYSTEMS WITHIN ENVIRONMENTAL LIMITS

Addressing Soil Degradation and Erosion

Reversing Ground and Surface Water Depletion and Pollution

Reducing Biodiversity Loss

Radically Decreasing Greenhouse Gas Emissions

Curtailing and Repurposing Food Loss and Waste

CHAPTER 5.

Grand Challenge 3: Managing Food Systems Within Environmental Limits

CURRENT FOOD SYSTEM practices are not environmentally sustainable: they damage the environment by degrading and eroding soils, depleting and polluting ground and surface water, driving biodiversity loss and causing substantial greenhouse gas emissions.

Food systems are responsible for over a third of greenhouse gas emissions globally. Agriculture is the main reason a third of the soil on Earth is highly degraded. It accounts for 70% of water withdrawal and causes significant biodiversity loss.[270]

Furthermore, about a third of all food produced for human consumption goes to waste, thereby unnecessarily exacerbating the environmental impacts of food production due to wasting resources.

To manage food systems within environmental limits, and to in turn increase their resilience to the impacts of climate change, five key food system challenges must be resolved:

ADDRESSING SOIL DEGRADATION AND EROSION

Soil degradation and erosion take many forms and cause further significant environmental damage. Degraded soil is also unproductive soil that reduces the nutritional quality of crops.

REVERSING GROUND AND SURFACE WATER DEPLETION AND POLLUTION

Water is essential to all life and is becoming scarcer in some parts of the world. Some agricultural practices are responsible for depleting ground and surface water across many regions and are a leading cause of water pollution.

REDUCING BIODIVERSITY LOSS

The survival of many species – soil microbes, plants, insects, fish, and other animals – is at risk due to the agricultural practices that predominate in most parts of the world. Beyond their intrinsic value, many of these species play crucial roles in the ecosystem and for human food security.

RADICALLY DECREASING GREENHOUSE GAS EMISSIONS

Food systems significantly contribute to global warming and human-induced climate change. In particular, it is a leading cause of deforestation and forest degradation, primarily through land-use changes as forest lands are converted for agricultural uses, which damages the Earth's ability to sequester carbon from the air.

CURTAILING AND REPURPOSING FOOD LOSS AND WASTE

Food loss and waste have major negative environmental impacts, as wasted food wastes natural and other resources. Food waste and loss also have further implications for productivity and efficiency, as well as for greenhouse gas emissions.

CHALLENGE 3.1

ADDRESSING SOIL DEGRADATION AND EROSION

APPROXIMATELY ONE-THIRD OF the world's soil resources are moderately to highly degraded. Soil degradation includes soil compaction, erosion, contamination, acidification, loss of soil carbon and biodiversity,[271] disruption of soil nutrient balances[272] for nitrogen and phosphorus, and changes in the composition of soil microbes.[273] Estimates of annual crop loss due to erosion imply that by 2050 we will have removed the equivalent of 150 million hectares from crop production, approximately 10% of our global farmland.[274]

Despite it being a universal problem, some of the main regions affected by soil nutrient depletion are Africa, Asia, and South America. For example, most countries in Africa extract more nutrients from the soil each year than are returned through use of fertilizer, crop residues, manure, and other organic matter. In developed countries, nitrogen and phosphorous imbalances have only recently been reduced by adding external inputs, but at the expense of polluting the environment.[275]

SOIL DEPLETION IN SUB-SAHARAN AFRICA

Farmers across 37 countries in sub-Saharan Africa lost an average 22 kg of nitrogen, 2.5 kg of phosphorus and 15 kg of potassium per hectare (ha) annually from their soils over a period of 30 years. Depleted soils have contributed to average yields of grain crops in sub-Saharan Africa stagnating at around 1 t/ha since the 1960s, compared to 2.5 t/ha in South Asia and 4.5 t/ha in East Asia.[276]

IMMEDIATE DRIVERS[277]

- FAILURE TO ADEQUATELY REPLENISH SOIL NUTRIENTS, THROUGH MANURE OR FERTILIZER APPLICATIONS, IS A LEADING CAUSE OF DECREASING SOIL FERTILITY AND SOIL DEGRADATION.
- CLIMATE CHANGE AFFECTS SOIL FERTILITY AND DEGRADATION THROUGH HIGHER TEMPERATURES, DROUGHTS, FLOODS, AND STORMS.
- SOIL EROSION OCCURS NATURALLY FROM WIND AND WATER. IT IS EXACERBATED BY REMOVAL OF PLANT COVER, EXCESSIVE TILLING, AND OVERGRAZING LIVESTOCK.
- OVER-IRRIGATION AND DISRUPTING HYDROLOGICAL BALANCE IS A LEADING CAUSE OF SOIL SALINIZATION.

IMPACT AND SIGNIFICANCE

Soil degradation has a major impact on food production and the environment. It reduces yield and quality, which leads to food insecurity, and can create uneven employment or unemployment, and increase food prices.[278] In sub-Saharan Africa, it is considered a key driver of declining agricultural productivity. It also pollutes water courses and can lead to enhanced methanogenesis, or formation of methane by microbes, from sediment organic carbon.[279]

Erosion leads to loss of nutrients, which then need to be replaced through fertilization, at a significant cost. Loss of topsoil in particular results in the reduction of the soil's rooting volume, nutrient availability and water holding capacity.[280]

In addition to its impact on food security, soil plays a critical role in regulating greenhouse gas emissions (carbon dioxide [CO2], nitrous oxide [N2O], and methane [CH4]). Soil is the world's largest terrestrial reservoir of carbon. If mismanaged, soil releases CO2 into the atmosphere, thereby contributing to global warming. Declines of organic carbon stock negatively affect the soil's fertility and climate change regulation capacity.[281]

SOIL AND HUMAN MICRONUTRIENT DEFICIENCIES

LOCAL MINERAL DEFICIENCIES IN SOILS CAN LEAD TO SUB-OPTIMAL NUTRIENT CONTENT IN CROPS, WHICH IMPACT POPULATIONS. OVER 2 BILLION PEOPLE SUFFER FROM MICRONUTRIENT DEFICIENCIES AND POOR SOIL NUTRIENTS ARE A KEY FACTOR: MANY ESSENTIAL NUTRIENTS AND MINERALS (E.G. ZINC, IRON, IODINE, SELENIUM) CANNOT BE DERIVED FROM BIOSYNTHESIS AND MUST BE OBTAINED BY PLANTS FROM SOILS.[282]

EXISTING REMEDIES

SUSTAINABLE SOIL MANAGEMENT

A variety of techniques exist to manage soils more sustainably, including, but not limited to:

» **CONSERVATION AGRICULTURE**

Conservation agriculture is a farming system that aims to preserve permanent soil cover, keep soil disturbance to a minimum (or zero tillage), and diversify plant species. It improves biodiversity both above and below ground, thereby increasing water and nutrient use efficiency and facilitating sustainable crop production.[283] These soil practices also minimize the amount of carbon released into the atmosphere through soil respiration.[284] Conservation agriculture is one type of sustainable intensification of agriculture, which involves producing more outputs with fewer inputs while simultaneously conserving resources, enhancing ecosystem services, and minimizing environmental degradation.[285]

» **ROTATION**

Crop rotation, or alternating the type of crop grown in a field from one season to the next, increases soil nutrients (especially if a legume is included in the rotation), decreases pests, and breaks cycles of disease.

» **ORGANIC FARMING**

Organic farming emphasizes a holistic approach to farm management, where crop rotations and farm animals play an integral role in the system. Most organic farming does not use synthetic chemicals, genetically modified organisms, growth regulators, or livestock feed additives. At the core of organic farming is maintaining and enhancing soil fertility through farming practices.[286] Evidence from research, field trials, and farm experience shows that organic farming is, overall, more environmentally friendly than conventional agriculture but its economic performance is more uncertain.[287]

» **INTEGRATED SOIL FERTILITY MANAGEMENT (ISFM)**

Integrated soil fertility management uses a balanced amount of both organic and inorganic fertilizers and has proven to be more sustainable and profitable than using either organic or inorganic fertilizers on their own.[288]

» **AGROECOLOGY**

Agroecology applies ecological theory and processes to manage agricultural systems more productively and sustainably. It uses both local and traditional knowledge, as well as innovations and technologies, to better integrate the ecological, economic, and social dimensions of

agricultural or food production systems, such as the interactions between plants, animals, humans, and the environment.[289,290]

» **AGROFORESTRY**

Agroforestry is the integration of forestry with agriculture, where trees, crops, and livestock are managed together using both traditional and modern land-use practices. Agroforestry can benefit crops by helping create soil cover against erosion, by minimizing damage from flooding and erosion, and help the soil retain water.[291,292]

GLOBAL SOIL INITIATIVES

Soil degradation has been elevated as a significant international issue in recent years. In fact, the largest soil health research initiative in US history was recently initiated by the Foundation for Food and Agriculture Research starting in 2017.[293] Many of the United Nations Sustainable Development Goals (SDGs) are related to protecting, restoring, and promoting sustainable soil and land management, and soil degradation is also a core component of numerous other international initiatives, such as the Global Soil Partnership (and its Voluntary Guidelines for Sustainable Soil Management) led by the FAO and The Global Symposium on Soil Organic Carbon, among others.[294,295]

SOILLESS FARMING

Aquaponics and hydroponics are becoming increasingly used in farming, particularly in urban farming and controlled environments. For example, Malaysia's Cityfarm uses hydroponic technology in soilless farming to help the urban population grow salad crops.[296]

SOIL TESTING TECHNOLOGIES

Soil testing technologies vary from large scale and more accurate sampling performed at labs to soil test kits that can be bought from farming cooperatives to measure major nutrients in plants. Recent technological advances have extended soil testing from measuring the nutrients mentioned above, to merging soil DNA sequencing and ongoing data collection and AI to learn more about the millions of microbes that live in the soil.[297]

INTEGRATED LANDSCAPE MANAGEMENT

Integrated Landscape Management (ILM) as a concept includes strategies and activities of land management that require long term collaboration among stakeholders to achieve diverse objectives, such as increasing productivity, biodiversity conservation, ecosystem service provision, etc.[298] ILM is particularly important as a remedy for soil degradation, which is usually caused by external shocks such as drought or certain farming practices. For example, in cases where farming households rely on migratory labor across different ecosystems or landscapes, ILM becomes a crucial alternative to other ecosystem-specific interventions.[299,300]

CHALLENGE 3.2

REVERSING GROUND AND SURFACE WATER DEPLETION AND POLLUTION

AGRICULTURE ACCOUNTS FOR 70% of water withdrawal globally,[301] with most of this withdrawal used for primary production purposes, such as farming. Water is also used for cleaning and sanitation, as a component of food, or in food processing, with the dairy, meat, and poultry, and fruit and vegetable processing, as the major water-intensive food processing sectors.[302]

Agriculture is also among the leading causes of water pollution, as farming activities discharge significant quantities of agrochemicals, nutrients, organic matter, drug residues, sediments, microplastics, pathogens, and induces salinization and alkalinization through saline drainage. Water pollution is further exacerbated by the reduction of flow in water bodies, which is largely driven by the need for crop irrigation.[303]

RAINFED VS. IRRIGATED

Approximately 80% of global cropland is rainfed, and 60% of the world's food is produced on rainfed land.[304] Irrigated agriculture represents 20% of global cropland and contributes to 40% of total food produced worldwide.[305] Globally, the area equipped for irrigation has more than doubled since the 1960s to over 320 million hectares.

IMMEDIATE DRIVERS[306]

- EXCESSIVE GROUNDWATER PUMPING FOR IRRIGATION OF CROPLANDS, I.E. PUMPING WATER OUT OF THE GROUND FASTER THAN IT IS REPLENISHED, IS THE MAIN CAUSE LEADING TO LOWERING OF THE GROUNDWATER TABLE AND ITS DEPLETION.
- POOR AND INEFFICIENT IRRIGATION SYSTEMS AND PRACTICES RESULT IN WATER CONSUMPTION THAT EXCEEDS WHAT IS NECESSARY.
- AGRICULTURAL INTENSIFICATION AND EXPANSION OF IRRIGATED AGRICULTURAL AREAS INCREASE THE USE AND DEPLETION OF GROUNDWATER SUPPLIES.
- CLIMATE-CHANGE-INDUCED INCREASES IN TEMPERATURES WILL INCREASE CROP WATER DEMAND, LEADING TO MORE GROUNDWATER PUMPING. RISING TEMPERATURES ALSO CAUSE GLACIERS TO MELT FASTER, WHICH SUBSEQUENTLY LEADS TO REDUCED SURFACE WATER FLOWS IN THE LONG TERM.
- SOME AGRICULTURAL PRACTICES, SUCH AS GROWING WATER-CONSUMING CROPS LIKE SUGARCANE, RICE, ALMONDS, AND COTTON, OR USING TILING, DITCHING, OR SOIL COMPACTION TO INDUCE RAPID DRAINAGE, ARE MAJOR DRIVERS OF GROUNDWATER DEPLETION, ESPECIALLY IN WATER-SCARCE REGIONS.
- WATER POLLUTION HAS NUMEROUS CAUSES, INCLUDING INDUSTRIAL SOURCES, OVERFERTILIZATION OF CROPS, AND OVERUSE OF ANTIBIOTICS IN FISH FARMS.

IMPACT AND SIGNIFICANCE

The depletion or lowering of groundwater reserves can have a severe impact on primary production and hence the productivity of agricultural land. This depletion initially leads to increased pumping costs; eventually water may become economically unreachable, leading to water and food shortages, and to subsequent social, economic, and political crises. Water pollution can also cause severe damage to human health.

Loss of groundwater or the lowering of the groundwater table can also lead to the physical collapse of land by removing support from beneath it. In coastal areas, pumping of groundwater can lead to its contamination by saltwater, as saltwater moves inland and upstream.[307]

Surface water supplies – such as lakes, streams, and rivers – can also decrease because of a lower groundwater table, since they are connected to groundwater. The supply of surface water has further suffered due to melting of mountain glaciers (e.g. in the Alps, the Andes, the Rocky Mountains etc.). This leads to the weakening of dry-season river flows and water shortages.[308]

WATER STRESS

IN SUB-SAHARAN AFRICA, IRRIGATION IS HEAVILY DEPENDENT ON GROUNDWATER AND SEVERAL AQUIFERS ARE BEING DEPLETED. A 2015 STUDY REPORTED THAT EIGHT MAJOR AQUIFERS IN AFRICA EXPERIENCED LITTLE TO NO REFILLING TO OFFSET WATER WITHDRAWALS BETWEEN 2003 AND 2013AND 2013.[309]

EXISTING REMEDIES

WATER-SAVING TECHNOLOGIES

Water-saving technologies can raise the productivity of water supplies, thereby reducing the rate of water use or loss. A vast range of water-savings technologies are already in existence for agricultural as well as domestic and industrial use. Most of these technologies are not specifically related to groundwater but rather water use in general. Evidence from both the developed and developing world has shown the effectiveness of these technologies in increasing water productivity as measured by the decrease in pumping (or diversions for surface water) necessary to produce a given output (see for example, Netafim[310] and Jain Irrigation).[311,312]

INSTITUTIONAL SOLUTIONS

The main institutional approaches to water governance include Participatory and Integrated Watershed Management, Water Allocation Policies, and Community and User-Based Local Management Systems.

» **PARTICIPATORY AND INTEGRATED WATERSHED MANAGEMENT**

These are multi-stakeholder programs and projects that are built on the basis of integrating technologies, policies, and practices to manage and enhance watershed resources that impact humans, plants, and animals sustainably and equitably. Some of the technologies used in integrated watershed management strategies are remote sensing, global positioning systems, big data, and geographic information systems.[313,314,315]

» **WATER ALLOCATION POLICIES**

These are centralized water management by formal authorities either through laws, regulations, and rights, or through pricing, taxes, and enforcement. For example, each November, the National Water Commission in Mexico decides how much surface water it is going to allocate next year for each district, based on scientific data and negotiation with irrigation districts.[316]

WATER TRANSFER

Increase local water supply by importing water from further afield. The water import model has been used as a purposeful remedy to groundwater problems in numerous locations, however, transferring water could have significant negative impacts by depleting water in other areas.[317]

INCREASED RECHARGE

Groundwater recharge, or replenishing aquifers, can be accomplished using a variety of techniques and water sources and with varying levels of complexity. Ironically, operation of inefficient irrigation systems, which allow surface supplies to seep into the groundwater table, is one of the best methods for recharge and plays a key role already in parts of India, Pakistan, and elsewhere. More purposeful efforts to capture water for recharge are also possible as perhaps exemplified by the use of storage tanks (ponds) across much of South Asia or through recharge structures.

CLOUD SEEDING

Cloud seeding is a weather modification method that improves a cloud's ability to produce rain or snow through adding droplet nucleation materials to the atmosphere. After cloud seeding takes place, precipitation falls from the clouds back to the surface of the Earth.[318,319]

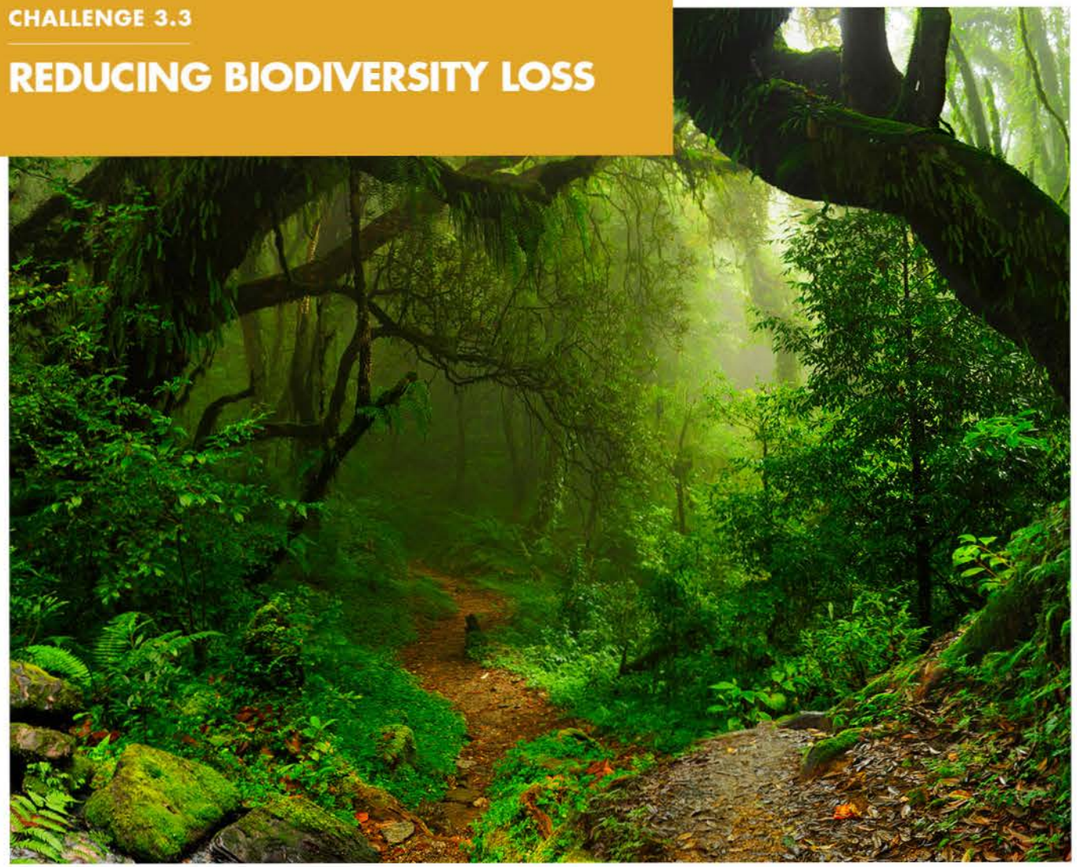
DEAD ZONES

DEAD ZONES ARE AREAS IN THE WORLD'S OCEANS AND LAKES WHERE UNDERWATER OXYGEN LEVELS ARE DEPLETED TO AN EXTENT THAT LEADS TO DEATH AND MIGRATION OF MARINE LIFE. ALTHOUGH DEAD ZONES CAN OCCUR NATURALLY, NUTRIENT POLLUTION IS THE PRIMARY CAUSE OF DEAD ZONES, ESPECIALLY NITROGEN AND PHOSPHORUS RESULTING FROM AGRICULTURE RUNOFF. AN EXCESS OF THESE NUTRIENTS LEADS TO BLOOMS OF ALGAE NEAR INHABITED COASTLINES, WHICH ARE DETRIMENTAL TO MARINE LIFE, FISHERS' LIVELIHOODS AND AQUACULTURE, AND HUMAN HEALTH.

THE PREVALENCE OF DEAD ZONES HAS INCREASED DRAMATICALLY, FROM 10 DOCUMENTED CASES IN 1960 TO 479 DEAD ZONES AND 228 AREAS OF CONCERN AROUND THE WORLD AS OF 2013.[320, 321, 322]

CHALLENGE 3.3

REDUCING BIODIVERSITY LOSS



CURRENT AGRICULTURAL PRACTICES, such as tilling, excessive use of pesticides and fertilizers, monocropping, land cover conversion, capture fisheries, and other hunting activities, have tremendous negative impacts on biodiversity. Agriculture also divides natural habitats and the gene flow among organisms, thereby threatening the survival of many species.[323]

Biodiversity is crucial not only for its intrinsic value; agriculture is also directly harmed by biodiversity loss. The productivity and stability of both domesticated and harvested plants and animals are directly impacted by the level of biodiversity within these food production systems, as well as by the degree of biodiversity of ecosystems as a whole. Biodiversity is even critical at the microbial level: food systems are sustained by a vast range of organisms that live in and around food and agricultural production systems.[324] The millions of organisms that live in soil play a pivotal role in preserving land fertility by redistributing nutrients and increasing soil porosity, and hence water storage.[325] Reduced soil biological activity and reduced pollinators leads to decreased productivity. Extensive monocrops increase the vulnerability of existing crops to pests and disease, ultimately affecting food security.[326]

IMMEDIATE DRIVERS[327]

- LAND AND HABITAT CONVERSION - SUCH AS FORESTS, WETLANDS, AND MARGINAL LANDS - TO LARGE-SCALE AGRICULTURAL PRODUCTION, AND OVERFISHING, LEAD TO SIGNIFICANT BIODIVERSITY LOSS.
- MONOCULTURES AND INCREASES IN SELECTIVE PLANT AND ANIMAL BREEDING CAUSE LOSS OF GENETIC DIVERSITY.
- AGRICULTURAL PRACTICES, SUCH AS TILLING, EXCESSIVE USE OF FERTILIZERS AND CHEMICAL INPUTS TO CONTROL WEEDS, PESTS, AND DISEASES, OVERGRAZING, AND INTENSIFICATION OF AGRICULTURAL SYSTEMS CAUSE BIODIVERSITY LOSS.
- PESTS, DISEASES, AND INVASIVE SPECIES HARM BIODIVERSITY IN MANY WAYS, INCLUDING BY INTRODUCING NEW SPECIES THAT ALTER DELICATE ECOSYSTEM BALANCES OR THAT REMOVE CRITICAL PREDATORS.
- OCEAN ACIDIFICATION HARMS VARIOUS SEA CREATURES, INCLUDING PTEROPODS AND CREATURES WITH HARD SHELLS, SUCH AS OYSTERS, THAT SERVE AS FOOD SOURCE FOR OTHER ANIMALS AND HUMANS ALIKE.[328]
- CHANGES TO LIFESTYLES LEAD TO LOSS OF TRADITIONAL KNOWLEDGE OF ANCESTRAL FOOD AND AGRICULTURAL PRACTICES, POTENTIALLY REDUCING BIODIVERSITY AS HISTORICAL VARIETIES AND SPECIES DIMINISH IN IMPORTANCE AND USE.

IMPACT AND SIGNIFICANCE

Agricultural biodiversity contributes to food security and nutrition through enabling food production in different types of environments and in the face of external shocks such as droughts and pest outbreaks. It is the source of nutritional diversity and presents income opportunities to the rural poor and sustains productive agricultural ecosystems.[329]

Soil biodiversity is crucial to farming. The millions of organisms that live in soil play a pivotal role in countering the negative effects of intensive farming, in preserving land fertility and yield capacity, in redistributing nutrients, and in increasing the amount of water absorbed by the soil.[330] Loss of soil biodiversity increases the need for and reliance on costly or environmentally harmful external inputs.

Biodiversity also increases the resilience of production systems to shocks and pressures associated with climate change.[331] This can occur through different mechanisms, for example, by raising species or breeds that are adapted to droughts or disease outbreaks, or by raising a number of different types of crops, livestock or aquatic organisms so as to increase the likelihood that at least some will survive such events.[332]

Biodiversity contributes to environmental ecosystem services, including by connecting humans to nature and having them benefit from its aesthetic, recreational, spiritual, and educational values.[333]

Biodiversity supports the consumption of wild foods, an important source of food for many people, especially in low-income countries or poor regions.[334] It also provides raw material for crop breeding programs and contributes to the supply of many ecosystem services that support food production.[335]

EXISTING REMEDIES

Existing remedies to protect or enrich biodiversity are plural and diverse. They range from reducing demand for food that has huge environmental impact (see existing remedies under "Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts" and "Radically Reducing Greenhouse Gas Emissions"), increasing productivity so that more land can be used for biodiversity conservation, landscape approaches to agriculture that integrate biodiversity and land-use (see existing remedies under "Addressing Soil Degradation and Erosion"), protecting forests (see existing remedies under "Radically Reducing Greenhouse Gas Emissions"), using labels and standards (see existing remedies under "Improving Food Literacy" and "Curtailing and Repurposing Food Loss and Waste"), etc. Some of these remedies are covered under other challenges here or the two other grand challenges of this report.

Below we highlight two existing remedies focused specifically on biodiversity.

INTERNATIONAL GUIDELINES AND INITIATIVES TO PROTECT AND PROMOTE BIODIVERSITY

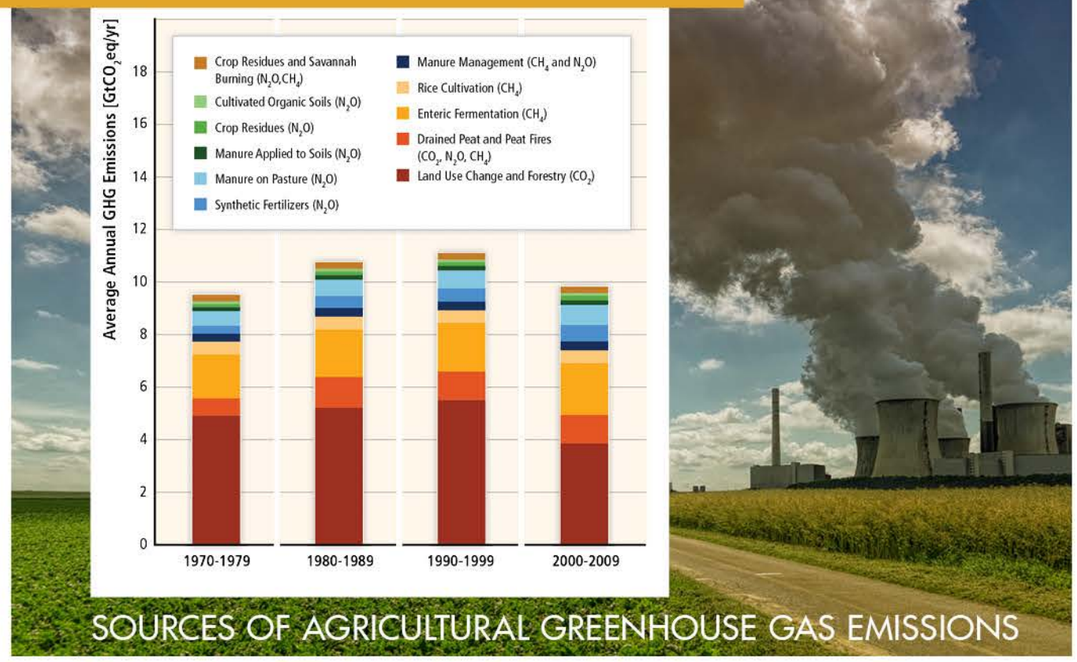
Several initiatives outlining specific efforts and parameters to support biodiversity have been implemented in different regions of the world as well as on a global level. These frameworks take slightly different approaches depending on the context of the implementation and how they are targeted. In the endnotes we highlight multiple examples of such efforts.[336,337,338,339]

SEED BANKS

Seed banks are secure, often remote repositories intended to enable the conservation of historical seed varietals and retain the world's crop genetic diversity. The uptake of high-yielding agricultural seed varietals has led to the "genetic erosion" of earlier varieties of crops. Seed banks sequester these historical seed varietals to both preserve their genetic information as well as secure their availability for future agricultural use.[340]

CHALLENGE 3.4

RADICALLY DECREASING GREENHOUSE GAS EMISSIONS



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THE GLOBAL FOOD system contributes up to 35% of global greenhouse gas emissions, of which 25% is due to agriculture, forestry, and other land uses. The remaining 10% is due to food system activities after primary production, including distribution, processing, cooking, storing, and refrigeration.[341]

Almost one-third of all agricultural sector emissions are due to methane produced by animal digestive processes;[342] overall, livestock are responsible for 14.5% of all anthropogenic greenhouse gases (GHGs), according to the FAO.[343] Other major greenhouse gas emitting activities in the system include deforestation, fertilizer manufacturing and use, mechanization, fishing, soil and manure management, and waste disposal. Deforestation caused by clearing land for livestock production further exacerbates the impact on atmospheric GHGs by reducing the ability of natural systems to sequester carbon dioxide.[344]

IMMEDIATE DRIVERS[345]

- LIVESTOCK, ESPECIALLY RUMINANTS SUCH AS CATTLE, PRODUCE METHANE (CH4) AS PART OF THEIR NORMAL DIGESTIVE PROCESSES. THIS PROCESS IS CALLED ENTERIC FERMENTATION, AND IT REPRESENTS ALMOST ONE THIRD OF THE EMISSIONS FROM THE AGRICULTURE SECTOR.
- FERTILIZERS ARE A SIGNIFICANT CONTRIBUTOR TO CLIMATE CHANGE DUE TO EMISSIONS ASSOCIATED WITH ITS HIGHLY FOSSIL-FUEL-DEPENDENT PRODUCTION AS WELL AS ITS APPLICATION, MADE WORSE BY INCORRECT DOSING AND LARGE-SCALE WASTAGE.
- CLEARING FORESTS, GROUNDWATER AND IRRIGATION PUMPING, FARM MECHANIZATION, THE GROWTH OF NITROGEN-FIXING CROPS, THE DRAINAGE OF ORGANIC SOIL, AND TRANSPORT OF INPUTS AND PRODUCTS, ARE THE MOST ENERGY-INTENSIVE COMPONENTS OF AGRICULTURE AND THE OVERALL FOOD SYSTEM RESPONSIBLE FOR EMITTING CO2.
- LIVESTOCK MANURE MANAGEMENT, TREATMENT, AND STORAGE CONTRIBUTE TO CH4 AND N2O EMISSIONS.
- SMALLER SOURCES OF AGRICULTURAL EMISSIONS INCLUDE CO2 FROM LIMING AND UREA APPLICATION, CH4 FROM RICE CULTIVATION, AND BURNING CROP RESIDUES, WHICH PRODUCES CH4 AND N2O.
- SOIL ORGANIC CARBON (SOC) LOSS TAKES PLACE WHEN SOIL CARBON IS CONVERTED TO GREENHOUSE GASES, MAINLY OXIDATION TO CARBON DIOXIDE (CO2) THROUGH OR REDUCTION TO METHANE (CH4) WHEN ERODED SOIL IS DEPOSITED IN WATER WAYS AND DAMS, OR THROUGH PRACTICES SUCH AS TILLING THAT CYCLE SOIL CARBON AND FACILITATE ITS RELEASE INTO THE ATMOSPHERE.
- RISING GLOBAL TEMPERATURES ARE INCREASING THE AMOUNTS OF CO2 RELEASED FROM SOIL, AS WARMER SOILS RELEASE MORE CARBON.

IMPACT AND SIGNIFICANCE

The food system is a major contributor to global warming and human-induced climate change, with its increasingly devastating effects on the planet.[346] Intensive land use for agricultural purposes can also lead to desertification, which increases temperatures, reduces water retention, and severely diminishes agricultural productivity. As desertified lands become more common, their impact on the environment and climate change is likely to increase as well.

Agriculture is a leading cause of deforestation and forest degradation, which represent Earth's largest natural land-based carbon sequestration system. Transforming forests for agricultural use makes these lands carbon emitters, thereby significantly accelerating global warming and climate change. Global warming in turn adversely affects all aspects of life on Earth. This is despite the fact that crops and agricultural soils do sequester some amount of carbon;[347] on net, however, this sequestration does not make up for the sequestered carbon lost when forested lands are converted for agricultural use.

As the human population grows in both number and wealth, and with it the demand for food and especially animal-based protein, food production systems will increase their emission of greenhouse gases, including carbon dioxide (CO2), nitrous oxides (NOx), and methane (CH4) - with severe environmental consequences.[348]

EXISTING REMEDIES

There are various existing remedies that deal with the different sources of GHG emissions from the agriculture and food sectors. Some of these are included in the existing remedies under "Addressing Soil Degradation and Erosion," in particular conservation agriculture. The below represent an additional set of existing remedies for addressing greenhouse gas emissions.

REDUCING LIVESTOCK CH4 EMISSIONS FROM ENTERIC FERMENTATION

Improving the use of pasture to increase animal productivity, which can reduce the amount of CH4 emitted per unit of animal product.[349] Also, increased productivity in livestock can be introduced through improved breeding practices.

LAND MANAGEMENT REMEDIES[350]

Reducing N2O emissions by fertilizing crops with the appropriate amount of nitrogen required for optimal crop production and avoiding the excessive use of nitrogen. For more details and examples, see remedies under the "Addressing Soil Depletion and Erosion" challenge.

COMPOSTING

Composting is an increasingly popular remedy for reducing emissions from food waste. It can be done at different scales, from backyard bins to large-scale operations. The process works by ensuring sufficient moisture, air, and heat for soil microbes to feed on the organic waste. This transforms the organic material into stable soil carbon and retains the water and nutrients from the waste, instead of leaving the waste to decompose and release methane. In 2015, 38% of food waste in the United States and 57% in the European Union was composted. Cities such as San Francisco in the United States, and Copenhagen, Denmark, have made composting mandatory.[351]

CLEAN COOKSTOVES

Cooking on open stoves produces 2% to 5% of annual greenhouse gas emissions, because of unsustainably harvested fuel from forests and smoke from burning the fuel, which produces carbon dioxide and methane. Improved or clean cookstoves have become increasingly available, although more expensive than traditional cookstoves. They work by forcing gases and smoke back into the stove, thereby reducing up to 95% of emissions. The most prominent initiative in this domain is the Global Alliance for Clean Cookstoves, a public-private partnership launched in 2010 and hosted by the United Nations.[352]

FOREST CONSERVATION

Conserving existing forest ecosystems serves as a bulwark against the negative impacts of deforestation in other areas. REDD+ (Reducing Emissions from Deforestation and Forest Degradation "plus" Conservation) – launched in 2008 by the United Nations – launched its UN-REDD Programme to provide financial incentives to developing countries to reduce emissions from deforestation and forest degradation through biocarbon projects.[353]

REFORESTATION AND AFFORESTATION

Reforestation (re-establishment of forests on land classified as forest) and afforestation (establishment of new forests) are two strategies of offsetting GHG emissions from agriculture, especially through integrating crop and forest components through agroforestry.[354],[355]

WATER MANAGEMENT REMEDIES

Draining water from wetland rice soils during the growing season helps to reduce CH4 emissions. For further details and examples, see existing remedies under "Reversing Ground and Surface Water Depletion and Pollution" challenge.

MANURE MANAGEMENT REMEDIES

These are methods of controlling the way in which manure decomposes to reduce N2O and CH4 emissions and capturing CH4 from manure decomposition to produce renewable energy.[356]

LESS ENERGY INTENSIVE DIETS

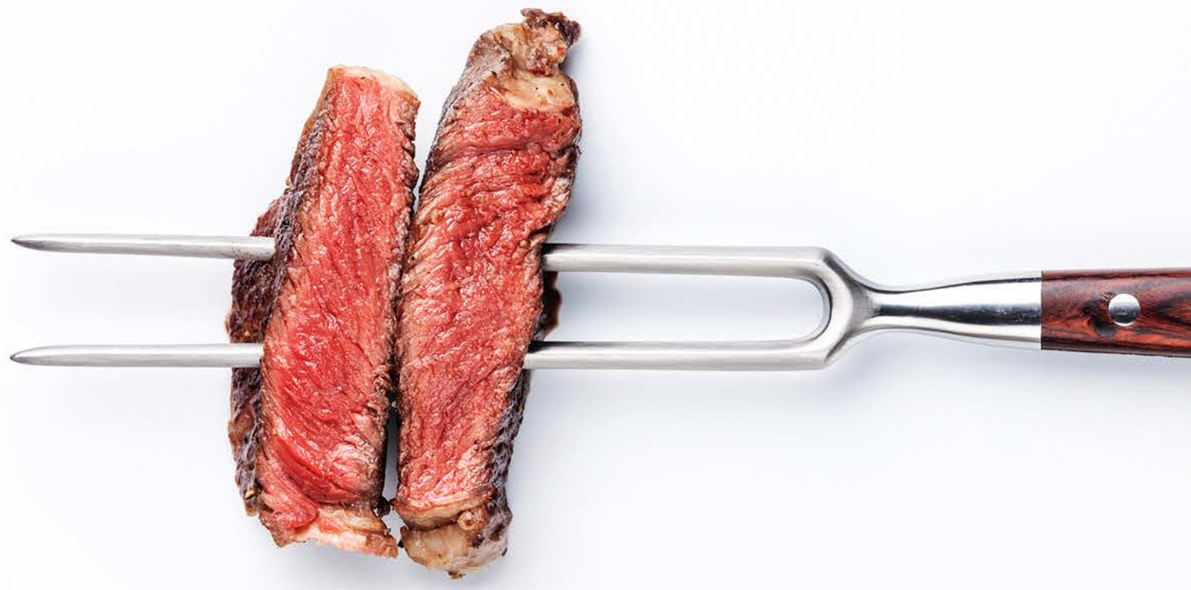
Promoting a healthy diet which encourages reduced meat and "empty calorie" consumption—from refined sugars, oils, and alcohols—may result in food production that is less energy intensive, thus emitting reduced concentrations of GHGs relative to current emission levels.

ENVIRONMENTAL IMPACTS OF LIVESTOCK AND ANIMAL PROTEINS

TODAY, 80% OF AGRICULTURAL LAND CURRENTLY IN USE AND 30% OF THE WORLD'S CROPS ARE USED TO RAISE AND FEED LIVESTOCK,[357] A TREMENDOUS RESOURCE ALLOCATION THAT CREATES SIGNIFICANT ENVIRONMENTAL IMPACTS. SPECIFICALLY:

- LIVESTOCK ARE RESPONSIBLE FOR 14.5% OF ALL ANTHROPOGENIC GREENHOUSE GASES (GHG), ACCORDING TO THE FAO.[358]
- DERIVING CALORIE ENERGY AND PROTEIN FROM LIVESTOCK TAKES AN ESTIMATED 2.5 TO 10 TIMES MORE ENERGY THAN FROM GRAIN OR OTHER PLANT SOURCES.[359]
- ABOUT 15,000 LITERS OF WATER ARE NEEDED TO PRODUCE A KG OF BEEF, COMPARED WITH ONLY 1,500 LITERS FOR A KG OF MAIZE OR WHEAT.[360]

AS INCOMES IN DEVELOPING COUNTRIES RISE, SO TOO WILL THE DEMAND FOR ANIMAL-BASED PROTEIN, POTENTIALLY INCREASING THESE ENVIRONMENTAL IMPACTS IN THE ABSENCE OF SIGNIFICANT CHANGES IN PRODUCTION METHODS.



CHALLENGE 3.5

CURTAILING AND REPURPOSING FOOD LOSS AND WASTE

A THIRD OF all food produced for human consumption is lost or wasted.[361] Food loss or waste occurs at different stages of the food value chain and has significant impacts on nutrition, enterprises, and the environment. Food loss generally refers to losses in primary production and along the value chain due to poor pest management, harvest loss due to poor technology, and loss in storage and processing, among others. Food waste generally refers to loss of food post-final purchase at the consumption stage.

Food loss from post-harvest to purchase occurs as a result of spoilage and degradation during handling, storage, transportation, processing, packaging, and at retail. Losses in edible produce can occur due to pests, fungus, and diseases, or during the process of preparation.[362] Food waste occurs in all consumption contexts and may be the result of excess portion sizes, spoilage, or taste or flavor issues.

GLOBAL AMOUNT OF FOOD LOSS AND WASTE

Every year, about 670 million tons of food are lost or wasted in high-income countries, and 630 million tons in low- and middle-income countries – a total of 1.3 billion tons, or one-third of the edible part of food originally intended for human consumption.[363] Food waste is a bigger issue in the developed world, while food loss is more significant in developing countries.

IMMEDIATE DRIVERS[364]

OF FOOD LOSS IN PRIMARY PRODUCTION:

- INSUFFICIENT ACCESS TO TECHNOLOGY, UNCERTAINTY ABOUT WEATHER CONDITIONS, AND LACK OF INVESTMENT IN PRODUCTION ALL CONTRIBUTE TO PREMATURE HARVESTING, AND POOR HANDLING OF FRUITS AND VEGETABLES THAT MAY BE BRUISED DURING PICKING OR THRESHING.
- FARMS SUFFER FOOD LOSS AS A RESULT OF MANAGEMENT AND TECHNICAL CONSTRAINTS IN HARVESTING.
- NEED FOR CASH LEADS POOR FARMERS TO HARVEST CROPS TOO EARLY, THEREBY CAUSING LOSS.
- PESTS AND DISEASES ARE A CAUSE OF CROP LOSS. THEY CAN REDUCE PRODUCTION AND PRODUCTIVITY OR LEAD TO ANIMAL DEATHS OR ANIMAL PRODUCTS BEING DISCARDED.
- CROPS THAT FAIL TO MEET MARKET QUALITY STANDARDS IN WEIGHT, SIZE, SHAPE, AND APPEARANCE ARE DISCARDED BY PRODUCERS.
- FARMERS MAY REACT TO SHARP DROPS IN PRICES OF SPECIFIC CROPS THAT BECOME UNECONOMICAL TO HARVEST BY LEAVING THEM IN THEIR FIELDS.
- POLICIES CAN CAUSE FARMERS TO DISCARD CROPS THROUGH, FOR EXAMPLE, SUBSIDIES THAT INCENTIVIZE THE PRODUCTION OF SURPLUS FOOD CROPS.

OF FOOD LOSS POST-HARVEST:

- UNHYGIENIC HANDLING CONDITIONS CAN MAKE FOOD UNSAFE AND THEREFORE CAUSE IT TO BE DISCARDED.
- IN SOME INDUSTRIALIZED FOOD PROCESSING SYSTEMS, DISPOSING OF EXCESS FOOD PRODUCTS IS CHEAPER THAN USING OR RE-USING THEM.
- LACK OF PROPER INFRASTRUCTURE FOR TRANSPORTATION, STORAGE, COOLING, AND MARKETS CAUSE POST-HARVEST FOOD LOSSES. FRESH PRODUCTS LIKE FRUITS, VEGETABLES, MEAT, AND FISH STRAIGHT FROM THE FARM OR AFTER THE CATCH CAN SPOIL IN HOT CLIMATES.

IMMEDIATE DRIVERS CONT.

» LACK OF PROCESSING FACILITIES IN DEVELOPING COUNTRIES LEADS TO HIGH FOOD LOSS. THIS IS PARTLY DUE TO THE SEASONALITY OF PRODUCTION THAT CAN CREATE BOTTLENECKS DURING SEASONS AND DECREASES THE INCENTIVE TO INVEST IN PROCESSING FACILITIES SINCE THEY WILL NOT BE USED YEAR-ROUND.

OF FOOD WASTE:

» OVER-PURCHASING IS A LEADING CAUSE OF POST-PURCHASE FOOD WASTE.

» LEFTOVER FOOD THAT IS STILL HEALTHY, NUTRITIOUS, AND SAFE IS OFTEN DISCARDED. THIS IS ESPECIALLY THE CASE WITH EXCESSIVE PORTION SIZES IN HOSPITALITY.

» IMPROPER STORAGE OF FOOD AT THE HOUSEHOLD LEVEL LEADS TO FOOD WASTE.

» CONSUMERS PREFER NOT TO BUY OR DECIDE TO DISCARD "IMPERFECT" PRODUCE THAT DOES NOT MEET HIGH QUALITY AND APPEARANCE STANDARDS.

» INADEQUATE UNDERSTANDING OF FOOD LABELS: sell-by, best-by, expiry date, etc., can cause food waste.

» STRICT FOOD SAFETY REGULATIONS AND "BEST BY" DATES CAN LEAD TO THE LOSS OF FOOD THAT IS SAFE TO EAT.

IMPACT AND SIGNIFICANCE

The later the food loss along the value chain, the greater the negative environmental impact. Wasted food not only means wasted resources that went into producing it, but also additional harm from replacing the wasted food by producing more. Furthermore, the wasted food itself, if dumped into landfills and left to rot, contributes to additional greenhouse gas emissions.[365]

When food is wasted, so too are the water, soil, seeds, energy, biodiversity, and other natural resources and inputs that were used to produce, process, and distribute it. It is also estimated that food loss and waste is a major contributor to greenhouse gas emissions, especially in the production of meat.[366] These impacts are referred to as the "food loss and waste footprint" on the environment.[367]

Food waste increases the proportion of a household's income allocated towards food, a problem of particular concern in low-income countries. Food loss represents lost income opportunities for farmers who either invest in lost inputs or are unable to sell the full volume of their produce, and for the millions of people who are employed in different jobs such as sorting, processing, storage, and transportation.[368] Loss of food reduces the food supply available in the market, which in turn can raise prices and make food less affordable, especially for low-income households.[369]

THE ECONOMIC AND ENVIRONMENTAL FOOTPRINT OF FOOD LOSS AND WASTE[370]

ECONOMIC: ACCORDING TO THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS:

» FOOD LOSS AND WASTE AMOUNTS TO ALMOST US$ 1 TRILLION ANNUALLY, WITH APPROXIMATELY US$ 680 BILLION IN INDUSTRIALIZED COUNTRIES AND US$ 310 BILLION IN DEVELOPING COUNTRIES.

» GLOBAL QUANTITATIVE FOOD LOSSES AND WASTE PER YEAR ARE ROUGHLY 30% FOR CEREALS, 40-50% FOR ROOT CROPS, FRUITS, AND VEGETABLES, 20% FOR OIL SEEDS, MEAT, AND DAIRY, PLUS 35% FOR FISH.

» EVERY YEAR, CONSUMERS IN RICH COUNTRIES WASTE ALMOST AS MUCH FOOD (222 MILLION TONS) AS THE ENTIRE NET FOOD PRODUCTION OF SUB-SAHARAN AFRICA (230 MILLION TONS).

» IN DEVELOPING COUNTRIES 40% OF LOSSES OCCUR AT POST-HARVEST AND PROCESSING LEVELS, WHILE IN INDUSTRIALIZED COUNTRIES MORE THAN 40% OF LOSSES HAPPEN AT RETAIL AND CONSUMER LEVELS.

ENVIRONMENTAL: THE ANNUAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH FOOD LOSS AND WASTE ARE OF UNPRECEDENTED MAGNITUDE; FOR EXAMPLE:

» IF FOOD WASTE WERE A COUNTRY, IT WOULD BE THE THIRD LARGEST EMITTER OF GREENHOUSE GASES IN THE WORLD, BEHIND THE US AND CHINA.

» THE WATER FOOTPRINT OF FOOD LOSS AND WASTE IS ESTIMATED AT 250 CUBIC KILOMETERS, OR THREE TIMES THE VOLUME OF LAKE GENEVA.

» PRODUCED BUT UNEATEN FOOD UTILIZES ALMOST 1.4 BILLION HECTARES OF LAND, REPRESENTING 28 PERCENT OF ALL LAND UTILIZED FOR AGRICULTURE.[371]

EXISTING REMEDIES

Existing remedies for food loss and waste can take numerous forms, ranging from developing better infrastructure, storage, transportation, packaging, distribution, and other solutions. Composting and recycling of food waste, and especially for industrial uses such as biofuels, has also been on the rise. Some existing remedies or interventions which focus on reducing food waste or recycling it for human consumption include:

EXTENDING SHELF LIFE THROUGH BETTER PROCESSING, PACKAGING, AND STORAGE

Better food packaging, storage infrastructure and technologies go a long way toward avoiding food loss and waste. While they could take many forms, the following provide a glimpse of existing initiatives and opportunities in this field. Examples include evaporative coolers, special plastic storage bags, small metal silos, and plastic crates.[372,373,374]

FOOD DATE LABELING

In the United States, there are over 10 different food date labels, such as "sell-by," "expires on," "best before," "use-by," etc. These cause consumer confusion and lead to edible food being discarded. In 2018, grocery industry retailers and manufacturers, led by the Food Marketing Institute (FMI) and the Grocery Manufacturers Association (GMA), launched a new initiative to reduce the different labels into two common phrasings: "best if used by" and "best by," where the latter is used to highlight perishable products that have a food safety concern.[375]

REDUCED PORTION SIZES

Health authorities, especially in developing countries, have issued numerous advisories and guidance on healthy food portion sizes. This, however, is of limited effect as there are no policy or other interventions in the market, where the food industry continues to create incentives for buying more and larger portion sizes.[376]

CONSUMER AWARENESS CAMPAIGNS

Consumer awareness campaigns to manage and reduce food waste have been on the rise, especially in the developed world where data is accessible. Dozens of campaigns have targeted individual consumers, supermarkets, educational institutions, businesses, community organizations, and governmental entities to cut food waste.[377,378]

RECYCLED OR UPCYCLED FOOD WASTE INDUSTRY

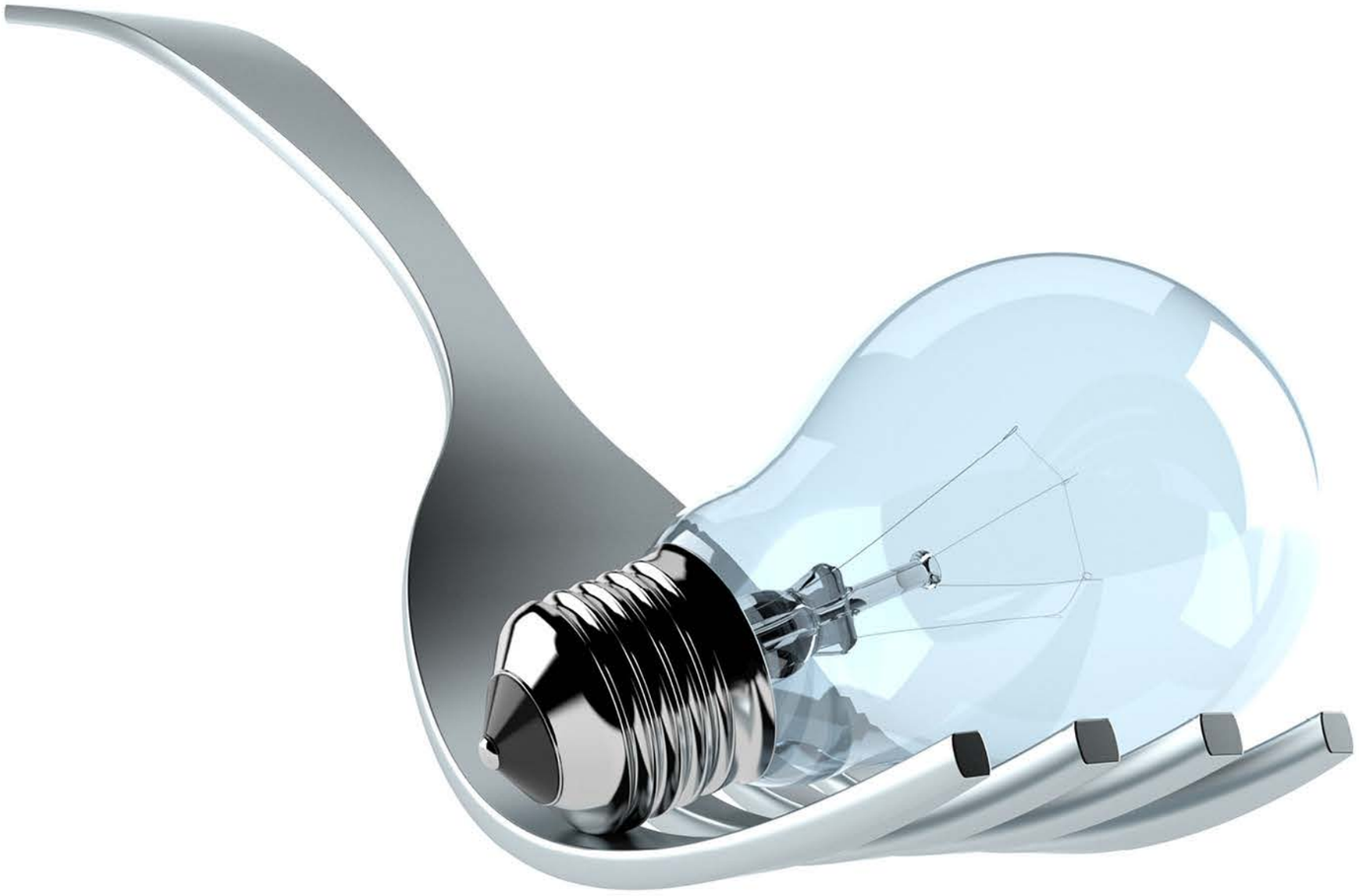
Recycling food waste or transforming wasted ingredients into food has been an increasing trend in many parts of the world. Both new startups and existing major food manufacturers have been developing new products with upcycled ingredients.[379,380,381]

FOOD REDISTRIBUTION

Food redistribution and donation programs collect food that would otherwise go to waste and distribute it to the needy. While charity organizations are the classical example of food donating organizations, commercial companies have also been emerging in this field, with mobile technology being particularly valuable for such solutions.[382,383]

06.

BREAKTHROUGHS



CHAPTER 6. BREAKTHROUGHS

Introduction

THIS REPORT HAS so far focused on the challenges we must overcome to achieve a preferred future of food systems that maximizes human health and nutrition, ensures sustainable livelihoods for small-scale producers and fair economic opportunities along food value chains, while staying within planetary boundaries and regenerating the environment.

In this chapter, we propose 12 breakthroughs that could address these challenges and thereby change the trajectory of humanity.

What is a Breakthrough?

A breakthrough is a discovery or disruption that causes significant, sometimes sudden or dramatic change of the trajectory of the future. Breakthroughs can be technological, social, political, cultural, economic, or a combination of these. While XPRIZE competitions typically incentivize technological breakthroughs, not all breakthroughs identified are technological.

"A BREAKTHROUGH IS A DISCOVERY OR DISRUPTION THAT CAUSES SIGNIFICANT, SOMETIMES SUDDEN OR DRAMATIC CHANGE OF THE TRAJECTORY OF THE FUTURE."

This points to a critical aspect of potential breakthroughs: while the competition model has proven its effectiveness over centuries in generating transformative solutions, it cannot be deployed to solve every problem. All of the breakthroughs outlined below include components that require political, social, or cultural changes in some form or another – while technological innovation can help catalyze or support change in these areas, it cannot be the sole driving force to do so. In these cases, we look to work with other stakeholders to identify how these breakthroughs can turn into actionable ideas that we collectively can seek to achieve. During this process, XPRIZE seeks to understand how an XPRIZE competition can serve as a milestone that helps chart a pathway towards a breakthrough's achievement.

In some cases, a potentially transformative breakthrough may not appear new or novel at first glance. This may be due to several factors:

- A breakthrough may be a function of the mass scaling of an existing idea or emerging technology. This is particularly relevant in the case of early-stage innovations that are developed and adopted at some baseline level within a developed world context, but which would only achieve transformative impact if adopted much more broadly and at a global scale.
- Similarly, a breakthrough may involve the adoption of multiple, related innovations together in a manner that exponentially increases their impact and generates transformative change.

In both cases, a breakthrough is needed to achieve the true potential of an existing innovation or set of innovations; without radical change and focused investment, the impact of such ideas fails to reach their transformative potential.

Furthermore, as shown in the list of breakthroughs that follows, many of these breakthroughs are interrelated, reflecting in large part the inherent complexity of our modern food systems.

Regardless of their constitution, every breakthrough, if achieved, creates radical change with regards to the trajectory of the future.

Identifying Breakthroughs

Identifying potential breakthroughs is a complex, multi-faceted process requiring both internal and external resources. To do so, we leveraged a combination of desk research, interviews with subject matter experts, an in-person convening of experts and food systems stakeholders, and crowdsourced activities on the Future of Food Impact Roadmap's online community platform.

At the in-person two-day Future of Food Lab at XPRIZE headquarters, we brought together 45 participants from diverse sectors including agriculture and food systems academics, behavioral economists, venture capitalists, entrepreneurs, futurists, farmers, and food innovators. In a series of guided sessions, participants identified over 400 innovative ideas across social, technological, economic, environmental, and political categories.

After the lab we combined these hundreds of breakthrough ideas with additional ones sourced through expert interviews, the online community, and our own desk research. These ideas were then analyzed, combined, and refined into a concise list of 12 breakthroughs that was then further vetted by subject matter experts and our online community.

Breakthroughs Assessment Criteria

We assessed each breakthrough against the challenges it is intended to address, the groups and users most impacted by it, the need for the breakthrough and its potential impact, the potential trade-offs and unintended consequences that could arise from the breakthrough intervention, promising technologies and innovations that facilitate its attainment, and specific pathways for impact.

Given the complex nature of food systems, the below overarching factors are necessary to ensure that breakthrough innovations will have enduring impact, global scale, and system-wide transformations:

- Political will among politicians, leadership among businesses, activism within public institutions, and behavior change among value chain stakeholders.
- Regulatory environments and governance strategies that ensure accountability and transparency and protect the public from risks and unsubstantiated claims.
- Availability, accessibility, affordability, and safety of breakthrough innovations across the value chain and especially for small-scale producers and low-income consumers.

Given these factors, the impact of any breakthrough may vary or take longer to manifest based on the above factors, in particular as a result of regional differences or differing local contexts.

We conducted an online survey of nearly 65 multidisciplinary experts to assess, on a scale of 1-to-10, which of these breakthroughs could have the most impact and which may be the easiest or most difficult to achieve. Based on the results, we created a four-quadrant chart to determine high impact and high audacity breakthroughs where an XPRIZE competition could play an instrumental role, depicted at the conclusion of this section.

WE DEFINE IMPACT AS: The significance of the role this breakthrough will play in transforming food systems and enable them to improve human health and farmer livelihoods while staying within planetary and environmental boundaries.

WE DEFINE AUDACITY AS: The difficulty involved in fulfilling this breakthrough solution.

The below list of breakthroughs presented in this chapter is not exhaustive and is rather intended to spark innovation in key areas where change is required to achieve a preferred future state of food systems.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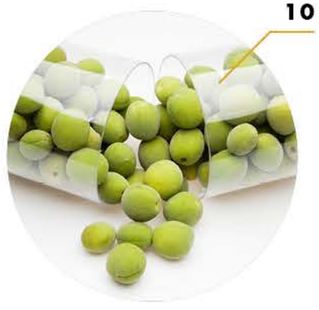
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Breakthroughs for the Future of Food

The below concepts represent breakthroughs which XPRIZE has identified as providing the potential to radically disrupt our current trajectory around the future of food. They are loosely organized along a "farm to fork" spectrum, both as a means to provide narrative logic as well as to help illustrate the relationships and interconnectedness among many of these measures.

1. Food System Data Trust

2. Land Use Revolution

3. Renewable Energy for All

4. Accessible Precision Agriculture

5. Ocean and Land Biodiversity Stewardship

6. Food Production in Urban Networks

7. Unleashing Local Knowledge: Enabling Small and Medium Enterprise Innovation

8. Extending Food Lifetimes

9. Alternative and Novel Proteins at Scale

10. Food as Medicine

11. True Cost of Food

12. Actionable Food Experiences: Crafting New Food Norms

BREAKTHROUGH 01

Food System Data Trust

A system or platform that ensures protected, democratized access to massive amounts of data on agri-food activities and consumption. This equitably owned and shared information can be used to create actionable intelligence that is leveraged for better health, livelihoods, and environmental outcomes.

1 **PRIMARY CHALLENGES**

- Improving Food Literacy
- Enhancing Livelihoods of Smaller-Scale Family Farms
- Optimizing Fair Economic Opportunities Along the Food Chain

2 **SECONDARY CHALLENGES**

- Addressing Soil Degradation and Erosion
- Reversing Ground and Surface Water Depletion and Pollution
- Reducing Biodiversity Loss
- Radically Decreasing Greenhouse Gas Emissions
- Curtailing and Repurposing Food Loss and Waste

NEED AND POTENTIAL IMPACT

Food systems generate vast amounts of environmental, economic, behavioral, and biological data about billions of people globally across the entire food value chain. The volume of this data will continue to increase exponentially over the coming decades: computing power will multiply, and digital tools will increasingly be utilized as components of agricultural production and food consumption.

These data are often under-valued and unknowingly offered by individuals and organizations, yet they represent enormous value and power to those who collect, analyze, and use them. At present, most of this intellectual capital is lost to those who might benefit most profoundly from it. Simultaneously, there is a growing consolidation of this powerful information in a few private sector companies, and a small window of opportunity to establish norms and systems designed to leverage this data to serve the global public good through such data.

Imagine all data related to agri-food activities and consumption is transparently collected, commonly accessible through an open-source data trust, and more equitably used. Individuals and organizations across the value chain are able to understand how resources are being used, where food is coming from, and how it is produced. The power of big data access creates clear incentives for value chain stakeholders to share their data to the platform. Such a system would become the most powerful engine for actionable intelligence and evidence-based research on food system improvements, such as by allowing farmers to understand the impacts of different production practices, sharing examples of effective practices and innovative possibilities throughout the agri-food chain, and unlocking insights into human health such as by comparing gut microbiome data across millions of people. Governance of the data trust will be decentralized, and collectively funded through a sustainable model, to avoid any undue influence from a single actor or group of actors. The combination of democratized access to information with actionable intelligence addresses anticipated challenges around digital equity and facilitates increased agency among users across the value chain. Furthermore, a data trust could create a common repository of knowledge that transcends boundaries, opening channels for unprecedented cross-fertilization of ideas, increased collaboration, technology transfer, and leapfrog opportunities.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Accessible Precision Agriculture	True Cost of Food
	Actionable Food Experiences

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- In certain contexts, the open source nature of such a data system may disadvantage entrepreneurs and innovators if intellectual property rights are critical to their competitive advantage and pathway for technological development.
- Without proper protections, such a data trust might be subject to data breaches that could be devastating to businesses, food producers, and consumers and reduce overall confidence across the value chain.
- The most powerful actors might be most capable of using data to advance their own interests that could potentially go against what is best for the environment, value chain livelihoods, and overall consumer health.
- The platform may neglect the information and concerns of stakeholders who are not yet digitally connected.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Pursuing Collective Value:** A step change in collaboration will be needed among technology companies and social sector institutions to create a practical approach for such a data trust.
- **Next Generation Intellectual Property Rights**: New laws, rules and norms around IP will be needed to protect privacy and business interests while offering open-source data in the common good.
- **Big Data Management and AI Sharing Platform:** An AI-enabled platform could be used to share all the gathered data along the value chain, including through the Internet of Things, and crowdsource innovative ideas. This breakthrough would represent an unprecedented scale and complexity of big data and AI application.
- **Blockchain and Cybersecurity Technology:** Methods to decentralize and secure data, ensuring its transparency and accuracy, will be essential. Modern encryption and advanced cybersecurity techniques will be needed to create a highly secure system resistant to hacking.

PATHWAYS FOR IMPACT

- Agreements with key countries can require that data collected by private entities be added to the data trust after a reasonable lead time to enable market competitiveness.
- The data trust must include diverse types of information including environmental, economic, behavioral, and biological data.
- The data trust must be accessible to people across the digital divide, low-literate individuals, and novice players in technology.

BREAKTHROUGH 02

Land Use Revolution

Methods of optimizing natural resources and inputs such as water, soil, seeds, and fertilizer to maximize efficiency and minimize waste and contamination, dramatically improve overall agricultural production efficiency, and regenerate ecosystems and the natural resource base.

1

PRIMARY CHALLENGES

Enhancing Livelihoods of Smaller-Scale Family Farms

Optimizing Fair Economic Opportunities Along the Food Chain

Addressing Soil Degradation and Erosion

Reversing Ground and Surface Water Depletion and Pollution

Reducing Biodiversity Loss

Radically Decreasing Greenhouse Gas Emissions

Curtailing and Repurposing Food Loss and Waste

2

SECONDARY CHALLENGES

Incentivizing the Production of Healthier Crops

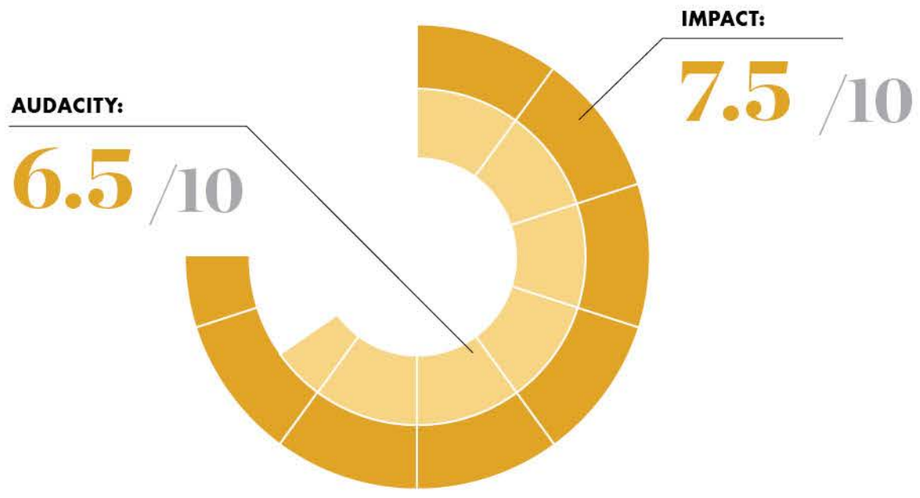
NEED AND POTENTIAL IMPACT

Increasingly, scientists point to land use for agriculture as a fundamental factor in our climate crisis. We need a transformation in attitudes and action that can shift toward regenerative practices and diversify our crop production. In many contexts, water scarcity is a constant struggle, droughts affect the ability of the soil to provide plant nutrients, and biofortified and drought resistant seeds are expensive and controlled by intermediaries and monopolies. Additionally, overuse of fertilizers can lead to soil degradation and water contamination. In a world projected to face increasing resource constraints due to climate change and population growth, it is imperative that farmers develop techniques to not only effectively manage these natural resources, but to support their regeneration through agricultural activities.

Imagine if agri-food systems produced no greenhouse gas emissions, regenerated soil rather than depleting it, and retained and regenerated water through farming. Imagine if production inputs like fertilizer came from organic sources, like compost and seaweed, and did not depend on fossil fuels. Imagine if government subsidies rewarded regenerative agriculture and nutritious crop production.

Farmers and food producers can be agents of a land use revolution. As stewards of the land, they can be the frontier in producing high quantities of nutrient-rich, diverse crops on small plots of land with increasingly efficient use of water, seeds, and sustainable inputs. This revolution is underway in pockets throughout the world with developments around conservation or regenerative agriculture and sustainable intensification, however major efforts are needed to reach the full potential of these changes, both in terms of further understanding mechanisms for their impact as well as scaling their implementation. Drawing on indigenous knowledge and the principles of regenerative agriculture, a shift in land use practices to grow food would contribute to the majority of other breakthroughs, most notably those regarding biodiversity and the true cost of food.

IMPACT & AUDACITY



INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Renewable Energy for All	Ocean and Land Biodiversity Stewardship
Food Production in Urban Networks	Food as Medicine
Alternative and Novel Proteins at Scale	Actionable Food Experiences

TRADE-OFFS AND UNINTENDED CONSEQUENCES

» Adoption of novel models and equipment might increase farmers' dependency on service providers and manufacturers, who might be able to set disadvantageous terms.

» Adoption of new equipment might increase the cost of production due to maintenance and other needs.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

» **Carbon Sequestration:** Technologies for carbon sequestration, along with the business models and policy measures that would incentivize it, would be essential to a land use revolution.

» **New Irrigation and Water Reclamation Techniques:** Applying sensors, data collection, and AI prediction models to scale up existing irrigation models and create new ones that precisely estimate groundwater depth and crop water requirements at different stages of growth periods to optimize irrigation networks and reduce overall water usage. These innovations would be supported by the development of new community-scale, highly modular, and energy efficient devices for water reclamation to maximize available water resources, particularly under conditions of constrained groundwater supplies.

» **Super Seeds:** Seeds and mature plants that can be genetically engineered to provide resistance to pests, diseases, soil salinity, and water scarcity. More advanced genetically engineered crops and plants could also be engineered to sequester more CO2 from the atmosphere, leading to more efficient growth and ripening patterns.

» **Transforming the Soil:** Methods to scale soil microbiome's natural abilities to capture carbon and nitrogen from the atmosphere and provide plants with needed daily amounts of nutrients and achieve highest efficiency instead of dependency on synthetic fertilizers that are capital intensive, especially in sub-Saharan Africa where there's a dependency on international sources due to lack of local or regional fertilizer manufacturing plants.

» **Repurposed Subsidies:** Garnering the political will to reward land stewardship and the production of nutritious crops would fundamentally shift economic incentives in support of a land use revolution.

PATHWAYS FOR IMPACT

» Integration of breakthrough innovations with indigenous knowledge of traditional farming.

» Monetizing regenerative practices, such as by putting a value on carbon sequestration in soil and by increasing the price farmers receive for utilizing sustainable production methods.

BREAKTHROUGH 03

Renewable Energy for All

Low cost and accessible grid and off-grid renewable energy sources that regularly supply and store reliable energy for rural and peri-urban households and farms, transforming efficiencies and opportunities along the food value chain while reducing resource dependencies and greenhouse gas emissions.

1 **PRIMARY CHALLENGES**

Incentivizing the Production of Healthier Crops
Enhancing Livelihoods of Smaller-Scale Family Farms
Optimizing Fair Economic Opportunities Along the Food Chain
Radically Decreasing Greenhouse Gas Emissions
Curtailing and Repurposing Food Loss and Waste

NEED AND POTENTIAL IMPACT

Today, around 13% of the global population (1 billion people) do not have access to electricity and 1 billion more do not have reliable power,[384] which consequently means that they are disconnected from the internet and are negatively affected by the digital divide. This challenge has dramatic consequences for farmers and food producers, reducing their productivity, leaving them at risk for food loss, and inhibiting their ability to develop and/or invest in innovative technologies.

Imagine if all rural households have access to low-cost, reliable renewable energy sources that are essential for small-scale production, processing, and distribution activities. This breakthrough unlocks many possibilities for enhancing quality of life of smallholder farmers and offers livelihood opportunities that are otherwise impossible. These opportunities include lighting, cold storage, access to information, ability to use mobile phones and diverse types of farming equipment. This breakthrough facilitates the activation of local knowledge, and in particular its utilization in the development of game-changing innovative technology tailored to local needs and conditions.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
True Cost of Food	Food System Data Trust
	Land Use Revolution
	Accessible Precision Agriculture
	Food Production in Urban Networks
	Unleashing Local Knowledge
	Extending Food Lifetimes
	Actionable Food Experiences

TRADE-OFFS AND UNINTENDED CONSEQUENCES

» Increased labor burden to maintain assets involved, such as solar panels, on food producers, especially for women.

» Adoption of new equipment might increase the cost of production due to maintenance and other needs.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

» **Low-Cost Conventional Renewable Energy:** Methods to decrease the costs of existing solutions such as wind turbines, solar panels, wave power, hydropower, and others to increase accessibility to rural households.

» **Cheaper and Easy to Assemble Minigrids:** Packages of minigrid components that can be easily assembled and installed to simplify operations and reduce dependencies on large companies, barriers to expansion, and risks. In addition to providing power to homes, minigrids can be used to power services such as water pumping and street lighting and could count as a source of additional income to low-income households.

» **Battery Technology:** Increased capacity, at lower costs, for storing large amounts of energy.

» **Clean Energy Harvesting Technologies:** Systems to harvest energy from the air, movement, plants, and other new sources to power small households and farms.

PATHWAYS FOR IMPACT

» Easy to maintain off-grid renewable energy sources without the need for specialized technical expertise.

» Incentives structures for farmers and rural households to sell excess energy to government and private entities to encourage uptake and create new sources of income.

» Design mechanisms to protect the assets involved, such as solar panels, from theft and deterioration in harsh environments.

BREAKTHROUGH 04

Accessible Precision Agriculture

Precision agriculture tools that are affordable, accessible across the digital divide, context specific, and widely available for smallholder farmers to help them make optimal growing and harvesting decisions.

1

PRIMARY CHALLENGES

Enhancing Livelihoods of Smaller-Scale Family Farms

Optimizing Fair Economic Opportunities Along the Food Chain

Addressing Soil Degradation and Erosion

Reversing Ground and Surface Water Depletion and Pollution

Reducing Biodiversity Loss

Radically Decreasing Greenhouse Gas Emissions

Curtailing and Repurposing Food Loss and Waste

2

SECONDARY CHALLENGES

Incentivizing the Production of Healthier Crops

NEED AND POTENTIAL IMPACT

Precision agriculture technologies and techniques are evolving rapidly in the developed world yet are out of reach for many in developing country contexts due to the high cost of such technologies and limited technical capacity necessary to fully adopt them. Tools such as sensors, satellites, robotics, drones, imaging equipment, and novel data processing techniques are allowing agri-business and developed world farmers to exponentially increase their understanding of their resource base and develop actionable insights to maximize productivity. Farmers in the developing world lack such abilities.

Imagine farmers in sub-Saharan Africa or South Asia taking an active role in partnership with tech-innovators to develop low-cost sensors, advanced visioning tools, context-appropriate AI and machine learning, mapping systems, data management systems, and other local solutions to implement precision agriculture practices. This breakthrough can revolutionize primary production and enhance farmer livelihoods by dramatically reducing the risk of making decisions based on wrong or limited information. Developing context-specific intelligent platforms and recommendations increases yield and can protect crops from externalities and threats, thereby enhancing farmer livelihoods, as well as minimizing impacts on soil and water health. This breakthrough can also radically reduce crop losses and increase food availability.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Renewable Energy for All	Extending Food Lifetimes
Unleashing Local Knowledge	Actionable Food Experiences

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- Big data generated by this breakthrough might be manipulated by governments or companies to promote products that are not necessarily beneficial to farmers or the environment and to enhance the development of their high-tech and expensive agriculture innovations that are out of reach for many producers.
- Farmers' decisions might be made on the basis of profitability and not nutrition or the environment.
- Farmers might get trapped in a digital/machinery ecosystem and therefore become more dependent on making ongoing capital investments and the companies that provide them.
- If certain precision agriculture products are developed for a limited set of crops, many farmers might switch their production choices, potentially reducing dietary diversity in the area and producing excess of the available produce.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Variable Rate Technology:** A suite of technologies enabling the variable application of inputs based on increasingly targeted intervention preferences. Map-based, sensor-based, and manual systems may all be useful in different contexts.

- **Low Cost Non-Invasive Sensors:** Technologies enabling mapping and measuring various data points across the farm without interfering with ongoing production activities through sensors embedded in crops to analyze temperature, fertilizer, and moisture and on livestock and fisheries such as electronic and biometric identification.
- **Aerial Imagery:** Imagery collected from increasingly sophisticated drones and satellites can be used in farm-specific and comparable ways to optimize decision-making, trace trendlines, make predictions, and mitigate collective challenges such as crop disease outbreaks.
- **Robotics:** Small and medium sized robots that are able to use sensor and aerial imagery data and combine it with artificial intelligence to precisely carry out agriculture activities such as irrigation and fertilizer application.

PATHWAYS FOR IMPACT

- An integrated system, informed by human-centered design, that is informed, operated, and updated by farmers and can store regional and local information in different languages.
- Reliable connected or off-grid renewable energy sources will be necessary, particularly in rural areas with no electricity infrastructure.
- Extended rural physical and internet infrastructure ensuring connectivity between precision agriculture devices.
- Market linkages must allow for the flow of produce into the rest of the food chain, minimizing loss.

BREAKTHROUGH 05

Ocean and Land Biodiversity Stewardship

A system for analyzing, tracking, and valuing biodiversity and ecosystem services, recognizing the vast benefits of biodiversity – from the pollination activities of bees, to the carbon sequestration of trees and beyond – in a manner that influences market activity at scale.

1

PRIMARY CHALLENGES

Addressing Soil Degradation and Erosion
Reversing Ground and Surface Water Depletion and Pollution
Reducing Biodiversity Loss
Radically Decreasing Greenhouse Gas Emissions
Curtailing and Repurposing Food Loss and Waste

NEED AND POTENTIAL IMPACT

The world contains an unimaginable and so far untold diversity of plants, animals, and micro-organisms. Humanity still lacks a full understanding of the range of life present on this planet. At the same time, food production has devastating impacts on this cornucopia of life, and our inability to measure it means we do not understand what we are losing. Agricultural biodiversity enables all species to evolve and adapt to environmental disruptions due to climate change and to resist diseases, insects, and parasites. Deforestation and loss of habitat to secure land for agriculture, in addition to farming practices such as tilling, excessive use of chemical pesticides and fertilizers, and monocropping are huge contributors to biodiversity loss. Chemical run-off and industrial over-fishing also contribute to the destruction of marine habitats. Fishing practices also often result in bycatch, which includes fish, sea turtles, seabirds, and other marine animals that get discarded. Overall, the value of our natural resources is primarily defined by market transactions, which in most cases ignore the range of benefits provided by plants, animals, and the natural systems they comprise.

Imagine the ability to measure and track biodiversity in oceans, the air, and on land to accurately understand, quantify, and minimize the effects of food production, processing, and distribution on biodiversity loss. This power of measurement would translate into public awareness and concern so profound as to reshape market and political norms toward conservation, supporting an extensive and diversified blend of crop production in harmony with the ecosystem. This breakthrough contributes to transforming food production practices to integrate better biodiversity management by maintaining valuable species in the water, soil, and sky, allowing scientists to understand and refine regenerative and ecologically-sound agricultural techniques that support biodiversity. Furthermore, this breakthrough would generate tremendous spill-over effects to other industries and domains struggling with this identical issue. Without the capabilities to accurately measure and track biodiversity, humanity lacks the tools to tackle this critical challenge; this breakthrough gives us a fighting chance to do so.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Land Use Revolution	True Cost of Food
	Actionable Food Experiences

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- The cost of new high-tech interventions might be prohibitive to smallholder farmers.
- Conventional pesticide and fertilizer producers and industries might be negatively affected and might push back.
- Conservation regulations or market stipulations may create tough economic trade-offs for some farmers; their compliance might in fact reduce their economic gain through production activities.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **eDNA:** A comprehensive analysis of environmental samples from the land or ocean via DNA sequencing and metabarcoding to determine the various organisms within a sample.
- **Bioherbicides:** Pesticides adapted from natural substances such as fungal strains already present in the environment that serve as precision weed and pest management tools that replace mass-spraying of chemicals, which are harmful for land biodiversity and increase the risks of run-off in surface and groundwaters creating 'dead zones' in waterways.

- **Remote Sensing Technologies:** Various sensing technologies and techniques can be used to detect threats to biodiversity. These sensors can be either located on the ground, on individual trees, in the ocean, or in the sky by using aerial drones, airplanes and satellites.
- **Livestock and Fisheries Trackers:** Portable, durable wireless sensor enabled trackers can be attached to livestock and in fisheries to track threats and diseases, overall health, geographical location, grazing and feeding habits and report the information gathered to a data platform.
- **Bycatch Reduction Technologies:** Face recognition technologies can be used to support identification of distinct types of fish caught and inform fish farmers about the legality of catching specific fish and avoiding those that are endangered.

PATHWAYS FOR IMPACT

- Increased awareness of the effects of agriculture on biodiversity loss to create a spike in demand among consumers for products produced in ways that are supportive of biodiversity. Capacity building for crop and fish farmers to adopt innovations and practices that prevent biodiversity loss.

BREAKTHROUGH 06

Food Production in Urban Networks

Expanding food production from crop farming, livestock rearing, and fisheries to encompass a range of new modalities in urban and peri-urban areas. Such innovations would de-couple some food production from land and sea and create connected, sustainable, circular value chains with holistic, systemic connections between consumer demand and food producers, primary processors, manufacturers, distributors, and waste resource managers.

1

PRIMARY CHALLENGES

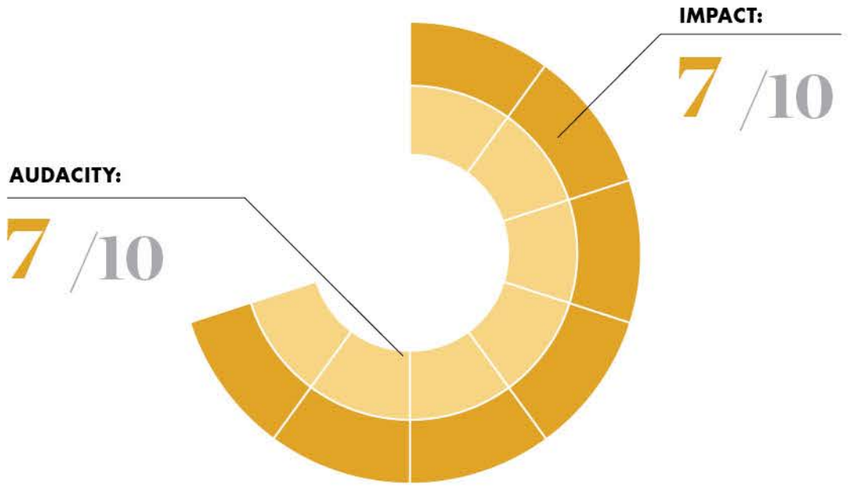
Increasing the Consumption of Healthy Diets
Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts
Improving Food Literacy
Incentivizing the Production of Healthier Crops
Addressing Soil Degradation and Erosion
Reversing Ground and Surface Water Depletion and Pollution
Reducing Biodiversity Loss
Curtailing and Repurposing Food Loss and Waste

NEED AND POTENTIAL IMPACT

With the rise of urbanization, consumers are increasing disconnected, both physically and culturally, from food production. This is putting increasing strain on farming, transportation, distribution and waste systems, as larger volumes of food are transported long distances to feed billions of urban dwellers. It is also contributing to poor health and obesity, as consumers prioritize convenient, processed food that is most easily accessible in urban contexts. At the same time, our definition of a food "producer" is changing, to include those farming insects in a factory or those cultivating plants indoors with "data recipes" under carefully calibrated lights. There is vast potential to test the scale capacity and unit economics of such approaches and to ramp up promising approaches accordingly.

Imagine if schools, hospitals, government organizations, and private companies are able to offset most of their nutritional needs by locally sourcing them. Urban and peri-urban consumers will not only have improved food literacy and appreciation for food producers and the environment, they will also be able to connect to a circular economy that repurposes their waste by redirecting it to the production end of the ecosystem for use as an input. These circular local hubs will enable agricultural innovators to flourish and integrate traditional farming practices by providing opportunities for the next generation of farmers looking to utilize novel farming systems to achieve more sustainable livelihoods and participate in this urban geographic transition. This type of breakthrough will also have consequential impacts on other sectors such as architecture, construction, and transportation given the infrastructure developed to facilitate its implementation. This would change access to fresh food in the urban environment, shorten supply chains, diversify the base of production, reduce reliance on a few industrial agriculture players, introduce more innovation into the agri-food system, and produce new types of jobs.

IMPACT & AUDACITY



INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Unleashing Local Knowledge	Extending Food Lifetimes
True Cost of Food	Alternative and Novel Proteins at Scale
Actionable Food Experiences	

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- Breakthrough technologies might reduce dependency on traditional farmers operating in rural areas, leading to increased impoverishment in and migration from these areas.
- Large institutions' increased investment in the means of food production might create vertically-integrated systems that might put smaller actors (restaurants, growers) out of business.
- Efficiency gains, such as through automation and the use of robots, might lead to a reduced need for agricultural producers and workers, resulting in fewer employment opportunities in the sector.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Novel Farming Systems:** Production systems that are not dependent on vast amounts of land for nutritious foods and livestock feed and can fit in a dense urban setting, such as vertical farming, aquaculture, lab-grown meat, insect farming, and cultured algae.
- **Automation:** Certain aspects of farm work such as harvesting and sorting produce could be automated, potentially leading to great gains in productivity, reductions in labor costs and cutbacks on the time of traditional harvesting methods. Automation could also benefit the transportation infrastructure needed to create these food hubs, such as through autonomous vehicles or drones.
- **Virtual Marketplaces:** Platforms to connect food producers with consumers and equip the former with means of negotiation and the latter with more visibility to food production practices.
- **3D Printing and Additive Manufacturing:** 3D printing machines capable of mass manufacturing edible, intricate food ingredients that come together to create unique flavors and textures of food.

PATHWAYS FOR IMPACT

- Innovations in renewable energy, including battery technology, that reduce the energy burden of urban food production.
- Incentives for big consumer hubs in urban and per-urban settings such as government organizations, education facilities, airports, and private companies to fulfill their nutrition needs through models that empower local economies and sustain the environment.
- Just transition for traditional farmers into these novel production hubs or other livelihood opportunities.

Source: https://africafeeds.com/2019/06/17/the-science-kit-making-stem-subjects-appealing-in-africa/

BREAKTHROUGH 07

Unleashing Local Knowledge: Enabling Small and Medium Enterprise Innovation

Accelerating the creation, scale, and efficacy of enabling environments that unleash small and medium-sized enterprises' (SMEs') potential, focused on strengthening access to assets, markets, and investment - especially among women - to encourage and de-risk grassroots value chain innovation.

1

PRIMARY CHALLENGES

Incentivizing the Production of Healthier Crops

Enhancing Livelihoods of Smaller-Scale Family Farms

Optimizing Fair Economic Opportunities Along the Food Chain

2

SECONDARY CHALLENGES

Addressing Soil Degradation and Erosion

Reversing Ground and Surface Water Depletion and Pollution

Reducing Biodiversity Loss

Radically Decreasing Greenhouse Gas Emissions

Curtailing and Repurposing Food Loss and Waste

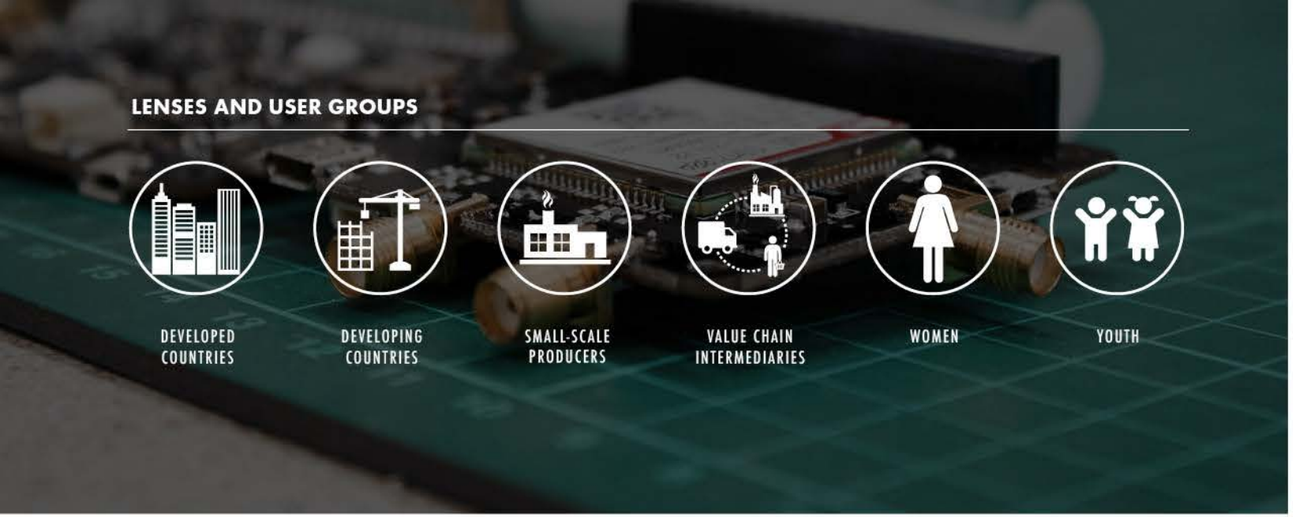
NEED AND POTENTIAL IMPACT

One of the biggest challenges facing millions of poor farmers and small-scale food producers in marginalized areas of developing countries is their inability to access or participate in markets or adapt to market fluctuations. They are forced to compete with large-scale producers and operate under economic regulations that usually exclude them. These farmers and producers possess tremendous knowledge about farming practices for diverse crops and market dynamics that oftentimes sit fallow given the barriers they face to turning these insights into market-changing innovations and competitive advantage.

Residents in developing countries have always engaged in "frugal" innovation to improvise solutions in resource-constrained environments (in India it is common enough to have its own name, *jugaad* innovation)[385], and corporations have increasingly identified this mindset as a vehicle for developing solutions at a global level.[386,387] However, there is a "missing middle" where local innovators are constrained from developing solutions at scale, attracting investment between pre-seed and Series C stages, and leveraging the power of modern technology.

Imagine an enabling environment for technological development, inclusive economic models, transparency, and governance that ensures that small-scale food producers, processors, distributors, and retailers can invest in their own farms and businesses and unlock the power of their insight and experience. This breakthrough aims to ensure access to resources, machinery, data, and innovative technology in a low risk, supportive economic environment to incentivize small-scale producers and value chain intermediaries to experiment and innovate without fear of exploitation or unfair competition. Transforming the agriculture economic model and enabling local solutions to local challenges allows for grassroot innovation to flourish, contributes to lifting food producers out of poverty, and optimizes value chain efficiency and relevance to local contexts. Women, who traditionally face unequal access to resources such as land, inputs, machinery, finance, and technical training in comparison to their male counterparts, will have new opportunities for inclusion. In particular, new platforms for sharing ideas, data, and examples across geographic contexts – adapted to appropriate technological, sociological, and linguistic context – could meaningfully close information gaps.

IMPACT & AUDACITY



INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Food System Data Trust	Land Use Revolution
Renewable Energy for All	Accessible Precision Agriculture
	Extending Food Lifetimes
	Alternative and Novel Proteins at Scale
	Food as Medicine
	Actionable Food Experiences

TRADE-OFFS AND UNINTENDED CONSEQUENCES

» Adoption of novel models and equipment might increase farmers' dependency on service providers and manufacturers, who might be able to set disadvantageous terms.

» Adoption of new equipment might increase the cost of production due to maintenance and other needs.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

» **Innovative Financing Models:** Redefining economic identities of food producers that are usually 'unbanked' or operate outside of global economies. From micro-lenders utilizing smartphone technology to using blockchain to connect food producers' assets such as land to economic opportunities including crop insurance and soil management.

» **Incubators and Makerspaces**: Much innovation emerges from interactions in spaces designed for creativity, prototyping, informal network-building, and practical support for entrepreneurs. Such spaces are already popular in many developed countries and are springing up quickly across the developing world; their increased scale-up, including in low-income countries and rural environments, will meaningfully support this breakthrough.

» **Processing and Packaging Technologies:** On farm processing and packaging equipment can increase profits via value addition while cutting food loss and exploitation of primary producers by intermediaries.

» **Innovative Machinery Models:** New models similar to 'ride sharing' that allow food producers to share the use of machinery and increase efficiencies from farm to retail throughout the value chain. Further, the innovation process for existing machinery could be opened such that it was practical and legal for anyone to build, repair or alter machines to fit their needs.

» **Inclusive Business Models:** Multi-national corporations are increasingly looking to deliver goods and services via existing developing country networks and to co-create new products and business models in conjunction with local stakeholders who best understand their local context and its market opportunities.

PATHWAYS FOR IMPACT

» Reliable connected or off-grid renewable energy sources will be necessary, particularly in rural areas with no electricity infrastructure.

» Extended rural physical and internet infrastructure ensuring increased access to markets and resources.

» Significant investment in training for small-scale food chain innovators by public and private sectors.

» Deep engagement with local communities, leveraging human-centered design principles, by public and private actors to support and foster the innovation process and provide pathways for scaling.

"Minds at the margins are not marginal minds."

ANIL GUPTA, FOUNDER OF THE HONEY BEE NETWORK

Source: https://pressfrom.info/us/news/offbeat/-214269-fertilize-by-drone-till-by-text-making-tech-work-for-africa-s-farmers.html

BREAKTHROUGH 08

Extending Food Lifetimes

Novel, affordable, and accessible methods to dramatically extend the life of fresh food by monitoring crop and food quality, reducing spoilage along the value chain, and educating consumers on usage options, while preserving food's nutrition value, freshness, safety, taste, and texture.

1

PRIMARY CHALLENGES

Increasing the Consumption of Healthy Diets
Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts
Improving Food Literacy
Incentivizing the Production of Healthier Crops
Enhancing Livelihoods of Smaller-Scale Family Farms
Optimizing Fair Economic Opportunities Along the Food Chain
Radically Decreasing Greenhouse Gas Emissions
Curtailing and Repurposing Food Loss and Waste

NEED AND POTENTIAL IMPACT

The limited life of perishable foods contributes both to their high prices and to significant loss and waste. This represents a vast loss of the resources embodied in such foods – water, greenhouse gas emissions, labor, investment – and lowers the physical and economic access to them among consumers. Yet there are technologies and innovations that could be better utilized ranging from simple preservation techniques in post-harvest handling; to new transportation platforms to serve last-mile communities; to off-grid cold chain solutions; to packaging innovations that reduce spoilage; to appliances, recipes and AI-enabled nudges that support consumers' ability to use food while it is good. Some of these technologies are available, but need significant scale; others, like food coatings on vegetables to extend their shelf life, are more nascent.

Imagine easily accessible and affordable innovations that allow consumers to assess the freshness and nutritional value of fresh food, and producers to significantly extend the shelf life of their excess harvest and reduce its spoilage, as well as diminish the impact or shorten the time between harvest and consumption. Farmers and food producers are encouraged to produce healthier and more nutritious products because it will last longer and limit food losses at production and post-harvest. Consequently, this reduces fresh food prices, extends geographical access, and makes them more appealing and affordable, especially to lower-income households. At the retail and consumption end, grocery stores are able to assess their stocks to determine what to sell first and at what price, while consumers have the ability to determine which food in the fridge will last the longest and which is the most nutritious, which drastically reduces post-purchase food waste.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Renewable Energy for All	Land Use Revolution
Unleashing Local Knowledge	Food as Medicine
Actionable Food Experiences	

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- Using any form of novel packaging might create food safety issues.
- Breakthrough technologies might re-enforce misperceptions of 'perfect produce' that fits high and unrealistic market standards not only in terms of shape (on the outside) but also in terms of chemical composition (on the inside).

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Innovative Coating and Packaging:** Utilizing nanotechnology, next generation biosensors, synthetic biology, and edible coating technologies to hinder the respiratory process in food, prevent microbial attacks, radically reduce food spoilage, and inhibit the processes responsible for aging.
- **Hyperspectral Imaging:** The ability to non-invasively 'see' the chemical composition of crops, livestock, and food products at all phases of the food value chain from production to consumption in order to visually determine the quality and characteristics of crops and food products.
- **Internet of Things (IoT):** IoT system to analyze food product attributes such as product ingredients and lifespan data, track point of origin and real time inventory locations, days until expiry and others.
- **Low-Cost and Accessible Uninterrupted Cold Chains:** Advances in technologies allowing for affordable uninterrupted temperature-controlled supply chains and refrigerated vehicles to increase access to markets for primary producers living in rural and peri-urban areas who have no access to electricity or energy.
- **Automated Delivery Systems:** Automated rapid delivery systems that can deliver food items quickly and securely, directly to the destination, without having to go through centralized distribution or retail centers.

PATHWAYS FOR IMPACT

- Fresh food spoilage assessment and shelf-life extension technologies must not produce waste or damage the environment.
- An approved decentralized system for food safety assessments that could be carried out at local and individual levels.

BREAKTHROUGH 09

Alternative and Novel Proteins at Scale

An unprecedented scale-up in consumption of protein sources that are not drawn from wild or farmed animals. This will require significant technological advances in an already-healthy industry, coupled with decreased price points, alongside significant changes in eaters' preferences in diverse contexts – all while maintaining positive health and environmental benefits as compared to animal-based proteins.

1

PRIMARY CHALLENGES

- Increasing the Consumption of Healthy Diets
- Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts
- Incentivizing the Production of Healthier Crops
- Addressing Soil Degradation and Erosion
- Reversing Ground and Surface Water Depletion and Pollution
- Curtailing and Repurposing Food Loss and Waste

2

SECONDARY CHALLENGES

- Improving Food Literacy
- Reducing Biodiversity Loss
- Radically Decreasing Greenhouse Gas Emissions

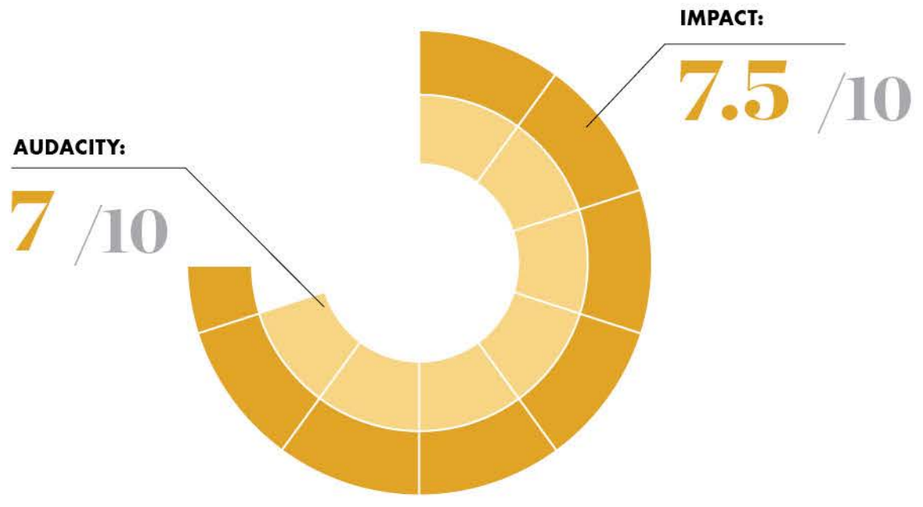
NEED AND POTENTIAL IMPACT

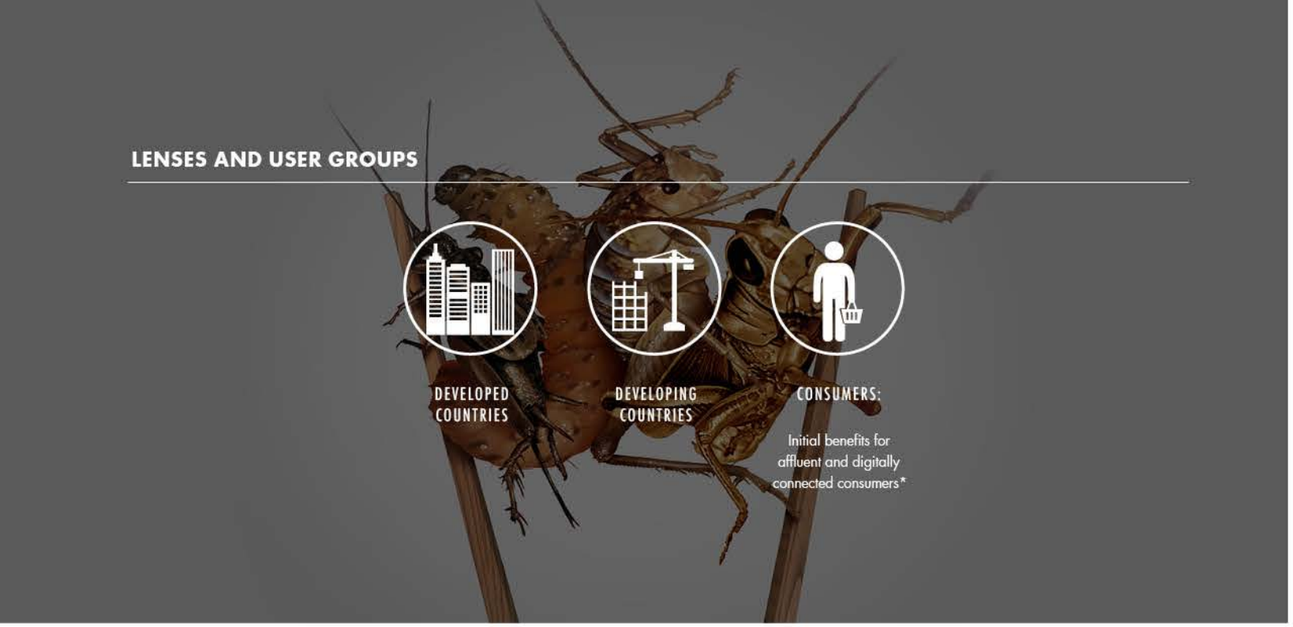
Livestock production represents around 15% of all anthropogenic greenhouse gas emissions;[388] at the same time, by 2050, global meat consumption is expected to increase by 76%[389], or from 41 kg to 52 kg a year per capita in developed countries, and from 30 kg to 44 kg in developing countries.[390]

An emerging industry offering cellular and plant-based proteins has captured the popular imagination and made inroads among investors and a subset of western consumers. The food products' scale potential is unsure, however – whether for cultural reasons, such as among societies that attach deep cultural value to livestock or fish; or for economic and practical reasons, where new technologies have not achieved economies of scale. Yet, if alternative proteins could displace even a fraction of demand for animal-based protein, this would represent a profound environmental reprieve.

Imagine if there are multiple and affordable alternatives to animal proteins that not only can replicate the exact taste and texture of fish, meat, and chicken steak, but are also widely available for consumers all over the world. Alternative or novel protein products have the potential to disrupt a major economic sector and transform our understanding of meat and the entire meat production industry. This breakthrough enables healthier diets given the potential ability to precisely inform the nutritional composition and incorporate supplementary nutrients and fibers to best meet the needs of human health, provided that a person's overall diet is balanced. Furthermore, there is significant potential for reductions in greenhouse gas emissions, especially by transitioning to plant- or insect-based alternatives. And while current estimates of emissions from cultured or lab grown meat suggest only modest reductions compared to traditional livestock, there is a possibility of significant emissions reductions depending on how production of cultured protein is scaled up.[391]

IMPACT & AUDACITY





INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Renewable Energy for All	Ocean and Land Biodiversity Stewardship
Food Production in Urban Networks	Actionable Food Experiences
True Cost of Food	

TRADE-OFFS AND UNINTENDED CONSEQUENCES

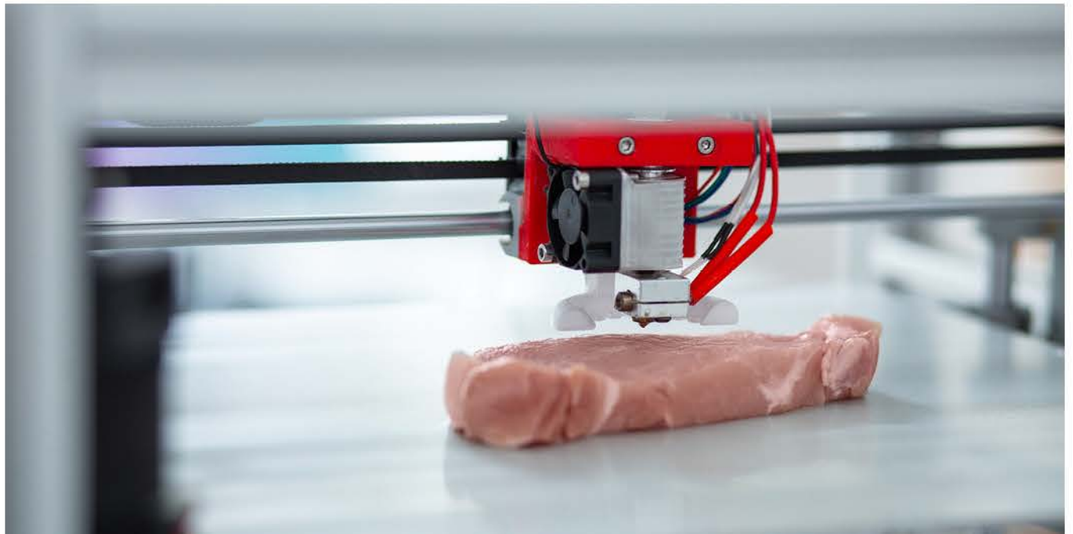
- Alternative proteins might lead to reduced demand for livestock and fish, creating hardship among some of the world's already poor populations whose livelihoods depend on selling such food items.
- Any changes in the availability of animal proteins due to shifts created from the development of alternative sources may complicate efforts to increase animal protein consumption among developing world consumers as a means of addressing malnutrition.
- A shift away from meat of farm animals might negatively affect holistic farming systems that benefit from raising fish and livestock sustainably.
- A reduction in traditional meat production might negatively affect the large feedstock industry and those employed in it.
- Some alternative proteins might have negative health impacts. For example, spirulina algae and some insect flours are high in salt content and could increase cholesterol levels if increasingly consumed at scale, and highly processed food products, even if plant-based, may divert from diets rich in whole foods.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Lab-Grown Meat:** Also called cell-based or cultured meat, this technology aims to grow meat in a laboratory with minimal involvement of living animals. Advances in stem-cell technology, synthetic biology, and biochemical engineering could enable developing lab-grown muscle structure to produce filets of beef, chicken, and fish, matching the original texture and taste of these meats.
- **Plant-Based Proteins:** Innovative and novel formulas combining plant sources such as pea protein, soy, mycoprotein, mung bean, lupin, and algae to replicate the texture, flavor, and color of animal proteins.
- **Insect Farming:** Some insects could be cultivated in substantial amounts at minimal energy and feed costs. They could be used as a source of nutrition either as a substitute animal feed, or for direct consumption by humans either in their original form or as a powder.
- **Carbon Sequestration by Algae and Bacteria:** Carbon dioxide can be sequestered from the atmosphere by algae or bacteria raised in large bioreactors. The carbon is turned into fatty acids, sugars, and proteins by the micro-organisms – and those can later be harvested and used for food.

PATHWAYS FOR IMPACT

- Alternative proteins should have the same or more desirable taste and texture to standard animal-based proteins to reshape demand for alternative proteins.
- Companies, nonprofits, and other entities promoting the shift towards alternative proteins should adopt narratives that highlight the good health and environmental effects and increase popularity of these products across multiple cultures and geographies.



BREAKTHROUGH 10

Food as Medicine

A comprehensive shift in our understanding and use of food as a cornerstone of human health, utilizing technological advances such as in personalized nutrition, human genetics, and the gut microbiome to optimize nutrition, manage consumption, and inform medical decisions.

1 **PRIMARY CHALLENGES**

Increasing the Consumption of Healthy Diets

Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts

Improving Food Literacy

Curtailing and Repurposing Food Loss and Waste

2 **SECONDARY CHALLENGES**

Incentivizing the Production of Healthier Crops

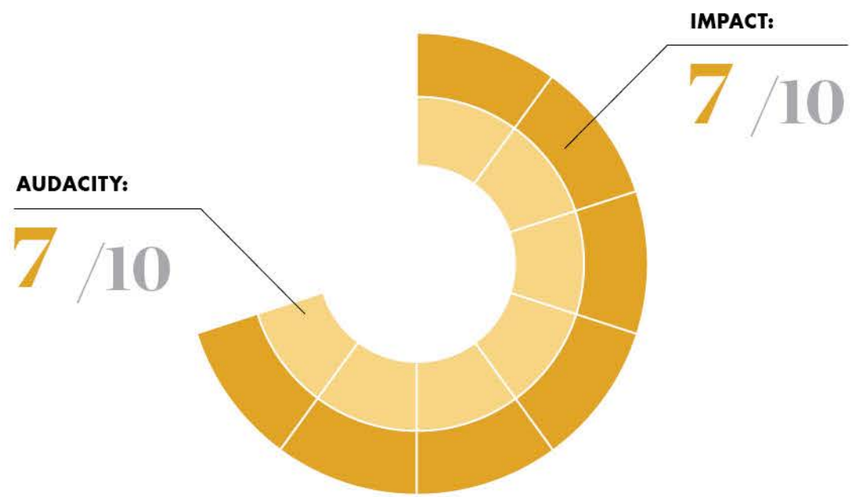
NEED AND POTENTIAL IMPACT

The food we eat interacts with complex systems throughout the human body, including the gut microbiome and our genetic make-up, and such interactions play a key role in many diseases and their comorbidities. While we directionally understand many of these relationships, broad generalizations are often incompatible with this complexity; there is no one-size-fits-all solution for every aspect of the relationship between food and human health. For example, one study found that people who avoided gluten without 'needing to' due to a proven intolerance suffered higher risks of heart diseases partially due to low whole grain consumption.[392] Furthermore, processes such as epigenetics mean these relationships can change over time.

Despite our increased understanding of the basic tenets of nutrition – and our increased investigation of nuanced interactions within the body – such awareness scarcely features in our health systems. Capturing this opportunity could improve human health, reducing obesity and undernutrition while lightening the burden on medical providers. Such changes would also have positive effects up the food chain, as farmers are incentivized to grow more high-value, nutritious crops in diversified systems.

Imagine a simple and efficient way to identify and track the relationship between each individual's genetic make-up, their gut microbiome, and their daily food consumption, including its constituent micro and macronutrients. Individuals will have the ability to target their gut microbiome with the right amounts of dietary fiber, grains, sugars, fats, etc. at the right time to enhance their health and reduce diseases, as well as the ability to identify and solve for linkages between micro and macronutrients and their impact on human health. This breakthrough also has the ability to transform the medical field through a shift towards preventative nutrition-based health care rather than reactive curative medical practices, refocusing doctors' training to include the nuances of diet, and shifting the insurance industry to reward preventative health through nutritious choices. It also contributes to drastically advancing research in other fields of science and medicine, and further our understanding of the linkages between the food we consume and the complex human body.

IMPACT & AUDACITY



INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Land Use Revolution	Actionable Food Experiences
Unleashing Local Knowledge	
Alternative and Novel Proteins at Scale	

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- Companies that test and track consumer behavior regarding personalized nutrition might collect an unprecedentedly vast and granular biological dataset without consumers' knowledge or permission.
- Consumers' knowledge of what specific food items their bodies require might lead them to choose less diversified diets, impacting food prices and production.
- Changes in demand based on such insights may have distortionary economic impacts in the short term, such as rising prices for nutrient-rich food or reduced income for some agricultural producers.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Individual Nutrition Tracker:** A micro or nano tracker inside the mouth or gut determining, tracking, and reporting on the exact micro-nutrient content of foods and beverages being consumed.

- **Interactive Food Labels:** The purpose and functionality of food labels is transformed to provide personalized nutritional information. Food labels could potentially interact with the biological and chemical properties of food to self-update as its properties change.
- **Bioinformatics and In Silico Clinical Trials:** Combining biological data and scientific knowledge with randomized control trial practices, data management and analysis, and computer simulation to assess changes in the gut microbiome composition and overall health outcomes based on food consumption.
- **Gene Research:** Linking food consumption with advances and scientific breakthroughs in gene editing, such as CRISPR, can open new possibilities for genomic analysis and manipulation technologies in disease diagnostics and treatment.
- **Preventative Medicine:** Doctors are able to access microbiome and genetic make-up through handheld devices and connected phone applications to learn how to better manage individual consumption and base preventive medical decisions targeted to each individual person's health.

PATHWAYS FOR IMPACT

- A system that addresses privacy concerns and ensures personal health data ownership and control to mitigate any associated risks.
- Microbiome and genetic data should be considered a key aspect in nutrition and be integrated within standard medical practice.
- An approach that pursues technological advances in tandem with social institution reform, such as the adjustment of medical students' curriculum, and business model adjustment, such as refocusing insurance packages on preventative care like good diets.

BREAKTHROUGH 11

True Cost of Food

An open source and universally standardized evaluation framework to monetize the external costs of food systems, translated into adjusted price points, that incentivizes the consumption of "good" food. Costs to be internalized include diet-related health impacts, effects on worker productivity, harsh labor conditions, and environmental degradation and natural resource depletion.

1 PRIMARY CHALLENGES

- Increasing the Consumption of Healthy Diets
- Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts
- Improving Food Literacy
- Incentivizing the Production of Healthier Crops
- Enhancing Livelihoods of Smaller-Scale Family Farms
- Optimizing Fair Economic Opportunities Along the Food Chain
- Curtailing and Repurposing Food Loss and Waste

2 SECONDARY CHALLENGES

- Addressing Soil Degradation and Erosion
- Reversing Ground and Surface Water Depletion and Pollution
- Reducing Biodiversity Loss
- Radically Decreasing Greenhouse Gas Emissions

NEED AND POTENTIAL IMPACT

The cost of food accounts for multiple factors including inputs, wages, and capital costs. However, it does not account for other 'invisible' but key costs arising from diet-related diseases (obesity, diabetes, heart disease), missed work or reduced productivity due to diet related conditions, harsh labor and animal welfare conditions, and environmental degradation and natural resource depletion.[393]

Imagine a universally standardized evaluation framework to measure and monetize these 'externalities' that can generate the 'real' cost of food. The mere knowledge of the true cost of food products can be leveraged to raise public awareness and inspire a transformation from caloric to nutrition-based food systems, actualizing new economic incentives that would materially shift consumption patterns, with health benefits spanning from strengthened child development to reduced obesity. The value of food products that offer good nutrition and positive impact on the environment will be monetized at a more moderate price point than alternatives that failed to meet these metrics; as such, consumers' default will be reset toward healthier food options with lowered environmental footprints. This breakthrough will also create new industries and markets around measuring and communicating the full cost of food globally. Furthermore, implementing mechanisms to actually integrate these external costs into the final commercial cost of food will naturally reshape supply and demand away from more harmful associated practices and toward products representing greater health, inclusive economic opportunity, and environmental stewardship.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Food System Data Trust	Actionable Food Experiences
Ocean and Land Biodiversity Stewardship	
Food as Medicine	

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- Implementing a True Cost of Food framework might suggest raising overall prices for many food items, even those that are healthier and responsibly produced, negatively impacting low-income consumers.
- Consumers that prefer certain convenient, but unhealthy or environmentally unfriendly foods might feel their freedom of choice is being curtailed if true food costs are implemented in the marketplace.
- Efforts to absorb externalities in the price of food may require policy actions that could have distorting effects on markets.
- Food producers and manufacturers in the business of ultra-processed, unhealthy, and or environmentally harmful foods might suffer if demand shifts away from these products.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

- **Political Will for True Cost Accounting:** This breakthrough would build upon existing efforts and frameworks for valuing non-financial forms of capital such as social and environmental assets. Actualizing such frameworks would depend on the skillful use of coordinated policy levers and business commitments, necessitating leadership and collaboration among influential governments and private sector actors.
- **Next Generation Sensors:** Widely available non-invasive sensors to monitor environmental, labor, and health costs of interest. Examples include: on-ground sensors or aerial satellites to measure soil and plant health, greenhouse gas emissions, water usage, biodiversity loss; wearables and in-body sensors to monitor nutrition, diet related diseases; and electronic and biometric identification (retinal scans, muzzle patterns in cattle, immunological labeling and DNA analysis) to monitor farming and manufacturing practices.
- **Traceability Technologies:** Product identification technologies such as QR codes, Radio-Frequency Identification (RFID) to track product movements along the value chain using smart labels and tags, genetic tracking methods, and Near Infrared (NIR) spectroscopy for food and crop quality control.
- **Blockchain:** A transparent ledger could be used to ensure accuracy and accountability of measuring and monitoring costs of interest such as water usage and labor conditions. The blockchain might also be leveraged to prompt desired behavior, such as through a crypto-based micro transaction reward system that incentivizes retail purchases of "better" foods, funded by government or other programs. Artificial Intelligence: Ongoing implementation of machine learning and deep learning techniques can increase and improve the ability to understand food system impacts by uncovering new relationships and data patterns in near real-time.

PATHWAYS FOR IMPACT

- Available, reliable, relevant, and interoperable data collected globally and from all stages along the value chain as well as information on short- and long-term health impacts post-consumption.
- Rebalancing economic incentive structures and a change in the behaviors of those who influence the market to promote the stewardship of non-financial assets.
- The framework, while universally standardized, will need to be flexible and sensitive to different economic and political contexts and inclusive of the needs and limitations of smallholder farmers and less affluent consumers.
- Actual implementation of a transparent, true cost pricing and regulatory systems would require compliance across a range of stakeholders, including companies, governments, and consumers.

BREAKTHROUGH 12

Actionable Food Experiences: Crafting New Food Norms

A range of tools to influence consumers, powered by innovative emerging technologies and behavioral science, to shift consumption toward food choices that are healthier and more environmentally sustainable.

1

PRIMARY CHALLENGES

- Increasing the Consumption of Healthy Diets
- Reducing the Over-Consumption of Foods that Lead to Diet-Related Health Impacts
- Improving Food Literacy

2

SECONDARY CHALLENGES

- Incentivizing the Production of Healthier Crops
- Enhancing Livelihoods of Smaller-Scale Family Farms
- Optimizing Fair Economic Opportunities Along the Food Chain
- Addressing Soil Degradation and Erosion
- Reversing Ground and Surface Water Depletion and Pollution
- Reducing Biodiversity Loss
- Radically Decreasing Greenhouse Gas Emissions
- Curtailing and Repurposing Food Loss and Waste

NEED AND POTENTIAL IMPACT

We are highly influenced by others' fashion choices seen on the street or our Instagram feeds; we are lulled by addictive music and binge-watching experiences; and we are routinely "nudged" toward behaviors like photo sharing. Advances in behavioral science have opened powerful avenues of influence on human behavior; and yet, with exceptions in the food advertising industry, little of this influence has been directed toward crafting healthier, more environmentally sustainable food norms.

At the same time, most consumers lack basic knowledge about the nutritious value of different food products and even less about their environmental footprints. There is also a lack of transparency about the sources, quality, and freshness of various food ingredients, compounded by the difficulty of interpreting food labels and expiry dates. Even when this information is available, it is rarely integrated in an actionable manner allowing consumers to adjust their consumption choices in real-time. Instead, consumers suffer from analysis paralysis and are often confused about the right mechanism to weigh certain product characteristics.

Imagine a range of smart, behavior-focused influences designed to shift consumer demand by transforming our relationship with food choices. A transformed and transformative consumer experience at points of sale, created by virtual and augmented reality, offer stories and actionable intelligence about the food's producers, its journey from farm to table, its impact on the environment, and its nutritional value. Badges or other signifiers on social media share our "food scores" with others, prompting us to compare and compete. Restaurants have 'smart' menus while online grocery stores and food purchasing applications are all equipped with an AI integrated 'expert' that recommends which foods to purchase, their sustainability scores, and their health impacts all based on a transparent algorithm that represents the consumer's selected priorities and is not manipulated by those in industry. This breakthrough contributes to transforming consumer behavior and people's relationship with food, significantly improving food literacy, and perpetuating large-scale shifts in the nature of demand, thus incentivizing the production of healthier and more environmentally friendly crops.

IMPACT & AUDACITY

INTERACTIONS WITH OTHER BREAKTHROUGHS:

ENABLED BY:	SUPPORTIVE OF:
Accessible Precision Agriculture	Food as Medicine
Food Production in Urban Networks	
Unleashing Local Knowledge	
True Cost of Food	

TRADE-OFFS AND UNINTENDED CONSEQUENCES

- Entities designing the algorithms recommending certain foods, quantifying "food scores" or creating AR/VR experiences might influence consumption to advance their agendas rather than for the consumers' good.
- Without a commonly-agreed framework for what "good" food constitutes – such as is proposed in the True Cost of Food breakthrough – this definition would be open to interpretation and manipulation, creating confusion and diluting the impact of consumer influence efforts.
- Producers of less healthy or ultra-processed food might suffer if healthy food consumption is made more desirable and convenient.

RELEVANT TECHNOLOGIES AND POTENTIAL INNOVATIONS

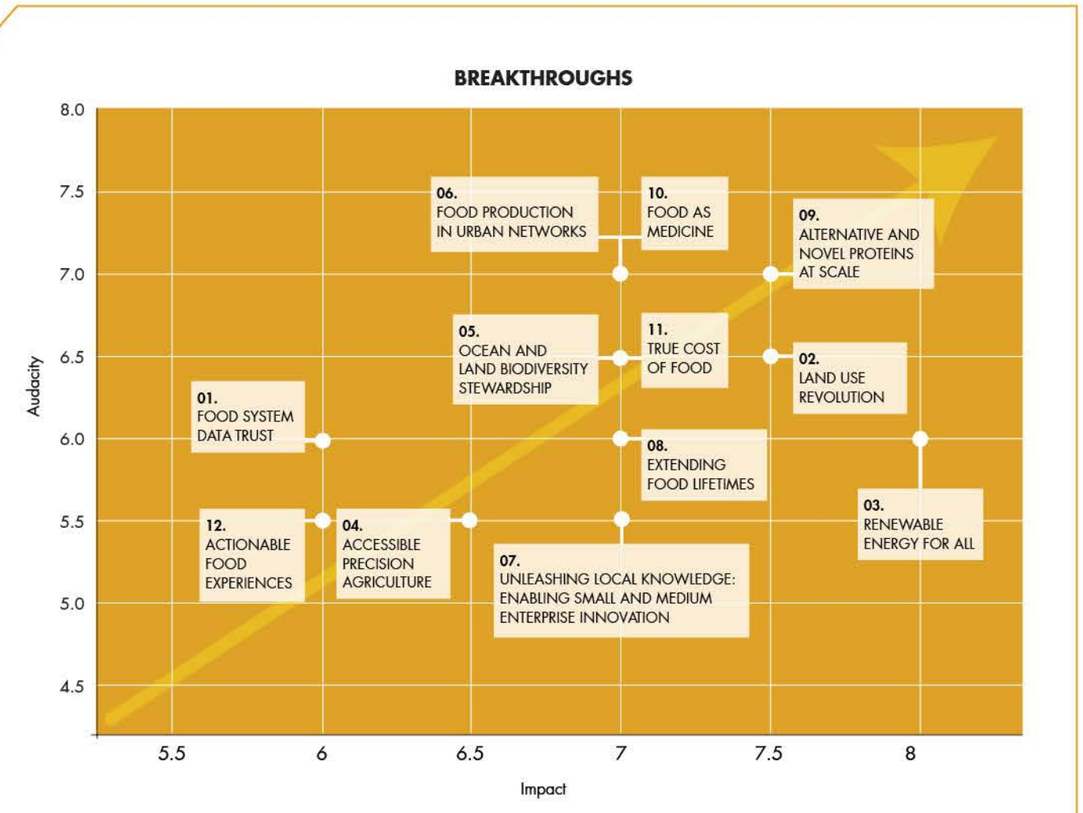
- **Interactive Food Labels:** The purpose and functionality of food labels is transformed to provide personalized nutritional information and educate consumers on food's environmental impacts. Food labels could potentially interact with the biological and chemical properties of food to self-update as these properties change.
- **Food Traceability and Label Scanners:** Scanning a code on the package to access information about the producing community responsible for the harvest, livestock or fishery, certifications, the journey of the food across the value chain, sustainability, freshness, and safety of the food.
- **Virtual Consumption:** Augmented and Virtual Reality (AR/VR) technologies can be used to create a more holistic food experience and offer personalized and optimized food consumption experience through sensory stimulations that take the consumer on an educational experience of their food's journey from farm-to-table to increase food literacy.
- **Gamification:** The agri-food sector can benefit enormously from learning and applying game-design elements and principles to the question of food choices.
- **Nudging and Behavioral Economics:** 'Nudging' techniques are already used in the food industry, such as through advertising products and in supermarkets, to focus attention on higher-margin products. As our understanding of human psychology and sociology increases, behavioral economics can be combined with artificial intelligence, big data, and social media platforms for significantly scaled influence on social norms and resulting choices.
- **Brain-Computer Interfaces:** Advances in brain-computer interfaces could be utilized to influence the way the brain interprets the taste, smell, and other properties of food, and to integrate more seamlessly embedded "food scores" into consumer decision-making. They can also be used to deal with harmful cravings – or to create a yearning for more healthy food.

PATHWAYS FOR IMPACT

- A commonly-respected authority – whether an institution or assessment framework – guides the assessment of "good" food.
- Accountability systems are implemented to ensure that consumers' own priorities, and science-based targets and data rather than certain industries' interests, are used for consumer influence.
- Traceability systems, attached to a commonly agreed framework, that provide coherent and clear nutritional and environmental information on products.

IMPACT AND AUDACITY - CHARTING THE BREAKTHROUGHS

WE CONSULTED A global community of food and agriculture experts to help us assess the potential impact and audacity of each of the breakthroughs we identified as part of this Impact Roadmap. Their ratings are the



07.

IMAGINING THREE FUTURE SCENARIOS

Introduction

EARLIER IN THIS report, we stated that our preferred future of food systems is a time when all people enjoy access to healthy and nutritious food, when food systems are characterized by social and economic equity and equal opportunities and are situated in a thriving natural environment. After analyzing the challenges and grand challenges that stand in the way of that desired future, we identified key breakthroughs necessary to help us overcome these obstacles.

In our analysis of global megatrends, we described the social, technological, economic, environmental, and political megatrends we believe will have a significant impact on global food systems, as well as all aspects of life on Earth, in the coming years and decades. These megatrends will now serve the purpose, based on their potential direction over the coming decades, of helping us draw a picture of different worlds, illustrating future scenarios based on their direction and plausible impacts on our global food systems and humanity more broadly.

Imagining different future scenarios helps to transcend the current reality in which we find ourselves by forcing us to think through the long-term implications of issues and trends identified in the present. By doing so, we hope to accomplish two goals: (1) gain a deeper understanding of the interrelationships, unintended consequences, and potential leverage points that may exist, and (2) convey to the reader a sense of urgency and realism around the challenges identified in this report that their earlier straightforward elaboration may not adequately convey.

In this chapter, we provide descriptions of three scenarios that depict life on Earth in 2050 in the context of global food systems and their impact on humanity and the natural environment. Each scenario begins with an overview of the overall characteristics of the food system in relationship to the sets of goals, outcomes, or grand challenges we have described. Following the overview and highlights, each scenario provides an explanation of how it came to be in light of social, technological, economic, environmental, and political changes or developments. Next, we describe the characteristics of each of the goals, outcomes, or grand challenges faced by food systems.

To further illustrate these scenarios, we provide short stories, or snapshots through which we imagine these futures through the lens of people inhabiting them. These snapshots further serve the purpose of exploring micro-level and everyday interactions, experiences, and aspects of the core issues we have identified, and any potential conflicts and trade-offs that may arise.

The three scenarios we describe consist of a dystopian future, entitled, "Dark Times," a business-as-usual future entitled, "The Paradox of Plenty," and a transformative or utopian future entitled, "A Nourished Planet." These scenarios are not meant to be predictions, projections, or forecasts, but rather, explorations of possible outcomes based on divergent paths for humanity and our global food systems. And as a result, such futures serve to help us visualize certain conditions, and plausible pathways.

Scenario 1: Dark Times

OVERVIEW

IN 2050, THE world is unrecognizable to those who so arrogantly made all sorts of optimistic predictions, forecasts, and projections. Everyone plays the blame game—aggressively shirking responsibility for the three decades of deterioration preceding the collapse that came to be known as, "Dark Times."

Failure to keep global warming 2°C under preindustrial levels accelerates a downward climate spiral that caused global disease outbreaks, extreme weather events, and an unprecedented loss of natural resources. To add fuel to the proverbial fire, almost all land is unproductive, and massive areas around the world, that were once fertile and hotbeds of civilization, are unsuited for human habitation or food production. Global warming causes desertification, extreme temperatures, floods, and depleted nutrients in soil and crops.

In the face of grave environmental and social degradation, one core factor that exacerbates the onset of the Dark Times is the failure of researchers, industry leaders, politicians, and academics, et al., to agree on common goals, and cooperate on the correct course of action to achieve them. Another factor is that in the face of increasing scarcity, biological survival overwhelms social coexistence. In more rural areas of developing countries, human life increasingly becomes "solitary, poor, nasty, brutish, and short."

The new currency of power and wealth is food. With natural resources running out, and technology under tight authoritarian control, food is the most valuable commodity in the world. Food shortages are commonplace, and the nutritional quality of food is so low, humans are feeding themselves into starvation.

The world is divided into two distinct social classes: the haves and have-nots. Real, nutritious food is only accessible by the wealthy, and becomes the singular socio-economic class indicator. In turn, this creates an atmosphere whereby food discrimination is the norm.

Natural ecosystems are in the midst of total collapse due to humanity's unwillingness to protect the environment. And for most, food is seen as any barely edible substance that isn't immediately fatal.

HIGHLIGHTS:

- Global climate change accelerates, and wreaks havoc on many parts of the world, rendering them uninhabitable and infertile.
- Failure to agree and cooperate reduces the effectiveness of human efforts to halt or reverse the damage.
- Technologies and nutritious food are exclusive and protected—serving only the interests of the wealthy.
- Food shortages and minimal nutritional food quality transforms real food into the most coveted commodity in the world and is used as the primary measure of wealth and power.
- The middle class is dead. There are only two distinct classes: the rich and poor—otherwise known as: those who can afford nutritious diets, and those who cannot.
- Due to scarcity, substances that are barely considered food are being consumed.
- In developing countries, rural areas are lawless, and the population of already overcrowded urban centers balloons far beyond capacity.
- Most life forms have disappeared due in part to desertification.

HOW DID WE ARRIVE HERE?

In the three decades leading up to the year 2050, quality of diets moved from bad to worse: the production and consumption of ultra-processed foods containing massive amounts of salt, sugar, and fats—and animal meat and dairy products extracted from natural animals—exploded. There were no serious, multi-stakeholder initiatives created or adopted to curb the direction of human consumption. As a result, there was only one possible, albeit, inevitable outcome.

Failure to keep global warming in check led to extreme temperatures, desertification, resource scarcity, rising sea levels, frequent floods, hurricanes, and tornados in many parts of the world. Irregular harvest seasons, increased food loss, skyrocketing prices, and frequent food shortages wreaked havoc on the populous.

A lack of will or concern, disconcerted efforts, denial of scientific facts, and unsustainable practices collided with an aging population confined in overcrowded urban centers and turned into a recipe for disaster. Rural neglect, primarily in developing countries, led to a mass exodus, further decimating the agricultural sector. In developed countries, masses of unemployed urbanites were forced into various forms of low-paying, insecure jobs created by the gig economy. In the developing world, initial optimism around an abundance of low-cost labor coupled with economic growth gave way to destitution and a failure of many systems and sectors.

Technological progress shifted away from serving the common good to promoting private interests. Due to a mix of protectionism and legislative policies, technologies became concentrated in the hands of a few all-powerful entities. Despite advances in technological innovation and science, only a small, wealthy minority are beneficiaries of said advancements.

In the second quarter of the 21st century, the developed world suffered periods of recession and depression. This led to reduced investment and research in agriculture in the developing

world. And when mixed with the desire to mimic Western economies, the farming and agriculture sector collapsed. As global trade and markets received one blow after another, governments and the private sector elite became less and less interested in sustainability and long-term solutions. Denial and procrastination became the dominant modes of thinking and governing.

The world moved further toward a fragmented existence wrought with conflict and war. In parts of the world where political institutions were relatively young and unconsolidated, the number of failed states grew exponentially creating a socio-political landscape where de facto rulers reigned supreme.

In developed and other high-GDP countries, inequality and declining resources caused the lower classes to surge, instigating an era of severe, concerted economic oppression to begin.

FOOD DISCRIMINATION

The middle class has disappeared. In its wake, a tiny wealthy minority and massive poor majority emerge. Over half of the world's population now suffers from the inevitable health impacts of poor diets. Nutritious, healthy food is scarce, and only accessible to a rich minority. Hunger and undernutrition are common across all societies—and heavily concentrated in the poor majority.

Access to animal-based proteins and fresh produce—such as fruits and vegetables—are the primary indicators of class and social status. For the poor majority, upward mobility is virtually impossible because they are powerless and too malnourished to work their way up.

Poverty and hunger are seen as merely a function of nature's survival-of-the-fittest paradigm. To soothe their consciences, the rich believe poor people are poverty-stricken and hungry because they are stupid and lazy, and as such, deserve their lot in life. Health systems are crippled due to the insurmountable costs instigated by diet-related health diseases. Government services and public sectors are mired in dysfunction, uncompromising red tape, immoral legislation, and corrupt agencies—all serving the will and interests of the upper class.

Food illiteracy helps protect the poor from the mental anguish associated with comparing the food they are eating to the real, healthy food they should be eating.

In wealthier countries, governments distribute inadequate rations to keep just enough people alive to serve as menial laborers. However, in poorer countries the majority of people are forced to fight over the few scraps of food available to them. Unfortunately, the hunting and gathering of wild foods are no longer options as they perished long before 2050 due to human overpopulation and climate change.

AN INDUSTRIAL-FOOD COMPLEX

In many parts of the world, working in the food sector is akin to working in a secret, highly protected military installation. Information on genetically modified seeds and other food technologies are closely guarded intelligence, as food is a high-value national security resource. The entire industry is compartmentalized and prone to covert espionage tactics akin to the military-industrial complex.

The food sector is no longer the vibrant and exciting industry that only two or three decades earlier had attracted much enthusiasm and mobilized innovators to take up many of its challenges. Food sector labor has shrunk tremendously compared to previous decades. Those who own farmland or food manufacturing companies prefer automated machines and robots to human labor. Machines don't need food or steal, and they are far more efficient than the malnourished humans who could be hired to work the fields or in factories.

Similarly, technologies developed and utilized in the food sector—including valuable algorithms, large datasets, sensors, gene-editing techniques, and others, are tightly guarded. The only people allowed near these technologies are select scientists, land and company owners, and their immediate family members and close associates. In this heavily controlled industry, scientists only have one employer, and are unable to leave their jobs alive.

Women increasingly suffer from social, economic, and dietary inequalities, in part a result of fiercer competition among men and women for increasingly scarce resources.

Most rural areas in the developing world resemble ghost towns as people mass-migrated from these areas when soil could no longer support the growth of plants or crops. As urbanization increases, poverty belts expand in concentric circles across cities. The closer one travels to the outer circles, the worse the poverty, hunger, and destitution gets.

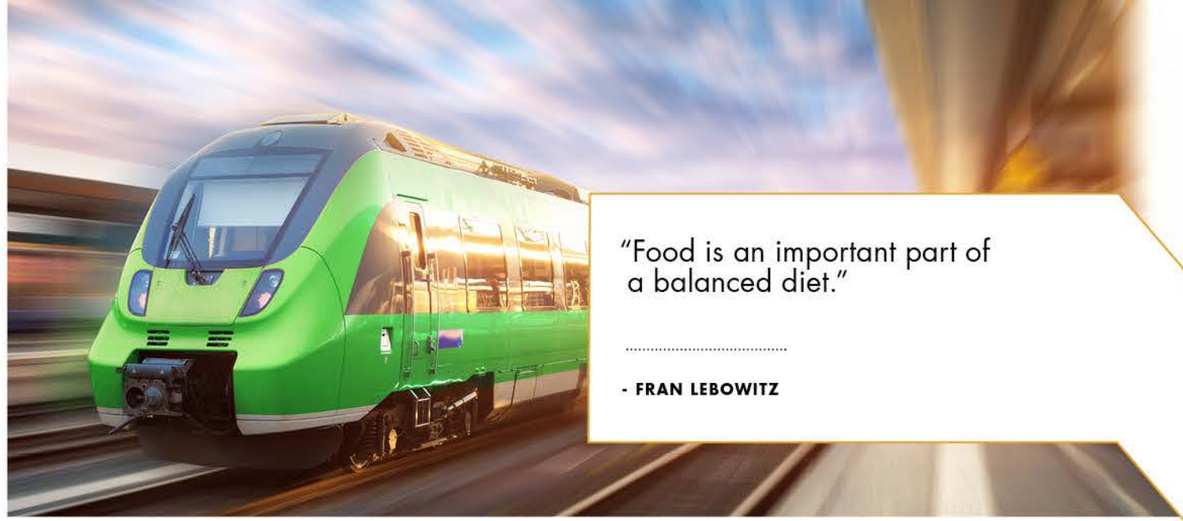
MOURNING THE ENVIRONMENT

Much of what created this world can be explained by humanity's inability to cooperate in order to mitigate the damage to the environment—most of which is a result of global food system practices.

In many parts of the world, soil resembles sand. It is depleted of all nutrients and microorganisms that give it structure and fertility. Lands containing relatively healthy soil were colonized or occupied by states or state-like private corporations long ago. Deserts spread across continents as climate changes continue to increase droughts and produce extreme temperatures, making most areas uninhabitable by humans or large animals.

Water shortages haunt territories previously unconcerned by water stress. Years of drought severely deplete ground and surface water and are often followed by major floods. And, almost all water on earth is contaminated with heavy metals and hazardous chemicals.

The air is polluted with excessive amounts of greenhouse gases produced from human activities. Unchecked fossil fuel use, unhealthy livestock farming, irresponsible waste disposal, and incredible rates of deforestation overheat and pollute the oceans, destroy coral reefs, degrade the soil, and kill off most living things across land, sea, and air. In turn, the environment is set on a path to its inevitable destruction, and nature's self-regenerative mechanisms are unable to stem the tide.



"Food is an important part of a balanced diet."

- FRAN LEBOWITZ

A Story from the Dark Times

THE GREAT TRAIN ROBBERY OF 2050

"Get ready," my father told me harshly. "We're going to get that loot, even if it kills us."

I rolled my eyes. My father sometimes dabbles in melodrama. That particular eye roll garnered a whack on the head, which quickly jogged my memory. That's right, he also dabbles in violence. At least he didn't use the gun butt on me this time.

"Tell me the plan!" he snapped.

"We're going to jump on the train while it passes under the cliff," I said. "Then, we'll locate the train wagon where they're holding it. We'll recognize the right wagon because it's green on the outside and has three guards inside. We'll get rid of the guards. Snatch the loot. And hop off the train before it reaches the city."

"Good," my father nodded. "And why do we do that? I want to hear it from you."

He told me once that before the world went mad, he was a schoolteacher—a principal, actually. I could believe that. He certainly knew how to give a lecture. I had the answer ready by rote.

"We're fighting the war of the little people!," I announced with the fervor of a disenfranchised Hitler Youth. I'd said it more times than I can count by now. "We're stealing from the rich and giving to the poor!"

"And that's everybody today," my father said. "You may not believe it, Tammer, but before you were born, people had farms of their own. They actually worked the fields instead of those damned robots. And the earth… The earth gave back to us. In some fields the corn grew so high it obscured the sky from your view. Miles upon miles of wheat and corn and soybean—"

"And then, the climate changed," I recited under my breath.

"And then, the climate changed," he said solemnly, looking off into the distance, as if reciting for an audience who had never heard this speech before. "Shore cities were flooded. New York City, Mumbai, Osaka. The global economy went haywire. Nobody knew what the heck to do. The weather turned hotter, and the storms kept tearing into us, sometimes in midsummer. Nothing would grow until Agro-Tech came along. It seemed like a good thing, at first. Not so much anymore. Now it's time for us to take back what is ours."

I nodded, and in spite of all my cynicism, could feel my excitement growing. We were doing something important. We were going to help others. And yes, it may have been 2050, and I was just 15 years old, but I knew we were going to change the world today—some small part of it, at least.

So, we did everything according to plan. We jumped the train. Made it to the green wagon. Got rid of the three guards. Only problem was, there were four guards in that wagon, and I never saw him coming. He ended up crushing me against his chest, his gun barrel held tight against my temple. The barrel was cold and hard, and I knew my skin would be bruised tomorrow. I only hoped that would be the worst of it.

PART TWO - THE GREAT TRAIN ROBBERY OF 2050

"Let him go."

My father had his gun pointed towards the lone remaining guard, his eyes narrow, laser focused. The guard crouched down to make better use of my body as a shield.

"Put your gun on the ground and move back," the guard said. I could feel his heartbeat against mine. His arms were thin, and I could see he was suffering from malnutrition. Brittle bones, like the rest of us. "Move back! I'll blow his brains all over this wagon if you don't move back!"

My father didn't budge. His hands did not shake in the least. He kept his gun trained in the same direction – straight at the guard, and coincidentally, at me.

"Let him go, friend," my father said again, no heat in his voice. It was like he was having a friendly chat with our neighbor. Or at least, that's what it would've sounded like if he hadn't hated our neighbors. "Why are you serving them?"

The guard went quiet for a moment.

"Who's them?" he finally asked.

"You know exactly who I'm referring to. The wealthy. The ruling class. The corporations. The ones who control almost every square foot of habitable land. The ones who destroyed the oceans and control every morsel of food on the entire planet. The ones who make us pay every dime we make on just enough rations to distract us from our misery and keep us working like dogs for them. The ones who are killing us all!"

I groaned inwardly. It was the speech. My father was always certain it would work on people. And he was constantly amazed when it didn't.

"Put… The gun… Down," said the man between clenched teeth.

"That is not going to happen," my father told him. "If or when you shoot the kid, I'm going to empty my clip into you. Either you both die, or you both live. I don't want to do it. You don't see it now, but we need you. The revolution needs everyone."

"You're crazy, man!" The gun wavered and shook on my skull. I was starting to get a headache.

"I'm crazy?" my father asked rhetorically. "The world is crazy. Three corporations own every seed in existence and engineer them so they only grow in fields they own. And, if you're caught in possession of a single seed, you are arrested or shot. And the robots… Tens of millions of people are out of work, just to increase revenues, and they receive more benefits than you and me. There's no more wildlife. You can't grow anything. Our children are starving in the streets… What's left? Nothing… We either rise up against all of this, or die."

A school principal, all right. But I guess the charm does work sometimes. The guard licked his lips nervously, parched from the drama and confrontation. "If I let him go, you'll go too? Without hurting anyone else?"

"You have my word, friend. We'll take you to our village. Share our food with you. When's the last time you had a good meal? Not just a protein bag, but an actual meal? Last month? Last year? Things don't have to be like that. We'll take mighty good care of you."

I felt my captor begin to relax his grip on the gun. At that instant, my father shot him right through me.

PART THREE - THE GREAT TRAIN ROBBERY OF 2050

A flash of pain, hot and vivid. I found myself lying on the floor, clutching my shoulder, with my father towering over me.

"You did well," he said. "You stayed relaxed and didn't say a word."

He helped me to my feet and scrutinized me head to toe. "One good thing about being so thin," he noted, "bullets pass right through you."

I collapsed to the ground, failing to appreciate my good luck. "I'll take you back to the village now," he whispered. "You'll be fine."

My father quickly strode over to the now unguarded insulated case in the center of the train car. He opened it and reached in. I saw him put the small sack of precious seeds in his pocket, and then he reached over, picked me up and put me on his back.

We made our exit. The river's surface parted for us as my father jumped off the train with me still on his back. My shoulder stung badly, and I prayed the seed sack was waterproof. With all the heavy metals, oil, and acid in the water, I wasn't sure the seeds would remain viable. My father was optimistic, though.

"We'll plant them," he panted while wading through the stream, "and grow them to maturity. And then, we'll harvest them for more seeds. They aren't locked for use like the useless grains Agro-Tech sells us. You took a bullet for the cause, Tammer. I won't forget that. It was worth it. Eventually, we'll win this war, and we'll get our power back. It's just a matter of time."

Then he chuckled and laughed to himself. I was fading out by then, but could still hear his last words.

"If someone told me thirty years ago I'd be a damn revolutionary, fighting against evil corporate overlords, I never would've believed you. But that was then, and this…" he sighed, "this is…"

Scenario 2: The Paradox of Plenty

OVERVIEW

IN 2050, PEOPLE around the world face a food paradox. While more than enough food is produced to exceed global calorie needs, that which is accessible to most people has limited diversity and nutritional value. The number of people suffering from hunger is falling due to advances in science, but undernutrition, overweight and obesity are on the rise, and in turn, so are the related health and economic costs incurred.

In many parts of the world, the increased awareness of healthy, environmentally sustainable diets only improves food literacy among the well off—those who can afford healthier diets. This is due to a variety of factors, such as misaligned policies that fail to encourage the production of diverse and nutrient-dense crops—thereby making them inaccessible to most people. In the developing world, urbanization, rising incomes, and a growing middle class increase the consumption of meat and dairy, which have positive health benefits for those who can afford it, but cause further environmental degradation due to the significant negative impact of raising livestock combined with low acceptance of more sustainable alternatives.

Technological advances and breakthroughs improve overall productivity and efficiency of food systems, but not in ways optimal to nutritious diets, improved livelihoods, and long-term environmental sustainability. In the developing world, diffusion of low-cost technologies and foreign investments encourage a vibrant entrepreneurial environment that is able to absorb many of the unemployed—many of whom were forced out of small-scale farming resulting from unchecked industry consolidation.

Science helps limit the ecological footprint of global food systems, but negative impacts continue to be externalized to both the healthcare and environmental sectors. Additionally, climate change continues to challenge farming operations in many parts of the world, while also negatively affecting overall food security.

HIGHLIGHTS:

- Technology advancements allow humans to improve productivity and availability of food, thereby reducing hunger, but at high health and economic costs.
- Misaligned policies and inconsistent stakeholder cooperation across food systems make the improvement of human health, economic equity, and long-term environmental sustainability.
- Convenience and price continue to drive consumer preferences, globally. Most consume inexpensive, convenient food that has low nutritional quality.
- Increased demand for animal protein is met with a mix of strategies including plant-based and other alternatives, lab-grown meat, and lab-produced dairy products.
- Globalization of markets and increased consolidation empower large manufacturers to gain influence and market share in developing countries.
- Smallholder commercial farming operations are either swallowed up by food and agriculture conglomerates, merge with other operations to create larger entities, or manage to succeed in limited areas by serving a demand for niche products or leveraging technologies.
- Science helped slow the rate of environmental degradation, but food systems continue to mistreat the environment at an increasing rate.
- Economic motives lead to the reduction of food loss and waste.

HOW DID WE ARRIVE HERE?

In the decades leading up to 2050, massive urbanization created megacities and other major urban centers, resulting in about 70% of the world's 10 billion people residing in urban areas. Migration increased due to the adverse effects of climate change, internal political conflicts, and limited economic opportunities. Rural outmigration was one of the most pronounced forms of migration, and it was both the outcome and cause of changes in food systems—especially in developing countries.

Humans realized major technological advancements, as artificial intelligence, coupled with innovations in the areas of big data and the Internet of Things, generated fascinating insights into biological, psychological, and natural processes. Bioengineering excelled thanks to advances in genetic engineering and nano-robots, which enabled people to manipulate biological and physical entities more easily. Food systems benefitted from technological innovation via increased productivity and efficiency, but not necessarily in ways sufficient to address the challenges of human nutrition, economic equity, or the environment.

Despite dizzying ebbs and flows, economic growth was insufficient. It did not completely eradicate poverty, but it did decrease the overall amount. However, wage gaps exacerbated intra-country economic and social inequality. While international trade grew, it also experienced phases and reversals, due in part to politics and tariffs pushing and pulling economies in different

directions. In developing countries, further industrialization, and insufficient investments in rural development and agriculture, led to large-scale structural changes in employment, shifting from agriculture to services and other economic sectors. Due to mechanization along most of the supply chain, labor shifted from working farmlands to working in hospitality and retail operations.

Climate change continued to adversely affect all aspects of life despite successful efforts to limit the impact of human-induced factors. Rising sea levels displaced dozens of coastal towns, droughts contributed to desertification in some areas, and extreme temperatures made it impossible to grow many types of crops outdoors. While humans were able to fulfill the additional demand for energy stemming from growing populations by utilizing renewable sources, fossil fuels remained one of the major sources of energy.

Politically, a multipolar world required an ongoing and delicate act of balancing international superpowers. This caused global governance and international cooperation to suffer as disagreements between these powers became more entrenched. While the gender gap continued to close, only those who were able to best adapt to economic and technological changes, benefitted.

NUTRITION DEFICIT

Globally, food security and overall availability of protein-rich diets improves. Additionally, the number of hungry, stunted, and wasted children declines. But heavily processed food of low nutritional quality is the most accessible, affordable, and convenient. It is food that can be mass-produced, and the core ingredients are supplied by a small number of crop species and breeds. However, healthier fresh and processed food items are expensive and difficult to acquire.

Access to fresh produce, such as fruits and vegetables, has declined. Global warming and extreme temperatures limit the growth of most items, as only a limited number of areas in the world can support fresh produce. And unfortunately, indoor, high-tech farming, cannot produce fresh items in mass volumes nor and replicate the nutritional richness and diversity of traditionally grown produce.

Science and technological advances offer viable alternatives to animal-based proteins. To the larger middle classes in the developing world, these only became affordable in the past decade. However, misperceptions of genetically modified crops deter many from consuming unnatural, lab-grown meats and insect-based alternatives. While the taste and texture of plant-based alternatives improved, the demand for meat and dairy sourced from farm animals continues to increase. People disagree about the nature of food, and if artificially and naturally produced crops are equal in terms of their effect on human biology.

Food literacy mirrors the paradoxical situation of food availability and malnutrition. While theoretical knowledge or awareness of what constitutes healthy and nutritious foods increases, globally, the cost of purchasing fresh ingredients, and time spent cooking, are outweighed by the benefits of consuming cheap, convenient food. Specialized and healthier diets, such as flexitarianism or semi-vegetarianism, continue to be adopted by the educated and affluent while healthy dietary options among the poor and uneducated steadily decline.

Poor diets are the leading cause of death, and people continue to experience a low quality of life despite achievements in technology, science, and medicine. However, the poor, needy, and vulnerable, who are unable to afford adequate health care or expensive, healthy diets, continue to suffer.

FOOD FOR MONEY

Food system practices do not support or improve livelihoods for the majority of the billions working in the sector. Further concentration and consolidation at the top create a powerful oligopoly that penetrates all markets. This exacerbates local inequity—particularly in areas where social responsibility and transparency are lacking.

In the developing world, a thriving food middle-sector has emerged—albeit one that is highly disorganized suffers from low-pay and poor labor conditions, and has trouble achieving minimum standards.

Small commercial farming has survived in areas with a demand for niche products, and where the natural environment allows for these products to be grown aided by specific technologies. Most commercial smallholder farmers in developing countries still require supplementary sources of income to maintain minimum acceptable livelihoods. Some of this stems from the choice to grow fuel biomass instead of food, which in turn, reduces the amount of land available to grow food.

Instead of adopting policies and aiding smallholder farmers, governments of developing countries opt instead to encourage rural out-migration to diffuse accumulated tensions from decades of little to no investment in rural areas. Controlling urban and peri-urban areas is far easier and efficient than maintaining a tight rein on dispersed farms and rural peasantry spread out over vast territories.

THE ENVIRONMENT AS AN EXTERNALITY

Short-term benefits trump environmental sustainability and well-being. While major manufacturers continue to improve their social responsibility practices, critical information access remains difficult, and universally agreed upon metrics have yet to be ratified.

Although humans have limited their environmental impact, these efforts remain dispersed and uncoordinated. Thanks to genetic engineering and high-tech agriculture, the pace of soil degradation and land expansion has declined, and soilless agriculture has thrived. Plants are genetically engineered to gain an optimal foothold in the ground—thus, inhibiting soil erosion, and allowing them to subsist on a wide variety of nutrients.

Similarly, technology is instrumental in the search for solutions to water shortage issues. However, wealthy countries can afford technologies and practices that do not deplete or pollute ground and surface water, allow for the efficient modification of crops and tools designed to optimize water usage, and improve water recycling. The problem is that these technologies are not made available across supply chains. Therefore, a divide widens between those who can afford it and those who cannot.

Humans manage to reduce greenhouse gas emissions resulting from enteric fermentation thanks to advances in science and technology. Demand for animal-based protein has skyrocketed in line with the rate of economic growth and bulging middle classes. But, the development of viable protein alternatives, and improved practices, make industrial animal production more sustainable.

Due to economic forces, food loss and waste decline to minimal levels. While decreasing food loss actually increases the cost of production, food waste has grown into a large industry in its own right, which includes not only recycling, but also some recycled food waste for human consumption, animal feed, and fuel biomass.

"After a good dinner one can forgive anybody, even one's own relatives."

- OSCAR WILDE

A Story from the Paradox of Plenty

A PREPAC STORY

"You are going to talk with my son, Tammer," the food executive said, "and make him cut out this nonsense."

I sat up straight. It's not every day I get a visit from a top executive at one of the largest corporations in the country.

"Please tell me more," I requested. "What do you need me to take care of, exactly?"

He rolled his eyes. "I don't have time for this. You talk with him. It's your job to find out. You're the shrink here. Use your psycho-babble voodoo on him or something. He'll probably spill everything the moment he comes through the door. He… he doesn't do that with me any longer."

I crossed my legs. "Can you at least give me some direction, sir? What do you want me to achieve with him?"

He considered the question for a few seconds, then gave an impatient sigh, and started pacing around the room.

"You know about PrePacs, right?" His tone indicated that a negative answer would not be well accepted.

"Yes, of course," I told him. Everybody knew about PrePacs. "I love having one every morning."

I didn't, really, but a little white lie to the wealthy never hurt me, thus far.

He ignored my remark.

"I invented them," he said curtly. "Years ago."

Wealthy indeed. I let my eyes widen a little as though I was a bit amazed. He didn't pay any attention to me, though.

"Everybody told me it would be a mistake," he growled. "The dietitians said the PrePacs had too much sugar in them, too much fat. But, I knew that was what people really wanted. And look where we are today: almost everyone has at least one PrePac a day. We have PrePacs for carnivores, for vegetarians, vegans, you name it. Hell, we even have PrePacs for babies—"

"And they all taste great!" I jumped in. "No matter what those scientists say. Why, I'd love for you to tell me more about— "

"Scientists," he snorted. "Damn turncoats. All they did was spout on and on about how people are going hungry. How the poor can't afford to eat. Then, I solve the problem, and now they're crawling all over themselves to bash me by saying they're addictive and unhealthy because of the sugar and whatever else. Screw 'em. They're all funded by my competitors, obviously. Truth is, because of my PrePacs, even the poorest beggar on the street can still feed himself."

"Yes, yes." I agreed with him. But then, I remembered why he was here in the first place. "I bet Tammer loves them too."

"Tammer." His face contorted in frustration. "Nobody goes hungry, except for Tammer. And you're going to get him to eat."

PART TWO - A PREPAC STORY

For a boy whose father invented PrePacs, Tammer was awfully skinny. He didn't look like he came from money, either. In fact, he just looked like a normal good kid. Big brown eyes. Earnest expression. Like his father, he didn't waste time after entering my office.

"I know why my father sent me to see you," he said without preamble. "I'm not going to do it."

I raised my eyebrows. "Do what?"

"Stop my hunger strike," he said. "I'm not eating anything until he gets rid of the PrePacs. Takes them off the shelves. Admits the scientists are right, and denounces them publicly."

I held my tongue. Young people never seem to do well with long periods of silence.

"Those things are an abomination," he went on heatedly. "Have you seen what they do to people? You can see how fat everyone is getting, yeah? It's 2050 and we beat world hunger. Yay for us. So instead of hunger killing us, obesity is. Just look at the statistics. Half of all humans are obese. Half of them are morbidly obese and get the wonderful pleasure of dying from heart diseases, diabetes, asthma, cancer! And you know what's worse?"

I kept quiet. He leaned forward with a feverish look in his eyes.

"It's not the bourgeois peeps like you or me or my father with deep pockets overflowing with Benjamins. It's the bottom 90 percent who literally have nothing."

I twitched at that. I'm well off, at most. But the kid didn't stop there. "It's the ones who can't afford fresh food, and don't have time to cook a healthy meal because they're working two or three jobs to keep the lights on. Or they have to run around doing anything my father and his buddies tell them to do. And they have no clue they're committing suicide by PrePac."

I twitched again. Okay, yeah… Maybe I have a spare tire or three, a little more fat under the chin than I would like, but that's not such a bad thing, is it? It seemed awfully important to Tammer, though. That was a lever I could pull. I reclined back in my seat, and steepled my hands in front of my face.

"I hear you," I said. "And I understand. You're not willing to stand by and let people suffer. You want to take action."

His eyes widened a little, and he gave a hesitant nod.

"So, you're starving yourself, to make your father see reason," I continued.

"It's not just me," he said. "My friends, too. They don't like where the world is headed, right now. We're all doing it together." He started rattling off the names of a long list of kids, some of whose surnames I recognized from my business news feed, and in some cases from my guilty pleasure, the young influencers I followed online.

Interesting. I kept that tidbit in mind for the future.

"But tell me," I leaned forward. "Have you considered that maybe, just maybe, your father doesn't realize the effect unhealthy food has on people, because it doesn't impact the people he really cares about?"

PART THREE - A PREPAC STORY

"You're a genius, doc!" Tammer's father stormed into my office. "I don't know how you did it, but he's eating now, like there's no tomorrow!"

I managed a little smile. It's been an entire month since I last saw Tammer, and I figured his father had simply given up on my services. His secretary did not return my calls, and I was still trying to collect my pay. But now that he was here again…

"Welcome back," I said. "Please, sir, take a seat, and tell me what happened."

"It only took a day after you had your little pep-talk with him," he announced. "And then he started eating again!"

"That's great," I nodded sagely. "That's exactly what I was aiming for—for him to halt his hunger strike and eat—and I am very happy the session worked. Now, there's the issue of my—"

"But there's still a problem," he said abruptly. "My son. He's eating PrePacs."

I was caught by surprise. "So… so what?" I stammered.

"It's not good for him," he said. "It's something other people should eat. Not my son. Look at this picture!"

He slammed a picture on my table.

I looked at the picture he put on my table. Tammer was not nearly as gaunt as before. His cheeks seemed to be bulging, a somewhat greenish expression to his face. He was in the middle of shoving an entire PrePac into his mouth. Alarm bells began clanging softly in my mind. Or was it Christmas Eve bells? There was an opportunity here for a sharp psychologist who knew how to play her cards right.

"I strongly advise you to talk with him," I said. But of course, he wouldn't. "Tammer is using the PrePac diet to get you to understand his concerns. He wants you to become more emotionally connected to his struggle against obesity, and the impact these things are having on society."

"I'm not going to engage in all of that touchy-feely-weepy talk with my son," he growled. "The boy needs to do as he's told. He needs to eat healthy food. I can't have my son putting on fat and looking like… like he's poor! I'll never hear the end of it from PR!"

That was the moment to strike. "I would love, of course, to keep on meeting with your son," I said, trying hard not to rub my hands together. "I have a special rate for recurring clients, and I am confident I can help him find his balance again."

"So it'll be okay?" he inquired. "I'm not going to have any problems with him?"

"It's going to take time," I said, "but eventually, he'll find his balance. It will all work out. Just have faith."

He nodded curtly, and left the room. I sat there in silence, thinking. Could it be that I had found a new niche? I scribbled some names onto a piece of paper, and then invited my secretary into the room.

"Start contacting the parents of the kids on that list," I instructed her. "Tell them I know what's happening. Tell them I can take care of their kids for them, with just a single meeting. But it'll cost them."

She ran away to do her job, and I sat back in the chair—finally allowing a satisfied smile spread over my face. Yes, the future was going to be just great. Eventually, I thought, I may even have enough money to stop eating those damn PrePacs.

Scenario 3: A Nourished Planet

OVERVIEW

IN 2050, PEOPLE around the world consume healthy and nutritious foods that are affordable, sufficient, and diverse—further incentivizing the production of healthy crops in both small and large-scale agriculture. A multitude of food system policies are designed to move the global food system away from a calorie-maximizing system to one optimized for nutritional quality. Food literacy improves; with more access to nutritious foods, people are able to make educated, and in turn, healthy dietary choices.

Both smallholder farming and large-scale industrial agricultural production systems are empowered and incentivized to grow healthier and more productive crops in inclusive food systems that improve the livelihoods and quality of life of workers. These inclusive food systems provide fair economic opportunities along the entire food value chain and allow small and medium enterprises to thrive.

This success is partially a result of transforming food systems to regenerate environmental systems, enrich our natural resource base, minimize the production of greenhouse gases, and achieve nutritional abundance and economic equity. Soil, water, and biodiversity are replenished and revitalized, in part due to efforts made to curtail and repurpose food loss and waste.

To realize this world, a number of breakthroughs and interventions had to occur or exist simultaneously. Technologies are created to collect and process vast amounts of data on agriculture, production, and consumption, such as a universal framework that accurately conveys previously invisible health, labor, and environmental costs of food. The availability of critical dietary information, and technological advancements that enhance people's experiences and understanding of the food they consume, has a transformative influence on a majority of consumers, shifting demand towards healthier diets, more equitably produced food, and environmental sustainability.

At the same time, low-cost precision agriculture has penetrated smallholder farming, empowering farmers to improve their farming and production practices. This is accompanied by an active effort to promote small and medium enterprises along food supply chains, and to invest in rural and midstream production infrastructures. The key breakthrough here is the affordable, off-grid, renewable energy source that allows rural and poor households to benefit from a myriad of precision technologies.

Additionally, the 70% of the population living in urban and peri-urban centers around the world have easy access to circular, sustainable food economies that offer locally produced fresh food. Due to technologies designed to increase the shelf life of fresh and nutrient-dense, perishable food, the consumption of healthier and nutrient-rich diets has increased while the environmental footprint of food has significantly declined.

Human behavior and awareness have also transformed to allow for widespread, global alignment on systematic solutions to food system issues, which is equally as important as the aforementioned technological advances.

HIGHLIGHTS:

- Convergence on a holistic food systems approach and universal global priorities fosters multi-stakeholder cooperation to avoid worsening health and environmental outcomes of food system policies and practices.
- Technological breakthroughs have deep, transformative effects on consumers' awareness and behavior, thereby shifting demand toward healthier, more equitably produced and environmentally sustainable foods.
- Hunger and nutrient deficiencies are eradicated, and everyone across the world has access to healthy, nutritious food.
- Technological and scientific breakthroughs are key catalyzing change agents—particularly in producing positive changes in smallholder farming, agriculture, and health and nutrition sciences.
- A global agreement on a universally standardized framework for valuing the real costs of food, including the invisible costs associated with health, labor conditions, animal welfare, and the environment.
- Across food systems, policies and instruments are realigned to advance the global agenda of promoting nutritional quality, economic equity, and environmental sustainability.
- Food systems are characterized by inclusivity and diversity. Both large-scale industrial agriculture and small-scale commercial farming have an equal place at the table
- Women lead the continued smallholder food system transformation in the developing world to create a viable small-scale commercial farming and food supply chain that offers equal opportunity to all.

HOW DID WE ARRIVE HERE?

The impact of breakthroughs in technology and science matched the unprecedented human appetite for multi-stakeholder action and cooperation across food systems and other major sectors. It became clear to stakeholders they needed to approach food systems in their entirety, and the manner in which food was produced and consumed needed to change to avert detrimental outcomes that would affect all life on earth.

What altered the trajectory that led us to this world in 2050 was not a single breakthrough or event. It was the convergence of many initiatives and changes. Toward the end of the second decade of the 21st century, scientific studies and findings irrevocably established the reverse relationship between consuming many common types of cheap processed and ultra-processed foods, and their harmful impact on human physical and mental well-being. This led to the defining moment when national and international health authorities intervened to create physical and economic barriers between these foods and human consumption.

Urban and peri-urban food economies thrived thanks to improved and efficient farming systems, such as vertical farming and lab-grown meat. The waste produced by these systems were repurposed as fertilizer, animal feed, and biomass energy. This reduced waste and pollution from food systems and increased the consumption of fresh produce with short shelf lives.
Three more breakthroughs were significantly responsible for altering the trajectory of our global food system by increasing overall transparency and confidence in supply chains, improving food literacy, changing consumer behavior around food, and promoting the production of environmentally friendly, nutritious crops.

First, vast amounts of data were collected and made accessible, including comprehensive information on agricultural activities such as: natural resources used, primary production, harvesting, storage, processing, manufacturing, distribution, retail shelf-life, and consumption. Much of this data was collected by sensors designed to measure soil health, water usage, greenhouse gas emissions, and other environmental components. Other data was gathered by biometric identification technologies created to assess animal welfare; wearable technologies that measure human nutrition and well-being; and many others. This breakthrough utilized numerous existing technologies such as sensors, big data management, artificial intelligence sharing platforms, blockchain, and cybersecurity technologies. The data offered a clear view into global food supply chains, and when combined with behavioral and biological data on consumers, stakeholders were able to accurately assess the impact and value of different food items on human health as well as the environment.

Second, a standardized evaluation framework was established to measure the true cost of food, which was able to ascertain any given food item's associated costs relative to human health, the environment, labor, and animal welfare. Existing technologies were used to accurately measure and capture these previously invisible costs. Even though the true cost of food was yet to be incorporated into prices, the knowledge itself was made widely available to everyone, allowing them to make educated choices beyond those based on calorie breakdown and price. This resulted in a major boost in food literacy that forever shifted consumption behavior toward making healthy choices.

Third, a proliferation of innovations in food consumption and overall interactions with food flooded markets and became integral to the entire consumer experience. It allowed people to virtually immerse themselves in the complete journey of their food from farm to fork. This breakthrough also relied on a number of preexisting technologies such as: interactive food labels, augmented and virtual reality, and other gamified activities. As a result, people could experience every aspect of the global food system and were incentivized to adopt healthy and sustainable diets.

Partly due to these changes, coupled with advancements in soil and plant sciences, food systems transformed into one of the largest, anthropogenic greenhouse gas sequestration systems in existence. This achievement required major efforts to realign policies and practices across all global food systems and governmental agencies.

NUTRITIOUS DIETS

Across the globe, nutritional quality is the benchmark of food valuation. Thanks to various interventions, consumers' relationship with food is now more nuanced and sophisticated. The above three breakthroughs have transformed perceptions around good food, and as such, its demand, which results in a lasting positive impact on the environment.

The increased awareness also elicits more proactive government and international measures to address the health, economic, and environmental costs of food production and consumption. In 2050, no one is hungry, and no child is stunted or wasted. This was achieved through the production of more nutritious food along with a worldwide effort to protect the human right to a hunger-free life, while simultaneously promoting the universal right to sufficient nutrition.

At the same time, thanks largely to nutrient trackers and genetics research, discoveries lead to affordable precision-nutrition technologies, that in turn, create a personalized nutrition industry based on exact scientific metrics of an individual's genetic make-up and nutrient intake. As a result, personalized nutrition intake allows for biofortification and fortification of food during emergency interventions or for target populations, which is crucial to the total elimination of hunger and micronutrient deficiencies.

INCLUSIVE FOOD SYSTEMS

A major portion of the success of global food systems in 2050 is due to diversity and inclusivity—as many production systems manage to seamlessly coexist with each other.

Advances in technologies around data collection, availability and storage, artificial intelligence, and the internet of things enable the global use of precision agriculture practices. Small-scale food production is forever transformed, as a result. Sensors and tools allow for continuous monitoring of hundreds of factors that determine optimal conditions for crop growth. Farmers no longer grow crops at the expense of impoverishing the soil or themselves. They are able to optimize production activities based on easily accessible and affordable data.

Due to low-cost and easy to assemble mini-grids, advanced battery technology, and aggressive investment in low-cost renewable energy research and development, rural households, smallholder farmers, and midstream food producers now enjoy reliable, safe, and affordable power. This provides virtually every industry professional access to up-to-date information on best practices and technologies designed to improve productivity and nutritional quality.

Thanks to public and private investment in rural development, small-scale producers are seamlessly integrated into food systems though infrastructure development programs. Farming no longer looks like the ancient practice of hard labor from dusk till dawn. The market is dominated by hip technologies and intriguing gadgets that incentivize and reward innovation and is considered a cool and sophisticated industry that fosters entrepreneurship.

Agriculture is now a vehicle to help alleviate poverty. Women smallholder farmers and entrepreneurs, that constitute more than half of the agricultural labor force in the developing world, lead the push for a fair and equitable food system that offers opportunities for all. Their knowledge and experience are key to helping the sector adapt to the deep changes occurring along food supply chains. As a result of their dedication and activism, consolidation is highly regulated to protect the interests of small- to medium-scale producers. The positive benefits of industrial agriculture are realized by all operations regardless of size, and environmental sustainability is always on major political and industry agendas.

HEALTHY ENVIRONMENT

The evolution of food systems in this nourished planet supports the environment's ability to regenerate the natural resource base, improve the provision of ecosystem services, and continue to provide for all life on earth. Instead of polluting the air, and warming the globe by emitting greenhouse gases, food systems are now one of the largest human-made greenhouse gas sequestration systems in the world. This is largely a result of advancements in soil science, but it is also the outcome of painstaking efforts to realign policies and practices across our entire global food system. To achieve this, a balance is struck between the facets of industrial agriculture that are far less harmful to nature and human health, and more localized small-scale production processes that utilize organic and regenerative agriculture. Both technology advancement and human cooperation amongst global stakeholders continue to enhance the productivity of organic systems, while simultaneously mitigating the environmental impacts of industrial methods.

Animals are no longer slaughtered in massive industrial facilities merely to gratify the rising global demand for meat and dairy products. Preferences shifted to alternative sources of rich proteins that are sustainably sourced and produced. Animals form part of a larger, regenerative, and cyclical system in which they play a key role by grazing on weeds and undesired grass, providing manure to be used as fertilizer, and offering other important farming benefits.

Food waste has become socially and politically unacceptable causing levels to decline to an all-time low. Sensors, devices, and interconnected appliances and platforms continue to minimize food loss throughout production and supply chains. Increased awareness, incentives, and technologies reduce food waste by consumers, and help forward-thinking operations transform waste unsuited for human consumption into agricultural inputs, such as animal feed or biofuels.

Building on decades of nutritional, productivity and efficiency gains, agriculture and farming continue to improve. This helps the sector produce more nutritious food with less input, waste, cost, and environmental impact, making it more affordable, available, and sustainable. Scaling the natural carbon and nitrogen capturing processes of the soil microbiome is a key scientific advancement, along with more efficient irrigation technologies, data and algorithms, holistic breeding practices, and genetically engineered seeds.

Aquaculture and wild foods thrive, as humans are more determined to regulate their environmental footprints. Large-scale production operations incorporate practices designed to reduce the environmental impacts of growing one or two crops. Subsidies and market incentives are now biased toward the production of crops that are nutritious for humans and the soil. All this was made possible by the creation and maintenance of direct and actionable links between consumers and producers.

"It's difficult to think anything but pleasant thoughts while eating a homegrown tomato."

- LEWIS GRIZZARD

A Story from A Nourished Planet

DVG, INCORPORATED

I opened my eyes groggily, and remembered what day it was, and what had to happen. My son Tammer was still working in the U-farm, so I had some time for myself. I brushed my teeth slowly, and then moved on to the kitchen for my daily breakfast. The super-oven recommended an omelet with beans and spinach, for my heart. I accepted, and watched dully as the robotic hands worked deftly with the kitchen tools, complemented by nozzles that could spray dough, egg whites, molten cheese or even minced meat, to create an infinite variety of meals. It only took a minute before the smell of scrambled egg filled the kitchen.

I ate without much joy. I didn't want to go on with the day. We'll become rich today, but at what cost?

I couldn't really eat the omelet. I felt too morose to enjoy the taste, even though the flavors were specifically engineered for my taste buds. I put the leftovers in the recycling bin, knowing that they would be sterilized, separated into their individual components, and reused in my super-oven. No food is wasted today, although honestly, we do have more than enough. With that cheery thought, I opened the door into the U-farm, where Tammer was already tinkering with the robots.

I paused for a moment to look at him. Really look. It was pretty clear from his body he was about to turn 16 soon. He was tall and gangly, his unkempt hair falling in tangles around his face, which he kept blowing up from his eyes while he worked on his drone. He looked like a teenage pop star, at least the kind that were around when I was his age. He raised his eyes to me as I entered the room, and smiled.

"You're gonna love this one, Dad," he said excitedly, and hoisted up the drone. "I just finished working on it. I've been collecting and analyzing data from Mr. Denison's next door forever, but I finally installed the new software update—I was up all night testing the code. It's a huge upgrade on the version of the robot I showed you last month, and it's going to—"

"Change the world." I completed his sentence. He laughed in agreement and released the drone into the air. It immediately flew out of the open window.

I raised my eyebrow at Tammer.

"Just wait." He promised. "Poachy will be back soon."

"Poachy?" I asked.

"Its name!" He said exasperatedly. "Watch!"

It only took a minute before Poachy came back, buzzing quietly into the room. It carried a basket, and from what I could see, it was full of apples. Tammer waved at the robot, and it turned towards him. One mechanized claw reached into the basket, picked an apple, and threw it unerringly at Tammer's head.

My son expected that. Hell, I was sure he programmed the robot that way, just for show. He snatched the apple right from the air and grinned at me. Poachy did a little dance in the air to indicate its appreciation, then landed on the floor and went silent.

"Take a bite, Dad." Tammer offered me the apple.

I bit into it. Fresh, crisp, sweet, and sour at the same time. Better than any apple I've ever had before.

"Good, right?" Tammer smiled at me. "It was plucked straight from Mr. Denison's, from the apple farm that grows on his roof next door to us, the one that's all the way at the top of the skyscraper."

"Stolen, you mean," said a stranger's voice, and we both turned around in surprise. My heart sank in my chest.

It was time for Tammer to meet his new benefactor.

PART TWO – DVG, INCORPORATED

I went to the visitor and shook his hand. He was meticulously well-groomed, and fashionably attired in a three-piece suit. I could feel Tammer's eyes on the back of my head.

"Welcome to our U-farm," I said, fumbling with the words. "Sir."

The man nodded at me, then glanced at Poachy.

"Let's see if I understand it correctly," he said. "You programmed this robot – all on your own and with no assistance – to autonomously fly to a neighboring U-farm, pick up a fruit, and bring it over to you. Is that right?"

Tammer didn't hesitate. He was proud of his creation.

"Yes sir," he said excitedly. "But – but it didn't steal the fruit. I got permission from the U-farm owner."

"I see," said the visitor. "But the robot could, hypothetically, reach into any U-farm, right?"

Tammer bobbed his head. "Yeah, that's the idea. The city is packed full of U-farms – urban farms. Every skyscraper holds dozens of them, with open windows to let the air in.. But I don't need to tell you that it's all mediocre - no way any of them could grow something as good as that apple I just got."

"And why is that?" The visitor asked this in a slightly condescending tone. Probably because he knew the answer, given who he worked for.

"Well I mean, sure they've got a bit of sunlight and some sensors, imaging systems, water circulation systems, you know, the standard stuff. Some of them are even making real use of the datatrust. And they all have robots. But none of them can figure out why the food doesn't taste very good, and only has basic nutrients," he said, with a hint of excitement. He was getting a bit riled up.

"And I suppose you've figured this all out?" There was that tone again.

Tammer's eyes narrowed, catching on. "The innovation hub is right down the street, and the data is in the cloud, free. I borrowed some compute power and got some seed money from my neighbors on the innovation exchange. That's all it took. The only reason no one else thought of it is that Agro-Tech made it too easy - take out a loan, manage the system they provide, keep the robots and the deliveries humming. Busy farms equals stability and Agro-Tech profits. Sure we're not hungry, but we're not thriving either," he said, with an obvious effort to calm himself. "It costs too much for ordinary people – like my dad and me – to turn a U-farm into anything more than just a U-farm."

He stopped to take a breath. "But it was all right there for the taking - you just had to know how to put the pieces together. Write an autonomous algorithm, reprogram the drone sensors to scan the water baths, not the crops, stuff like that. None of that breaks any existing patents; it's all just repurposing some existing tech and some new code. And I'm going to give it away for free. That would – "

He stopped and glanced at me. I kept silent. He lowered his head and muttered, "That would change the world."

"No," said the man. "It won't. Because as of right now, it is no longer yours. Kindly hand the drone over, along with your research notes and code, and make your way to the exit. I've already taken some images at the innovation hub - nice rig by the way - and my team will take a look as soon as I get back to the office with the ledger info. All of that and this entire U-farm are now Agro-Tech's legal property. Congratulations, by the way – you are both millionaires now. You can thank your father for that."

I hung my head low. For a millionaire, I wasn't feeling all that great about myself.

PART THREE – DVG, INCORPORATED

"Dad?" Tammer turned to me. "What is he talking about?"

I mumbled something. I wasn't sure myself what it was.

"Dad!" Tammer's voice was louder, more frantic. "What did you do?!"

"He sold us your inventions." The Agro-Tech executive told him calmly. "Plus, this wreck of a U-farm."

"You can't take them away!" cried Tammer. "And it won't do you any good. I issued a patent on them just to protect them from vultures like you!"

"We know," said the man, nonplussed. "Your father was kind enough to include the patents in the deal as well."

He sat down next to the boy, his face and tone surprisingly gentle.

"He arranged for a better future for you, boy. That's what fathers do. And he also profited off your invention. Now you know that's what people do, too—and it's a lesson best learned early."

Tammer looked at me again, and the hurt expression on his face gave me some strength to resist. I glowered at the executive sullenly. "The deal is not signed yet," I said.

He rose to his feet again and laughed at me, the gentleness all gone. "Look around you," he said scornfully. "Your U-farm is failing, miserably. Yes, you get free electricity, same as everyone today, but your crops still fail. There's a reason you called us and told us about your son's inventions. You need the money. Think about all the things you could use it for. You could quit working for the rest of your days. You could even send this fine young man to get a formal education in the most prestigious universities in the country. The deal is done. You don't really have a choice. The signature is merely a formality."

I hesitated, and then turned away from him to look into Tammer's eyes.

"We need the money, Son." I told him. "You don't get it, but—"

He cut me short.

"I get it, Dad. I really do. But you can't make a better future by not sacrificing something today! Please, dad, just trust me. I know I can make it work. It's going to—" He hesitated. "It's going to make things better for everyone!"

His hand touched mine, beseechingly. I could feel its heat, full of warmth and life. Full of passion for change and optimism, which I no longer possessed. But maybe I could borrow some of it.

I closed my hand around his.

The executive clicked his pen, and stepped forward expectantly. I turned to him.

"Get out," I said curtly. I didn't give him time to talk back at me. A pause might weaken my resolve, and give him an opening. Tammer's hand pulsed in mine. "Get off my property. It's still mine, and no deal is being signed today."

I took a shuddering breath, and went on. "I know I've made some pretty bad decisions in my life before, but it ends now." I was babbling by this point, tears in my eyes. "I won't let you crush my son's dreams with a payoff. We're going to struggle. It'll be hard, but it will get better, eventually. For everyone, because—"

Tammer squeezed my hand. Neither of us let go.

"We're going to change the world."

What Comes Next?

WHAT SHOULD BE clear from the content offered in this report is that global food systems require a substantial transformation, which demands not only persistent and serious efforts, but also audacious, impactful disruptions designed to permanently change the trajectory of the future. While the final future scenario entitled, "A Nourished Planet," is but one representation of how an idealized transformation of the world's food systems can unfold, we are certain the breakthroughs identified in the heart of this report can help humanity chart a course in this direction.

So, where do we go from here? At the outset of this report, we outlined XPRIZE's mission: (1) articulate a vision of a preferred and positive future; (2) identify the roadmap needed to get there; and (3) establish incentive competitions that focus the resources, talent, and technology required to realize the aforementioned breakthroughs, and in turn, accelerate this preferred future. This report has accomplished the first two steps. Now, the hard work begins in earnest.

XPRIZE uses the identification of potential breakthroughs, and the research that underpins them, to help the organization and our stakeholders identify not just where change is needed, but ways in which an XPRIZE competition can help bring about that change. This comes with one important caveat: while the competition model has proven its effectiveness over centuries in generating transformative solutions, it cannot be deployed to solve every problem. This Impact Roadmap has identified breakthroughs that require political, social, and cultural changes in some form or another—given the timescale and audacity of a breakthrough—such factors will always be a component. While technological innovation can help catalyze or support change in these areas, it cannot be the sole driving force to do so.

Herein lies your charge: we need your help, and we cannot do it alone. The ideas outlined in this report require your support to come to fruition. XPRIZE will work with our stakeholders to identify how these breakthroughs can turn into actionable ideas that we can collectively seek to achieve. Will you accept the challenge to help us in these endeavors and alter the future of humanity?

APPENDIX

Glossary of Terms

Acute Food Insecurity: Food insecurity found in a specified area at a specific point in time and of a severity that threatens lives or livelihoods, or both, regardless of the causes, context or duration. Acute food insecurity is relevant to providing strategic guidance to actions that focus on short-term objectives to prevent, mitigate or decrease severe food insecurity that threatens lives or livelihoods.[394]

Aeroponics: The growing of plants in a soilless environment where nutrients are intermittently or continuously misted on to the plant roots.[395]

Afforestation: Establishment of forest through planting and/or deliberate seeding on land that, until then, was not classified as forest.[396]

Agroecology: Application of ecological science to the study, design, and management of sustainable agrosystems.[397]

Agroforestry: An agroforestry system is a form of multiple land use where woody perennials (trees, shrubs, bamboos, palm trees, woody lianas) are grown on the same land management unit with crops and/or animals.[398]

Anthropocene: Unofficial interval of geologic time, making up the third worldwide division of the Quaternary Period (2.6 million years ago to the present), characterized as the time in which the collective activities of human beings (Homo sapiens) began to substantially alter Earth's surface, atmosphere, oceans, and systems of nutrient cycling.[399]

Biodynamic Farming/Agriculture: A view of agriculture based on a holistic and spiritual understanding of nature and humans' role in it, which considers a farm as a self-contained evolving organism, relying on home-produced feeds and manures with external inputs kept to a minimum.[400]

Biofuel: Biofuel is fuel produced directly or indirectly from biomass.[401]

Biodiversity (biological diversity): The variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Diversity indices are measures of richness (the number of species in a system); and to some extent, evenness (variances of species' local abundance).

Biomass: Organic material both above-ground (stem, stump, branches, bark, seeds, foliage) and below-ground (roots), living or dead.[402]

Biosphere: That part of a planet — including air, land and water — in which life develops, and which life processes in turn transform.[403]

Breakthrough: A breakthrough is a discovery or disruption that causes significant, sometimes sudden or dramatic change of the trajectory of the future. Breakthroughs can be technological, social, political, cultural, economic, or a combination of these.[404]

Carbon Budget: The area under a greenhouse gas (GHG) emissions trajectory (i.e. the amount of carbon emissions) that satisfies assumptions about limits on cumulative emissions estimated to avoid a certain level of global mean surface temperature rise.[405]

Carbon Credit: A generic term for any tradable certificate or permit representing the right to emit one ton of carbon dioxide or carbon dioxide equivalent (CO2-e)[406].

Carbon Offset: Arrangements under which an electric utility, for example, could be authorized to build a new power plant, provided it compensates for the predicted increase in carbon emissions by planting a certain number of trees, by financing reduced-impact logging, enrichment planting, forest protection or reforestation in a developing county in order to sequester carbon and offset emissions (i.e., increase carbon fixation and reduce atmospheric carbon).[407]

Carbon Reservoir: A system which has the capacity to accumulate or release carbon.[408]

Carbon Sequestration: The process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change. There are two major types of carbon sequestration: geologic and biologic.[409]

Carbon Stock: The absolute quantity of carbon held within a pool at a specified time. The units of measurement are mass.[410]

Cellulose: The principal constituent of plant cell walls accounting for about 30% of vegetable matter.[411]

Challenge: A challenge is the outcome of a set of issues, typically brought about by a number of causes or factors, and presents an opportunity for intervention.[412]

Chronic Food Insecurity: A situation that exists when people lack long-lasting secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life.[413]

Climate Change: Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external factors, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. The United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.[414]

Conservation: A series of measures required to maintain or restore the natural habitats and the populations of species of wild fauna and flora at a favorable status.[415]

Deforestation: The conversion of forest to other land use or the long-term or permanent loss of forest cover and transformation into another land use such as agriculture, pasture, water reservoirs and urban areas, which are usually considered more profitable.[416]

Desertification: Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.[417]

Ecological Reserve: Ecological reserves are areas selected to preserve representative and special natural ecosystems, plant and animal species, features and phenomena. Scientific research and educational purposes are the principal uses of ecological reserves.[418]

Ecosystem: An organizational unit consisting of an aggregation of plants, animals (including humans) and microorganisms, along with non-living components of the environment.[419]

Endangered Species: Species threatened with extinction.[420]

Endemic Species / Indigenous Organism: An indigenous organism is an organism that is naturally occurring (i.e. has not been introduced by man) in a specific area. Indigenous organisms are sometimes called native.[421]

Environment: Prevailing conditions reflecting the combined influences of climate, soil, topography, and biology (other plants and animals) in an area. Environmental factors determine how well a particular species will grow in a given area.[422]

Erosion: The loss of surface soil due to water, wind, gravity and/or human activities.[423]

Extreme Poverty: Refers to the percentage of people living on less than USD 1.90 a day (2011 PPP prices) in a country in a given year.[424]

Food Loss: Decrease in quantity or quality of food.[425] In this report, food loss generally refers to losses in primary production and along the value chain due to poor pest management, harvest loss due to poor technology, and loss in storage and processing, among others.

Food Security: A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food security dimensions can be identified: food availability, economic and physical access to food, food utilization, and stability over time.[426]

Food Systems: The entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products. Food systems comprise all food products that originate from crop and livestock production, forestry, fisheries and aquaculture, as well as the broader economic, societal and natural environments in which these diverse production systems are embedded.[427]

Food Waste: Removal from the food supply chain of food which is fit for consumption, by choice, or which has been left to spoil or expire as a result of negligence by the actor – predominantly, but not exclusively the final consumer at household level.[428] In this report, food waste generally refers to post-final purchase at the consumption stage.

Forage: Edible parts of plants, other than separated grain, that can provide feed for grazing animals, or that can be harvested for feeding. Includes browse, herbage, and mast.[429]

Foreign Direct Investment: Refers to a category of investment where the objective is to establish a lasting interest by a resident enterprise in one economy (direct investor) in an enterprise (direct investment enterprise) that is resident in the economy of a different country than that of the direct investor. It implies the existence of a long-term relationship between the direct investor and the direct investment enterprise and a significant degree of influence on the management of the enterprise.[430]

Forestation: Establishment of a forest on an area, whether previously forested or not.[431]

Forest Degradation: The destruction of specific aspects of forests such as a decrease in tree cover, changes in their structure or a reduction in the number of species that can be found there, resulting in reduction of the capacity of a forest to provide goods and services.[432]

Forest Health: A generally observed, somewhat subjective condition whereby the forest is evaluated according to its age, growth, diversity, existence (or absence) of injurious insects, diseases, exotic invasive pests, wildlife attributes, aesthetics, degree of resiliency, etc., all of which are weighed against the land management goals.[433]

Grand Challenge: A set of complex and overlapping challenges that are commonly multi-dimensional; in that they contain social, technological, economic, environmental, and political dimensions. Grand challenges present both opportunities and obstacles for change.[434]

Greenhouse Gas Emissions (GHG): The discharge of greenhouse gases, such as carbon dioxide, methane, nitrous oxide and various halogenated hydrocarbons, into the atmosphere. Combustion of fossil fuels, agricultural activities and industrial processes contribute to the emissions of greenhouse gases.[435]

Genetic Engineering: Directed modification of the gene complement of a living organism by such techniques as altering the DNA, substituting genetic material by means of a virus, transplanting whole nuclei, transplanting cell hybrids, etc.[436]

Genetically Improved Seedlings: Genetically improved seedlings are the result of a long-term genetic selection process of tree breeding over multiple generations. The trees that perform well across a range of conditions are selected and propagated by grafting in seed orchards or by vegetative cloning.[437]

Genetically Modified Organisms (GMO): Organisms that have been transformed by the insertion of one or more transgenes.[438]

Geographic Information System (GIS): An information system for capturing, storing, integrating, analyzing and displaying geospatial data.[439]

Global Positioning System (GPS): A technology that uses the position of satellites to provide precise location coordinates on the Earth's surface.[440]

Global Warming: A rise in temperatures near the Earth's surface caused by an increase in the atmospheric levels of GHGs. Global warming is the result of the greenhouse effect.[441]

Green Belt: Areas of land whose main purpose it to curb the outward expansion of a large urban area and in which development is strictly controlled.[442]

Habitat: The natural environment where an organism, population or community lives, including biotic and abiotic factors.[443]

Harvest: As generally used, to remove all or portions of the trees in an area. Technical definition: To remove trees in an area (1) for financial gain; (2) to develop the environment necessary to regenerate the forest; and, (3) on occasion, to achieve some special objectives, such as the development of special wildlife habitat needs. Contrast with intermediate cut.[444]

Horticulture: 1. The science or art of cultivating fruits, vegetables, flowers, or ornamental plants. 2. The cultivation of a garden.[445]

Hunger: Hunger is an uncomfortable or painful physical sensation caused by insufficient consumption of dietary energy. In this report, the term hunger is synonymous with chronic undernourishment.[446]

Hydrology: Hydrology is the scientific study of the movement, distribution, and quality of water on Earth and other planets, including the water cycle, water resources and environmental watershed sustainability.[447]

Hydroponics: A technique of growing plants (without soil) in water containing dissolved nutrients.[448]

Incremental Silviculture: Incremental silviculture refers to the silvicultural prescriptions and practices in stands that are past free-growing conditions for the purposes of enhancing stand value and yield.[449]

Integrated Pest Management: Managing forest pests by considering several methods, including cultural, chemical, biological and the use of genetically modified organisms.[450]

Integrated Resource Management (IRM): Integrated Resource Management is a planning and decision-making process that attempts to consider the many interests and issues within the wildlife, parks, forestry, and minerals sectors that affect lands. Once these are considered, an operational plan is formulated. This plan attempts to balance the many concerns with provincial guidelines so that long term sustainable benefits are optimized and conflicts among uses are minimized.[451]

Invasive Species: Species that are non-native to a particular ecosystem and whose introduction and spread cause, or are likely to cause, socio-cultural, economic or environmental harm or harm to human health.[452]

Large-Scale Farming: In this report, refers to commercial intensive agriculture, including industrial agriculture, which involves large fields or numbers of animals, reliance on resource inputs (pesticides, fertilizers, etc.), and a high level of mechanization.

Legumes: Fabales family, most of which are herbaceous, sometimes woody plants, including beans, pods, chickpeas, soy, lentils, peas, such as the family.[453]

Livestock: Any domestic animal produced or kept primarily for farm, ranch, or market purposes, including beef and dairy cattle, hogs, sheep, goats, and horses.[454]

Macronutrients: Proteins, carbohydrates and fats available to be used for energy; measured in grams.[455]

Malnutrition: An abnormal physiological condition caused by inadequate, unbalanced or excessive consumption of macronutrients and/or micronutrients. Malnutrition includes undernutrition (child stunting and wasting and vitamin and mineral deficiencies) as well as overweight and obesity.[456]

Megatrends: Megatrends are potentially transformative, global forces that shape the future, and have far-reaching implications for industries, economies, societies, cultures and personal lives. These implications are varied and dependent on the direction of change megatrends, and especially some of the more uncertain ones, will take over years and decades.

Micronutrients: Vitamins, minerals and other substances that are required by the body in small amounts; measured in milligrams or micrograms.[457]

Micronutrient Deficiency: Generic term designating dietary deficiencies in vitamins, minerals and other substances such as, Ariboflavinosis (riboflavin deficiency), Pryidoxine (vitamin B6 deficiency), Niacin deficiency, Iodine deficiency, and Iron deficiency.[458]

Monoculture: The growing of the same crop species in the same field continuously year after year.[459]

Multiple Burden of Malnutrition: The coexistence of forms of undernutrition (child stunting and wasting and vitamin and mineral deficiencies) with overweight and obesity in the same country, community, household or individual.[460]

Net Food Importers: Refers to countries or territories where the value of imports of basic foodstuffs outweighs the value of exports of basic foodstuffs.[461]

Non-Communicable Diseases: A non-communicable disease (NCD) is a disease that is not transmissible directly from one person to another. NCDs include Parkinson's disease, autoimmune diseases, strokes, most heart diseases, most cancers, diabetes, chronic kidney disease, osteoarthritis, osteoporosis, Alzheimer's disease, cataracts, and others. NCDs may be chronic or acute.[462]

Nutrition Security: A situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment and adequate health services and care, in order to ensure a healthy and active life for all household members. Nutrition security differs from food security in that it also considers the aspects of adequate caregiving practices, health and hygiene, in addition to dietary adequacy.[463]

Nutrition-Sensitive Information: An action designed to address the underlying determinants of nutrition (which include household food security, care for mothers and children, and primary healthcare and sanitation) but not necessarily having nutrition as the predominant goal.[464]

Organic Farming: A method of agricultural production that avoids or largely reduces the use of synthetic chemical inputs such as fertilizers, pesticides, additives and medical products, using instead fertilizers derived from living organisms.[465]

Overweight and Obesity: Body weight that is above normal for height as a result of an excessive accumulation of fat. It is usually a manifestation of expending less energy than is consumed. In adults, overweight is defined as a BMI of 25 kg/m2 or more, and obesity as a BMI of 30 kg/m2 or more. In children under five years of age, overweight is defined as weight-for-height greater than 2 standard deviations above the WHO Child Growth Standards median, and obesity as weight-for-height greater than 3 standard deviations above the WHO Child Growth Standards median.[466]

Pests: A pest is any animal or plant which has a harmful effect on humans, their food or their living conditions.[467]

Photosynthesis: A biochemical process by which the energy of light is converted into chemical energy in plants, algae and certain bacteria.[468]

Planetary Boundaries: Nine boundaries, each representing a system or process that is important for regulating and maintaining stability of the planet. They define global biophysical limits that humanity should operate within to ensure a stable and resilient Earth system—i.e., conditions that are necessary to foster prosperity for future generations.[469]

Pollination: The transfer of pollen from the male organ i.e. anther, where it is formed, to the receptive region of a female organ i.e. stigma by a pollinating agent such as wind, insects, birds, bats, or in a few cases the opening of the flower itself.[470]

Rainforest: A forest of broad-leaved, mainly evergreen, trees found in continually moist climates in the tropics, subtropics, and some parts of the temperate zones.[471]

Reforestation: Re-establishment of forest through planting and/or deliberate seeding on land classified as forest.[472]

Regeneration: Re-establishment of a forest stand by natural or artificial means following the removal of the previous stand by felling or as a result of natural causes, e.g. fire or storm.[473]

Regenerative Agriculture: Describes farming and grazing practices that, among other benefits, reverse climate change by rebuilding soil organic matter and restoring degraded soil biodiversity – resulting in both carbon drawdown and improving the water cycle.[474]

Remote Sensing: Measurement or acquisition of information on some property of an object or phenomenon by a recording device that is not in physical or intimate contact with the object or phenomenon under study.[475]

Renewable Resource: Resource that potentially cannot be used up because it is constantly or cyclically replenished or regenerated.[476]

Resilience: Resilience is the ability of individuals, households, communities, cities, institutions, systems and societies to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning and without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all.[477]

Ruminants: Animals having a stomach with four compartments (rumen, reticulum, omasum and abomasum) and whose digestive process is more complex than that of animals having a true stomach. Some commonly known ruminants are cattle, sheep and goats; an example of a true stomach animal is the pig.[478]

Shade-Tolerance: Shade tolerance is a comparative term used to describe a tree species' ability to become established, grow and persist under shade or low light intensity, quality and duration.[479]

Silvicultural System: Long-range harvest and management schemes designed to optimize the growth, regeneration, and administration of particular forest types.[480]

Silviculture: The art and science of controlling the establishment, growth, composition, health, and quality of forest and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis.[481]

Smallholder Farming: Smallholder farming has been defined in a variety of ways. According to the World Bank's Rural Development Strategy, smallholders are defined by their low asset base and operate on less than two hectares of cropland.9 Smallholder farmers are also defined as having limited resources in relation to other farmers in the agricultural sector.10 The various definitions agree that smallholders cultivate both food and non-food products – including field and tree crops as well as livestock, fish and sea products – with limited resources such as land, capital, skills and labor.[482]

Soil Carbon: Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series.[483]

Stunting: Low height-for-age, reflecting a past episode or episodes of sustained undernutrition. In children under five years of age, stunting is defined height-for-age less than -2 standard deviations below the WHO Child Growth Standards median.[484]

Subsidy: Payment or benefit given to partially offset the cost of specific activities, such as the manufacture, production, or export of an article.[485]

Subsistence Farming: Form of farming in which nearly all of the crops produced or livestock raised are used to maintain the farmer and the farmer's family, leaving little, if any, surplus for sale or trade.[486]

Succession: Replacement of one plant community by another until a climax ecosystem in achieved.[487]

Sustainability: The ability of a process or human activity to meet present needs but maintain natural resources and leave the environment in good order for future generations.[488]

Sustainable Development: Development that "meets the needs of the present without compromising the ability of future generations to meet their own needs".[489]

Sustainable Forest Management (Sustainable Forestry): A dynamic and evolving concept, that is intended to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations.[490]

Sustained Yield: The yield that a forest can produce continuously at a given intensity of management. Sustained yield management implies continuous production to quickly achieve a balance between increment and cutting.[491]

Transpiration: Evaporation of water from the leaves or stems of plants.[492]

Undernourishment: Undernourishment is defined as the condition in which an individual's habitual food consumption is insufficient to provide the amount of dietary energy required to maintain a normal, active, healthy life. For the purposes of this report, hunger is defined as being synonymous with chronic undernourishment.[493]

Undernutrition: The outcome of poor nutritional intake in terms of quantity, quality, poor absorption and/or poor biological use of nutrients consumed as a result of repeated instances of disease. It includes being underweight for one's age, too short for one's age (stunted), dangerously thin for one's height (suffering from wasting) and deficient in vitamins and minerals (micronutrient deficiency).[494]

Urban Forestry: The practice of forestry in an urbanized environment.[495]

Vertical Farming: Practice of growing plants in vertically stacked layers, vertically inclined surfaces and/or integrated in other structures.[496]

Wasting: Low weight-for-height, generally the result of weight loss associated with a recent period of inadequate dietary energy intake and/or disease. In children under five years of age, wasting is defined as weight-for-height less than -2 standard deviations below the WHO Child Growth Standards median.[497]

Wetlands: Marshes, swamps and other water-saturated soils. These areas offer important habitat for wildlife, significant support of nutrient cycling in ecosystems, and protection against severe storms and floods.[498]

APPENDIX

Research Interviews

NAME:	ORGANIZATION:
Alafia Samuels	Caribbean Institute for Health Research
Anna Swaithes	Government of the United Kingdom - Government Inclusive Economy Unit, Office for Civil Society, Department of Digital, Culture, Media and Sport
Ben Hammersley	Hammersley Futures
Claire Baker	The Toothpick Project
David Ceaser	AgriTecture
David Just	Cornell University - Charles H. Dyson School of Applied Economics and Management
David Sands	The Toothpick Project
Don Seville	Sustainable Food Lab
Florence Oyosi	The Toothpick Project
Hal Hamilton	Sustainable Food Lab
Henry Gordon Smith	AgriTecture
Jayson Lusk	Purdue University - Department of Agricultural Economics
Jessica Fanzo	Johns Hopkins University - Berman Institute of Bioethics
Jim Woodhill	University of Oxford - Environmental Change Institute
John Ingram	University of Oxford - Environmental Change Institute
Julie Reynes	Foundation for Food and Agriculture Research
Jun Suto	S-Cubed
Karen Rodriguez	Kiss the Ground
Lauren Baker	Global Alliance for the Future of Food
Lorin Fries	Consultant, technologist
Max Elder	Institute for the Future
Mellissa Wood	Australian Centre for International Agricultural Research

NAME:	ORGANIZATION:
Ndidi Nwuneli	Sahel Consulting
Paula Daniels	Center for Good Food Purchasing
Santiago Alba Corral	International Development Research Centre
Thomas Tomich	University of California at Davis - Agricultural Sustainability Institute
Wendy Bigham	World Food Programme, Tanzania

Future of Food Lab Attendees

NAME:	ORGANIZATION:
Alafia Samuels	Caribbean Institute for Health Research
Alex Duong	Ancient Provisions
Autumn Barnes	Canola Council of Canada
Ben Hammersley	Hammersley Futures
Bill Welser	Nano
Christine Pahlman	Australian Centre for International Agricultural Research
Claire Baker	The Toothpick Project
Daniel Walker	Australian Centre for International Agricultural Research
Dave Lee	ARPA-E
David Sands	The Toothpick Project
David Ceaser	AgriTecture
David Meyer	Food System Innovations / Adopt-a-Pet.com
Ela Madej	Fifty Years
Elliot Swartz	The Good Food Institute
Gareth Asten	Acre Venture Partners
Hal Hamilton	Sustainable Food Lab
Jim Berger	Start-up Executive & Entrepreneur

NAME:	ORGANIZATION:
Jim Woodhill	University of Oxford - Environmental Change Institute
John Ingram	University of Oxford - Environmental Change Institute
Julie Reynes	Foundation for Food and Agriculture Research
Karen Rodriguez	Kiss The Ground
Keith Pitts	Marrone Bio Innovations
Kevin Costa	SynBioBeta
Kyle Murphy	The Abdul Latif Jameel Poverty Action Lab (J-PAL)
LaKisha Odom	Foundation for Food and Agriculture Research
Lara Jeremko	Beyond Ventures
Lisa Dreier	Stanford University
Lorin Fries	Consultant
Madiha Ahmed	International Development Research Centre
Matt Zieger	Village Capital
Matt Ridenour	OpenIDEO
Max Elder	Institute For The Future
Maya Lockwood	IndieBio
Melissa Rowe	RAND Corporation
Mellissa Wood	Australian Centre for International Agricultural Research
Paula Daniels	Center for Good Food Purchasing
Philip Saneski	ReGrained
Raymond McCauley	Singularity University
Renaud DePlaen	International Development Research Centre
Santiago Alba-Corral	International Development Research Centre
Taylor Quinn	JUST
Thomas Tomich	University of California at Davis - Agricultural Sustainability Institute
Udi Lazimy	JUST

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For adults:
- Fruit, vegetables, legumes (e.g. lentils and beans), nuts and whole grains (e.g. unprocessed maize, millet, oats, wheat and brown rice).
- At least 400 g (i.e. five portions) of fruit and vegetables per day, excluding potatoes, sweet potatoes, cassava and other starchy roots.
- Less than 10% of total energy intake from free sugars, which is equivalent to 50 g (or about 12 level teaspoons) for a person of healthy body weight consuming about 2000 calories per day, but ideally is less than 5% of total energy intake for additional health benefits.
- Less than 30% of total energy intake from fats. Unsaturated fats (found in fish, avocado and nuts, and in sunflower, soybean, canola and olive oils) are preferable to saturated fats (should be kept to less than 10%) and trans-fats of all kinds (should be kept to less than 1%), including both industrially-produced trans-fats (should be avoided) and ruminant trans-fats.
- Less than 5 g of salt (equivalent to about one teaspoon) per day. Salt should be iodized.

For infants and young children
Optimal nutrition during the first two years is critical for child's growth, development and health later in life. In addition to the above for adults, the following are also important components of a healthy diet for children:
- Exclusive breastfeeding during the first 6 months of life.
- Continuous breastfeeding until 2 years of age and beyond.
- From 6 months of age, breast milk should be complemented with a variety of adequate, safe and nutrient-dense foods, with no added salt and sugars."

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204. An example from the European Union: From the 2009/2010 school year onwards, the European Union Council of Agriculture Ministers began to implement the School Fruit Scheme – a subsidy scheme to provide free fruit and vegetables to children in schools. In return, schools must teach children about healthy eating and food production through appropriate programs. The scheme now reaches over 8 million children in over 54,000 schools across the 25 participating member states. Source: Using price policies to promote healthier diets. (Geneva: World Health Organization, 2015), http://www.euro.who.int/__data/assets/pdf_file/0008/273662/Using-price-policies-to-promote-healthier-diets.pdf, 24.

205. Denmark – tax on saturated fats: In October 2011, Denmark became the first country in the world to introduce a "fat tax" on saturated fat, with the taxable base including all foods containing saturated fat (for example, meat, dairy, edible oils and fats, margarine and blended spreads) In November 2012 it was announced that the tax would be abandoned, Subsequent to the abandon-

ment of the tax, a data analysis has demonstrated that the consumption of fats decreased by between 10% and 15% as a result of the tax. Source: Ibid, 13-17.

206. France – tax on sugar- and artificially-sweetened beverages: In 2011, concerned about the high levels of sugar intake among the population, the French government adopted a tax on sodas. It was then decided to extend the tax to "light" sodas containing sweeteners, thus covering all non-alcoholic beverages with added sugar or sweeteners. The tax was effective from January 2012 and is levied on sugar-sweetened and diet sugar-sweetened beverages. The general public have not expressed any significant opposition to the tax, even though industries initially opposed it. However, reactions to similar attempts at taxing sugar- and artificially-sweetened beverages in Mexico and New York City were much more pointed in their opposition. Source: Ibid, 21-24.

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239. Woodhill et al, p. 72

240. Example, Public-Private Partnerships: The Global Agriculture and Food Security Program (GAFSP) - Launched in 2010, GAFSP is a demand-led and recipient-owned global partnership dedicated to fighting hunger, malnutrition, and poverty by supporting resilient and sustainable agriculture in developing countries that benefits and empowers poor and vulnerable smallholder farmers, particularly women. The program cost-effectively pools development resources and selectively allocates them to where they are most needed, effective, and catalytic through a mix of public and private investment tools that expand the horizon of agricultural financing. Source: "Our Approach," GAFSP, https://www.gafspfund.org/approach.

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