CGIAR

IFPRI INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

What do we know about THE FUTURE OF FOOD SYSTEMS?

Edited by Keith Wiebe and Elisabetta Gotor

CGIAR

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS?

Edited by Keith Wiebe and Elisabetta Gotor

Handle: https://hdl.handle.net/10568/175019

Recommended citation: Wiebe, K., and E. Gotor, eds. 2025. *What Do We Know About the Future of Food Systems?* Washington, DC: International Food Policy Research Institute.

International Food Policy Research Institute
1201 Eye Street, NW, 12th floor
Washington, DC 20005 USA
Telephone: +1-202-862-5600
www.ifpri.org

Cover photo: Ricky Martin/CIFOR
Cover design and book layout: Jason Chow and Amit Bisht

TABLE OF CONTENTS

ACKNOWLEDGMENTS

This book was prepared under the leadership of Keith Wiebe and Elisabetta Gotor.

Chapters were written by Victor Afari-Sefa, Fahmi Salam Ahmad, Arega Alene, Syarifah Amaliah, Weston Anderson, Robert Andrade, Ronald Jeremy Antonio, Bustanul Arifin, Channing Arndt, Yee Mon Aung, Jean Balié, Isabelle Baltenweck, Irfan Syauqi Beik, Pratap S. Birthal, Elizabeth Bryan, Pihri Buhaerah, Silvia Kanadani Campos, Bianca Carducci, Nicola Cenacchi, Chin Yee Chan, Kevin Chen, Tracy Davids, Barun Deb Pal, Nicoline de Haan, Paul Dorosh, Dolapo Enahoro, Jessica Fanzo, Irfan Thofiq Firdaus, Aymen Frija, Sherwin Gabriel, Sika Gbegbelegbe, Juan Pablo Gianatiempo, Joseph Glauber, Elisabetta Gotor, Mohsin Hafeez, Xinru Han, Guy Hareau, Faaiqa Hartley, Mario Herrero, Yan Hoong, Xiangdong Hu, Jarot Indarto, Syahid Izzulhaq, Erizal Jamal, Nicolas Jorge, Mmatlou Kalaba, Evelyne Kihiu, Komalawati Komalawati, Jawoo Koo, Gideon Kruseman, Cody Kugler, Els Lecoutere, Marilia Magalhaes, Hazel Malapit, Ifan Martino, Daniel Mason-D’Croz, Cargele Masso, Matthew McCartney, Charles Mensah, Wulan Metafurry, Ferdi Meyer, Abhijeet Mishra, Carlo Montes, Aline Mosnier, Wupe Msukwa, Aditi Mukherji, Dadang Jainal Mutaqin, Ravi Nandi, Swamikannu Nedumaran, Agus Eko Nugroho, Steven Were Omamo, Jyosthnaa Padmanabhan, Karl Pauw, Valerien Olivier Pede, Diego Pequeno, Vanessa da Fonseca Pereira, Athanasios Petsakos, Louw Pienaar, Valeria Piñeiro, Angga Pradesha, Michael Puma, Ranjitha Puskur, Roseline Remans, Matthew Reynolds, Claudia Ringler, Ricky Robertson, Marie Ruel, Sahara Sahara, Benjamin Schiek, Sedithippa Janarthanan Balaji, Dewa Setyawati, Kai Sonder, Tahlim Sudaryanto, Timothy B. Sulser, Johannes Svensson, Kindie Tesfaye Fantaye, Shakuntala H. Thilsted, Judy Thomas, Timothy Thomas, Philip Thornton, James Thurlow, Nhuong Tran, Harold Glenn Valera, Irwanda Wisnu Wardhana, Keith Wiebe, Wenqian Xu, Vivi Yulaswati, Heather Zornetzer, and Monika Zurek.

Earlier versions of Chapters 4, 5, 7, 8, 9, 12, 14, 15, 17, 18, 19, 20, 21, 29, 30, 31, 32, and 34 were originally posted online at https://www.cgiar.org/news-events/news/foresight-init-what-do-we-know-about-series/.

We are grateful for the skillful and efficient contributions of the editorial and production team, led by Pamela Stedman-Edwards. Jason Chow was responsible for design and layout. Editorial assistance was provided by Amy Gautam, Evgeniya Anisimova, and Claire Davis. Nicola Cenacchi helped coordinate preparation of figures.

Preparation of this book was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders).

AUTHORS AND AFFILIATIONS

Victor **Afari-Sefa** (Chapter 20) is Director of the Global Research Program on Enabling Systems Transformation at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Fahmi Salam **Ahmad** (Chapter 26) is a Lecturer in the Department of Economics and Researcher in International Trade Analysis and Policy Studies (ITAPS) in the Faculty of Economics and Management at IPB University, Indonesia.

Arega **Alene** (Chapters 31 and 33) is an Agricultural Economist (Principal Scientist) and Program Leader for Foresight, Impact Assessment, and Scaling at the International Institute of Tropical Agriculture (IITA).

Syarifah **Amaliah** (Chapter 26) is a Lecturer in the Department of Economics and Researcher in International Trade Analysis and Policy Studies (ITAPS) in the Faculty of Economics and Management at IPB University, Indonesia.

Weston **Anderson** (Chapter 15) is an Assistant Research Professor in the Department of Geographical Sciences at the University of Maryland, and formerly an Assistant Research Scientist in the Earth System Science Interdisciplinary Center at the University of Maryland and the Earth Sciences Division at NASA.

Robert **Andrade** (Chapters 22 and 33) is a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at the International Center for Tropical Agriculture (CIAT).

Ronald Jeremy **Antonio** (Chapters 21 and 32) is a Bank Economist IV in the BSP Department of Economic Research at the Bangko Sentral ng Pilipinas (BSP) in Manila, the Philippines, and formerly an Assistant Scientist at the International Rice Research Institute (IRRI).

Bustanul **Arifin** (Chapter 26) is a Professor of Agricultural Economics at the University of Lampung (UNILA) and Senior Economist with the Institute for Development Economics and Finance (INDEF), Indonesia.

Channing **Arndt** (Chapter 11) is Director and Research Professor of Global Trade Analysis in the Department of Agricultural Economics at Purdue University, and formerly Senior Director of Transformation Strategies at the International Food Policy Research Institute (IFPRI).

Yee Mon **Aung** (Chapters 21 and 29) is a Lecturer at Yezin Agricultural University, Myanmar.

Jean **Balié** (Chapter 2) is Director of the CGIAR Poverty Reduction, Livelihoods and Jobs Impact Platform.

Isabelle **Baltenweck** (Chapter 28) is a Program Leader at the International Livestock Research Institute (ILRI).

Irfan Syauqi **Beik** (Chapter 26) is Dean of the Faculty of Economics and Management, IPB University, Indonesia.

Pratap S. **Birthal** (Chapter 25) is Director of the National Institute of Agricultural Economics and Policy Research at the Indian Council of Agricultural Research (ICAR).

Elizabeth **Bryan** (Chapter 4) is a Research Fellow in the Natural Resources and Resilience Unit at the International Food Policy Research Institute (IFPRI).

Pihri **Buhaerah** (Chapter 26) is a Senior Researcher at the National Research and Innovation Agency (BRIN), Indonesia.

Silvia Kanadani **Campos** (Chapter 23) is a Researcher at the Brazilian Agricultural Research Corporation (Embrapa).

Bianca **Carducci** (Chapter 35) is a Postdoctoral Scientist in the Columbia Climate School at Columbia University.

Nicola **Cenacchi** (Chapters 7, 9, and 36) is a Senior Research Analyst in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Chin Yee **Chan** (Chapters 21 and 29) is a Scientist at WorldFish.

Kevin **Chen** (Chapter 24) is a Senior Research Fellow at the International Food Policy Research Institute (IFPRI) and Qiushi Chair Professor at Zhejiang University, China.

Tracy **Davids** (Chapter 27) is Executive Director of the Bureau for Food and Agriculture Policy (BFAP) and Research Fellow in the Department of Agricultural Economics, University of Stellenbosch, South Africa.

Barun **Deb Pal** (Chapter 25) is a Research Coordinator in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Nicoline **de Haan** (Chapter 4) is Director of the CGIAR Gender Equality and Inclusion Accelerator.

Paul **Dorosh** (Chapters 2 and 14) is a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Dolapo **Enahoro** (Chapters 17 and 28) is a Senior Agricultural Economist at the International Livestock Research Institute (ILRI).

Jessica **Fanzo** (Chapter 35) is Professor of Climate and Food and Director of the Food for Humanity Initiative in the Columbia Climate School at Columbia University.

Irfan Thofiq **Firdaus** (Chapter 26) is a Policy Planner at the Ministry of National Development Planning/ Bappenas, Indonesia.

Aymen **Frija** (Chapters 19 and 34) is a Senior Scientist and Agricultural Economist in the Social, Economic, and Policy Research Team at the International Center for Agricultural Research in the Dry Areas (ICARDA).

Sherwin **Gabriel** (Chapters 13 and 18) is a Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Sika **Gbegbelegbe** (Chapters 17, 18, 30, 31, and 33) is an Agricultural Economist at the International Institute of Tropical Agriculture (IITA).

Juan Pablo **Gianatiempo** (Chapter 23) is a Research Analyst in the Markets, Trade and Institutions Unit at the International Food Policy Research Institute (IFPRI).

Joseph **Glauber** (Chapter 13) is a Research Fellow Emeritus at the International Food Policy Research Institute (IFPRI).

Elisabetta **Gotor** (Chapters 1, 5, and 7) is a Principal Scientist and Lead of the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International.

Mohsin **Hafeez** (Chapter 10) is Strategic Program Director of Water, Food and Ecosystems at the International Water Management Institute (IWMI).

Xinru **Han** (Chapter 24) is a Professor at the Institute of Agricultural Economics and Development (IAED), Chinese Academy of Agricultural Sciences (CAAS).

Guy **Hareau** (Chapters 22 and 33) is a Principal Scientist in Social and Nutritional Sciences at the International Potato Center (CIP).

Faaiqa **Hartley** (Chapters 18 and 30) is a Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Mario **Herrero** (Chapters 12 and 28) is Professor, Cornell Atkinson Scholar, and Nancy and Peter Meinig Family Investigator in the Life Sciences in the Department of Global Development at Cornell University.

Yan **Hoong** (Chapter 29) is an Economist at S&P Global, and formerly a Research Analyst at WorldFish.

Xiangdong **Hu** (Chapter 24) is Director General and a Professor at the Institute of Agricultural Economics and Development, Chinese Academy of Agricultural Sciences (CAAS).

Jarot **Indarto** (Chapter 26) is Director of Food and Agriculture at the Ministry of National Development Planning/Bappenas, Indonesia.

Syahid **Izzulhaq** (Chapter 26) is a Postgraduate Student in the Research School of Economics, College of Business and Economics at The Australian National University.

Erizal **Jamal** (Chapter 26) is a Senior Agricultural Economist at the Research Center for Cooperatives, Corporations, and People's Economy, the National Research and Innovation Agency (BRIN), Indonesia.

Nicolas **Jorge** (Chapter 23) is an Economist at Bolsa de Cereales, Argentina.

Mmatlou **Kalaba** (Chapter 27) is Research Director of the Bureau for Food and Agriculture Policy (BFAP) and Research Fellow in the Department of Agricultural Economics, University of Stellenbosch, South Africa.

Evelyne **Kihiu** (Chapter 33) is an Agricultural Economist in Social and Nutritional Sciences at the International Potato Center (CIP).

Komalawati **Komalawati** (Chapter 26) is a Senior Researcher at the Research Center for Cooperatives, Corporations, and People's Economy, the National Research and Innovation Agency (BRIN), Indonesia.

Jawoo **Koo** (Chapter 15) is a Senior Research Fellow in the Natural Resources and Resilience Unit at the International Food Policy Research Institute (IFPRI).

Gideon **Kruseman** (Chapter 34) is Founder of Kruseman Foresight and Metrics Consultancy.

Cody **Kugler** (Chapter 12) is an independent agrifood innovation and sustainability consultant.

Els **Lecoutere** (Chapter 4) is a Science Officer at the CGIAR Gender Equality and Inclusion Accelerator.

Marilia **Magalhaes** (Chapter 4) is a Senior Research Analyst in the Natural Resources and Resilience Unit at the International Food Policy Research Institute (IFPRI).

Hazel **Malapit** (Chapter 4) is a Senior Research Coordinator in the Poverty, Gender, and Inclusion Unit at the International Food Policy Research Institute (IFPRI).

Ifan **Martino** (Chapter 26) is Coordinator for Food at the Ministry of National Development Planning/ Bappenas, Indonesia.

Daniel **Mason-D'Croz** (Chapters 12, 28, and 37) is a Senior Research Associate in the Department of Global Development at Cornell University and a PhD Candidate with the Agricultural Economics and Rural Policy Group at Wageningen University and Research.

Cargele **Masso** (Chapter 5) is with CGIAR, based at the International Livestock Research Institute (ILRI) in Nairobi, Kenya.

Matthew **McCartney** (Chapter 10) is Research Group Leader in Sustainable Water Infrastructure and Ecosystems at the International Water Management Institute (IWMI).

Charles **Mensah** (Chapters 17 and 28) is a PhD student in the Department of Agricultural Economics and Agribusiness, University of Ghana, and formerly a Research Officer at the International Livestock Research Institute (ILRI).

Wulan **Metafurry** (Chapter 26) is a Policy Planner at the Ministry of National Development Planning/ Bappenas, Indonesia.

Ferdi **Meyer** (Chapter 27) is Managing Director of the Bureau for Food and Agriculture Policy (BFAP) and Professor Extraordinary in the Department of Agricultural Economics, University of Stellenbosch, South Africa.

Abhijeet **Mishra** (Chapters 9 and 36) is an Associate Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Carlo **Montes** (Chapter 8) is a Climate Scientist in Climate Action at Bioversity International.

Aline **Mosnier** (Chapter 37) is Scientific Director of the Food, Agriculture, Biodiversity, Land-use, and Energy (FABLE) Pathways Consortium and the Sustainable Development Solutions Network.

Wupe **Msukwa** (Chapter 31) is a Research Associate at the International Institute of Tropical Agriculture (IITA).

Aditi **Mukherji** (Chapter 6) is Director of the CGIAR Climate Change Adaptation and Mitigation Impact Platform.

Dadang Jainal **Mutaqin** (Chapter 26) is Director of Forestry and Water Resource Conservation at the Ministry of National Development Planning/Bappenas, Indonesia.

Ravi **Nandi** (Chapter 20) is an Innovation Systems Scientist at the International Maize and Wheat Improvement Center (CIMMYT), Bangladesh.

Swamikannu **Nedumaran** (Chapters 20 and 31) is a Principal Agricultural Economist in the Global Research Program on Enabling Systems Transformation at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Agus Eko **Nugroho** (Chapter 26) is Chairman of the Research Organization for Governance, Economy and Community Welfare at the National Research and Innovation Agency (BRIN), Indonesia.

Steven Were **Omamo** (Chapter 16) is Director of the Development Strategies and Governance Unit and Director for Africa at the International Food Policy Research Institute (IFPRI).

Jyosthnaa **Padmanabhan** (Chapter 20) is an Associate Scientist at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Karl **Pauw** (Chapter 2) is a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Valerien Olivier **Pede** (Chapters 21 and 32) is a Senior Agricultural Economist at the International Rice Research Institute (IRRI).

Diego **Pequeno** (Chapters 8, 30, and 34) is a Scientist and Wheat Crop Modeler in the Sustainable Agrifood Systems Program at the International Maize and Wheat Improvement Center (CIMMYT).

Vanessa da Fonseca **Pereira** (Chapter 23) is an Advisor at the Ministry of Agriculture and Livestock (MAPA) and analyst at Embrapa, Brazil.

Athanasios **Petsakos** (Chapters 7, 8, 33, and 37) is a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International.

Louw **Pienaar** (Chapter 27) is a Senior Analyst at the Bureau for Food and Agriculture Policy (BFAP) and Research Fellow in the Department of Agricultural Economics, University of Stellenbosch, South Africa.

Valeria **Piñeiro** (Chapters 22 and 23) is Regional Representative for Latin America and the Caribbean and Senior Research Coordinator in the Markets, Trade and Institutions Unit at the International Food Policy Research Institute (IFPRI).

Angga **Pradesha** (Chapter 26) is a Senior Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Michael **Puma** (Chapter 35) is Professor of Climate in the Columbia Climate School and Unit Director of the Center for Climate Systems Research at Columbia University and the NASA Goddard Institute for Space Studies.

Ranjitha **Puskur** (Chapter 4) is a Principal Scientist at the International Rice Research Institute (IRRI).

Roseline **Remans** (Chapter 12) is an Honorary Research Fellow at Bioversity International.

Matthew **Reynolds** (Chapter 34) is Head of the Wheat Physiology Group at the International Maize and Wheat Improvement Center (CIMMYT).

Claudia **Ringler** (Chapter 10) is Director of the Natural Resources and Resilience Unit at the International Food Policy Research Institute (IFPRI).

Ricky **Robertson** (Chapter 9) is a Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Marie **Ruel** (Chapter 3) is a Senior Research Fellow in the Nutrition, Diets and Health Unit at the International Food Policy Research Institute (IFPRI).

Sahara **Sahara** (Chapter 26) is a Professor in the Department of Economics and Director of International Trade Analysis and Policy Studies (ITAPS) in the Faculty of Economics and Management at IPB University, Indonesia.

Benjamin **Schiek** (Chapters 7 and 8) is a Senior Research Associate in the Performance, Innovation and Strategic Analysis for Impact Program at CIAT.

Sedithippa Janarthanan Balaji (Chapter 25) is a Scientist in the National Institute of Agricultural Economics and Policy Research at the Indian Council of Agricultural Research (ICAR).

Dewa **Setyawati** (Chapter 26) is a Researcher in International Trade Analysis and Policy Studies (ITAPS) in the Faculty of Economics and Management at IPB University, Indonesia.

Kai **Sonder** (Chapters 8, 30, and 34) is Head of the Geographic Information System Unit in the Sustainable Agrifood Systems Program at the International Maize and Wheat Improvement Center (CIMMYT).

Tahlim **Sudaryanto** (Chapter 26) is a Senior Agricultural Economist at the National Research and Innovation Agency (BRIN) and Indonesian Agriculture Research Alliance (APPERTANI), Indonesia.

Timothy B. **Sulser** (Chapters 3, 29, and 36) is a Senior Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Johannes **Svensson** (Chapter 37) is a Technical Manager of Research on Terrestrial Ecosystems and the Governance of Land Use Transitions at the Basque Center for Climate Change (BC3), and an associated researcher at the Institut du Développement Durable et des Relations Internationales (IDDRI).

Kindie **Tesfaye Fantaye** (Chapters 18 and 30) is Head of Climate Adaptation and Resilience at AGRA, and formerly a Principal Scientist at the International Maize and Wheat Improvement Center (CIMMYT).

Shakuntala H. **Thilsted** (Chapter 3) is Director of the CGIAR Nutrition Impact Platform.

Judy **Thomas** (Chapter 20) is a Research Fellow at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Timothy **Thomas** (Chapters 6 and 18) is a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Philip **Thornton** (Chapter 12) is an Emeritus Fellow at the International Livestock Research Institute (ILRI), a visiting professor at Cornell University, a Research and Innovation Strategist with Clim-Eat, and an Honorary Professor in the School of Geosciences at the University of Edinburgh.

James **Thurlow** (Chapter 14) is Director of the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Nhuong **Tran** (Chapters 21 and 29) is a Senior Researcher and Lecturer at Hanoi School of Business and Management, Vietnam National University (HSB-VNU), and Honorary Associate Professor in the Crawford School of Public Policy at The Australian National University (ANU), and formerly an Applied Economic Senior Scientist at WorldFish.

Harold Glenn **Valera** (Chapters 21 and 32) is a Principal Researcher in the BSP Research Academy at the Bangko Sentral ng Pilipinas in Manila, The Philippines, and formerly a Scientist at the International Rice Research Institute (IRRI).

Irwanda Wisnu **Wardhana** (Chapter 26) is Director of the Research Center for Cooperatives, Corporations and People's Economy at the National Research and Innovation Agency (BRIN), Indonesia.

Keith **Wiebe** (Chapters 1 and 37) is a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Wenqian **Xu** (Chapter 2) is a Research Analyst in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Vivi **Yulaswati** (Chapter 26) is Deputy Minister for Economy and Digital Transformation at the Ministry of National Development Planning/Bappenas, Indonesia.

Heather **Zornetzer** (Chapter 12) is Coordinator of the Innovative Food System Solutions (IFSS) Portal at Bioversity International.

Monika **Zurek** (Chapter 37) is a titular associate professor and lead of the Food System Transformation Group at the Environmental Change Institute at the University of Oxford.

CGIAR

IFPRI INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

Introduction: WHAT ARE FOOD SYSTEMS AND WHAT CAN WE KNOW ABOUT THEIR FUTURE?

Keith Wiebe (IFPRI) and Elisabetta Gotor (Bioversity International)

Key messages

- Food systems are made up of the people, resources, and activities involved in the production, processing, distribution, and consumption of food.
- We cannot know the future of food systems with certainty, but we can make informed projections about alternative possible futures and ways to achieve (or avoid) them.
- This book provides a mosaic of perspectives from a diverse group of experts on the state of knowledge about different aspects of the future of food systems and how they are interlinked.
- Pressure on land and water resources is projected to increase, extreme events will become more frequent, and healthy diets will remain out of reach for many, but innovation and improved policies and investments can help address these challenges.
- Synergies and trade-offs between these different challenges and goals mean that they need to be understood and addressed as integrated parts of dynamic food systems.

WHAT ARE FOOD SYSTEMS (AND WHY DO WE CARE ABOUT THEM)?

After air and water, food is our most basic need. Yet unlike air and water, food also forms an essential part of our identities as families and communities. Food production is the world's largest use of water and land (FAO 2024, 2025; Ritchie and Roser 2019). Until recently, agriculture was also the world's largest source of employment. Today, a quarter of the world's labor force still works in agriculture, with an even greater proportion in low- and middle-income countries (Roser 2023).

But food involves much more than production and consumption. The tremendous growth in variety, abundance, and year-round availability of food that we have experienced in recent decades has been enabled by related growth in the supply chains that link producers to consumers, including processing, storage, transportation, and marketing. This wider set of essential and closely connected activities makes up our food system (Erickson et al. 2010; Ingram 2011; HLPE 2014, 2017; Food Systems Dashboard 2025).

These activities are in turn related to energy, innovation, technology, roads, and many other domains, so in a sense, food systems are all-encompassing. Instead of considering a single food system, it can be useful to think of multiple interconnected food (or agrifood) systems operating at different scales, just as local markets are connected to a larger global market, and local internet service providers are part of a larger worldwide web. While the boundaries of these various food systems may be difficult to delineate, it is not necessary to define food systems precisely to appreciate their importance. Indeed, it is estimated that nearly half the world's people live in households that depend at least partly on agrifood systems for their livelihoods (Davis et al. 2023), and all 8 billion of us are part of food systems as consumers.

Food systems have achieved remarkable progress in recent decades, but they will also face significant challenges in delivering the many outputs and services we expect and need from them in the future (ISDC 2023). For example, progress in reducing hunger has slowed and even reversed in recent years, while the incidence of micronutrient deficiencies and obesity is rising (FAO, IFAD, UNICEF, WFP, and WHO 2024). Pressure on land, water, biological, and atmospheric resources is increasing (FAO 2017; IPCC 2023). Meanwhile, despite the fundamental importance of food systems, those who earn their living from food production often earn much less than those in other economic sectors (World Bank 2025). Looking ahead, the Independent Science for Development Council identifies nine major trends that will continue to affect agrifood systems: demographic trends, changing consumption patterns, market concentration, climate change, environmental degradation, shifting global health challenges, geopolitical instability, growing inequalities, and new technologies and innovations (ISDC 2023).

These interrelated challenges mean that to consider the future of food, we need to look beyond food production to the wider set of activities that bring food to our tables and beyond food consumption to the wider set of impacts and outcomes for people and planet that characterize the performance of those activities. We need to look at food systems.

WHAT CAN WE KNOW ABOUT THE FUTURE OF FOOD SYSTEMS?

Strictly speaking, nothing. Without a crystal ball, we cannot know the future with certainty. But decisions that will affect the future of food systems still need to be made today, and there are insights we can offer with confidence to help guide those decisions.

First, we can draw on experience and understanding of the past and present to make reasoned inferences about the future. This may involve a variety of foresight approaches. Since the dawn of agriculture, farmers (such as the family of 3-year-old Rosita on the cover of this book) have had to make decisions about when and where to plant their crops without knowing what weather and market conditions would be like during the weeks and months before harvest time. Instead, they have drawn on their experience and expectations as a guide. When we consider the future of larger and more complex food systems in a world that is becoming more uncertain, more complex foresight methods are needed, including quantitative tools such as statistical analysis and simulation modeling (see Chapter 37 on foresight modeling).

Second, the future depends partly on choices we — as individuals and society — have not yet made. This presents an opportunity but also a challenge. The opportunity is that we have the chance to inform those choices through analysis and engagement with public and private decision-makers and other stakeholders. The challenge is that the interacting processes that make up food systems are extremely complex, and the goals of decision-makers and other stakeholders are extremely diverse (and sometimes conflicting).

By combining sophisticated quantitative analysis of food systems and qualitative engagement processes with stakeholders, we can identify and explore the likely impacts of alternative future scenarios based on alternative development pathways and external factors, and use the resulting insights to inform the decisions we make about food systems today. So, although we cannot know the future of food systems with certainty, we do know something about *possible* futures of food systems, and what we can do to help achieve (or avoid) them. That is the subject of this book.

THIS BOOK

This book presents a collection of short chapters on the current state of knowledge about different aspects of the future of food systems, written by a diverse group of scientists with experience and expertise in a wide range of related topics, disciplines, and regions. The 109 contributors come from across CGIAR and many other partner research institutions around the world. This collection was begun as part of the CGIAR Research Initiative on Foresight during the 2022–2024 period and completed as part of the ongoing area of work on foresight and prioritization under the CGIAR Science Program on Policy Innovations.

Each chapter examines a particular aspect of food systems, using a standard format to concisely describe recent trends and challenges that highlight the importance of the topic, summarize the latest available foresight research on that topic, and identify key gaps in existing foresight research that merit further attention in the future. These chapters are intended as brief and accessible overviews of the latest foresight research on each topic, guides to help readers find more detailed information if desired, and indications of where our current knowledge of future trends needs to be improved.

The collection includes 15 chapters focused on major drivers and impacts of change in food systems, 11 chapters that provide regional and national perspectives on the future of food systems, 7 chapters on the future of major food commodities, and 3 chapters on food systems measurement and modeling tools.

Even with this diverse set of contributions, the picture remains incomplete. Given the complexity of food systems, it is impossible to characterize them fully. Some topics are missing, and others could easily be developed in much greater detail. We look forward to adding topics that are missing from this collection (such as demographics and genetic resources) and to developing aspects of included chapters that merit expansion.

In a world of complexity and uncertainty, the goal of this book — and the purpose of foresight analysis, more generally — is not to predict the future with precision, but rather to carefully consider and present what can be known about possible future pathways in order to inform choices today.

KEY INSIGHTS

The picture that emerges from this collection highlights the continuing **challenges** that food systems will confront in the coming decades. Poverty will become more geographically concentrated (Chapter 2), healthy diets will remain out of reach for many (Chapter 3), inequalties will persist (Chapters 4 and 14), pressure on land, water, and other resources will increase (Chapters 5 and 7–10), and extreme events will become more frequent (Chapters 6 and 15). Regional and commodity perspectives (Chapters 17–22 and 28–34) illustrate the diversity of challenges, including continued population growth in Africa (versus slowing growth or population declines elsewhere), projected increases in dependence on food imports in low-income countries, and rapid growth in demand for animal-source foods from middle-income populations. They also illustrate commonalities, including rising health concerns associated with overweight and obesity in most regions.

The collection also highlights the importance of **interactions** — including both synergies and trade-offs — across the many dimensions of food systems, including between drivers of change, regions, commodities, and time periods, as well as among the many outcomes that food systems deliver. For example, improving access to markets may reduce costs for both producers and consumers, but it may also increase pressure on land and water resources. This does not mean that one goal is necessarily more important than another, just that care is needed to understand the multiple consequences (including the unintended ones) of different food systems pathways in order to make better-informed decisions and minimize their costs.

The collection also highlights **opportunities** to address these challenges, including rapid growth in renewable energy (Chapter 11); the critical importance of innovation more generally (Chapter 12), along with its potential to improve efficiency, reduce costs, and lessen trade-offs across multiple goals and interests; and the importance of trade (Chapter 13) and food assistance (Chapter 16) in helping to offset local and regional impacts of conflict and weather shocks. Insights from various countries (Chapters 23–27) show how foresight analysis is already informing food systems policies and investment strategies around the world. Finally, continuous improvements are being made in the data and analytical tools needed (Chapters 35–37) to explore alternative food systems futures, identify challenges and solutions, weigh trade-offs, and inform the choices we face today.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Keith Wiebe**, a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); and **Elisabetta Gotor**, a Principal Scientist and Lead of the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Wiebe, K., and E. Gotor. 2025. "Introduction: What Are Food Systems and What Can We Know About Their Future?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 1. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Ricky Martin/CIFOR

References

Davis, B., E. Mane, L.Y. Gurbuzer et al. 2023." Estimating Global and Country-Level Employment in Agrifood Systems." FAO Statistics Working Paper Series, No. 23-34. Rome, FAO. https://doi.org/10.4060/cc4337en

Ericksen, P.J., B. Stewart, J. Dixon, D. Barling, P. Loring, M. Anderson, and J. Ingram. 2010. "The Value of a Food System Approach." In *Food Security and Global Environmental Change*, eds. J. Ingram, P. Ericksen, and D. Liverman, 25–45. London: Earthscan.

FAO (Food and Agriculture Organization of the United Nations). 2017. *The Future of Food and Agriculture: Trends and Challenges*. Rome. https://www.fao.org/global-perspectives-studies/fofa/en/

FAO. 2024. *World Food and Agriculture – Statistical Yearbook 2024*. Rome. https://openknowledge.fao.org/handle/20.500.14283/cd2971en

FAO, IFAD (International Fund for Agricultural Development), UNICEF, WFP (World Food Programme), and WHO (World Health Organization). 2024. *The State of Food Security and Nutrition in the World 2024 – Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms*. Rome: FAO. https://doi.org/10.4060/cd1254en

FAO, OECD (Organisation for Economic Co-operation and Development), and World Bank. 2025. "Agricultural Water as a Share of Total Water Withdrawals." Our World in Data dataset. Accessed June 16, 2025. https://ourworldindata.org/grapher/agricultural-water-as-a-share-of-total-water-withdrawals

Food Systems Dashboard. 2025. "About Food Systems." Accessed May 20, 2025. https://www.foodsystemsdashboard.org/information/about-food-systems

HLPE (High Level Panel of Experts). 2014. *Food Losses and Waste in the Context of Sustainable Food Systems: A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Rome. https://www.fao.org/cfs/cfs-hlpe/publications/hlpe-8

HLPE. 2017. *Nutrition and Food Systems. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Rome. https://www.fao.org/cfs/cfs-hlpe/publications/hlpe-12

ISDC (Independent Science for Development Council). 2023. *Responding to Evolving Megatrends*. Rome: CGIAR Independent Advisory and Evaluation Service. https://iaes.cgiar.org/isdc/publications/responding-evolving-megatrends

Ingram, J. 2011. "A Food Systems Approach to Researching Food Security and Its Interactions with Global Environmental Change." *Food Security* 3: 417–431. https://doi.org/10.1007/s12571-011-0149-9

IPCC (Intergovernmental Panel on Climate Change). 2023. "Summary for Policymakers." In *Climate Change 2023: Synthesis Report*, ed. H. Lee, 1–34. Geneva: IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Ritchie, H., and M. Roser. 2019. "Land Use." *Our World in Data*. Accessed June 16, 2025. https://ourworldindata.org/land-use

Roser, M., 2023. "Employment in Agriculture." *Our World in Data*. Accessed June 16, 2025. https://ourworldindata.org/employment-in-agriculture

World Bank and OECD. "Agriculture Value Added per Worker vs. GDP per Capita, 2022." Our World in Data dataset. Accessed June 17, 2025. https://ourworldindata.org/grapher/agriculture-value-added-per-worker-vs-gdp-per-capita?time=2022

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FOOD SYSTEMS DRIVERS AND IMPACTS?

What do we know about THE FUTURE OF POVERTY IN RELATION TO FOOD SYSTEMS?

Karl Pauw (IFPRI), Paul Dorosh (IFPRI), Wenqian Xu (IFPRI), and Jean Balié (CGIAR)

Key messages

- The global poverty headcount rate declined rapidly over the past 25 years, from around 30 percent to 8.5 percent today, but a series of global crises caused the pace of poverty reduction to slow down from 2020 onward. Some regions have done well; for instance, the East Asia and Pacific region has now effectively eliminated extreme poverty, a Sustainable Development Goal (SDG), while extreme poverty in South Asia is expected to be eradicated by 2030. But with almost no further reduction in the extreme poverty rate in sub-Saharan Africa until 2030, the number of poor people in this region will increase by 10 percent to reach 500 million. This means that by 2030, around 80 percent of the world's poor people will live in sub-Saharan Africa.
- Poverty and food systems are closely intertwined. Both theory and evidence support the notion that investments in food systems that reduce food prices or create food systems jobs will be highly effective at reducing poverty, and likely more so than investments outside of the food system, especially during the earlier stages of a country's development. With respect to investments within food systems, since the majority of the world's extreme poor are engaged in farming, investments in the on-farm part of food systems are likewise more effective at reducing extreme poverty than off-farm investments, such as in processing, distribution, and food services. However, rural-urban migration and structural shifts in employment into off-farm jobs, combined with growing demand for processed foods from retail or food service outlets, will gradually increase the poverty-reducing impacts of off-farm investments. Foresight analysis

can help policymakers anticipate employment and dietary shifts and identify the mix of food systems investments that would maximize their impact on extreme poverty.

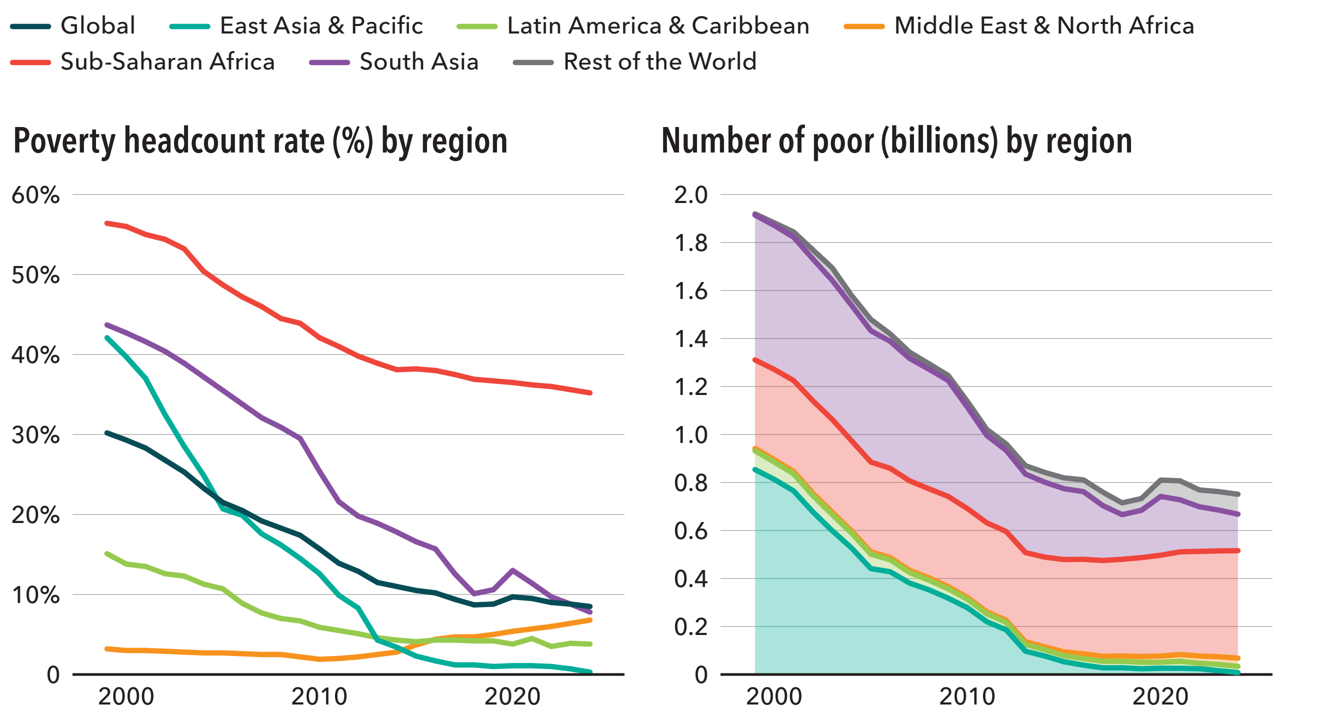
- Policies and investments designed to facilitate food systems transformation may be associated with trade-offs across development outcomes. For instance, while investments in staple crop productivity may be most effective at reducing poverty and calorie availability, they may not contribute to improving dietary quality or health outcomes, which are also important SDGs. Likewise, regulations that encourage the adoption of environmentally conscious food production processes, also central to several of the SDGs, may raise the cost of food, with negative consequences for poverty. At the same time, inaction now to facilitate a transition toward more sustainable food systems will contribute to conflicts, disasters, physical displacement, and adverse health and economic outcomes in the future, the burden of which will fall disproportionately on future generations of poor people. Foresight analysis can help policymakers understand these trade-offs as they consider alternative investment choices and measures to protect vulnerable populations from any adverse impacts.

RECENT TRENDS AND CHALLENGES

Although poverty is a complex, multifaceted phenomenon, it can be broadly defined as the lack of basic capacity to maintain a minimum standard of living and participate effectively in society. Important strides have been made in the fight against poverty over the past 25 years. As shown in Figure 1, the global poverty headcount rate — measured at the World Bank's "extreme" poverty line of US$2.15 per day (2017 PPP prices) — fell from 30.0 percent to 8.5 percent between 1999 and 2024, while the number of poor people declined from 1.8 to 0.7 billion — even as the global population grew from 6.1 to 8.1 billion (World Bank 2024a).

Figure 1 also highlights regional disparities in poverty outcomes. South Asia, renowned for successfully transforming

FIGURE 1 Poverty rates and number of people in poverty, 1999–2024



Source: Authors' representation based on World Bank (2024a, 2024b).

its agriculture sector during the "Green Revolution" in the 1960s and 1970s (Pingali 2012), saw its poverty rate decline faster than the global average from 1999 to 2024. Poverty in the East Asia and Pacific region was effectively eliminated over the same period on the back of the "East Asian Miracle" from 1965 to 1990, a period of rapid structural change and growth led by manufacturing exports (Birdsall et al. 1993). Sub-Saharan Africa experienced its own "African Growth Miracle" in the early 2000s, with economic growth outpacing that in the rest of the world (McMillan, Diao, and Verduzco-Gallo 2014) and a decline in poverty that was evidently much faster than previously thought possible (Sala-i-Martin and Pinkovskiy 2010).

Unfortunately, by 2012, poverty reduction in sub-Saharan Africa slowed down. Today the region is home to almost two-thirds of the world's poor despite only making up 15 percent of the global population. Several other regions also started experiencing a decline in the rate of poverty reduction from 2020 onward as the COVID-19 pandemic adversely impacted livelihoods (Pauw, Smart, and Thurlow 2021) and the Russia-Ukraine war contributed to rising costs of living (Arndt et al. 2023).

LATEST FORESIGHT RESEARCH

The World Bank (2024b) projects that poverty in sub-Saharan Africa will decline only marginally, from 8.5 to 7.3 percent during the 2024–2030 period. Regional poverty projections by Kharas and Dooley (2022) suggest that South Asia will eradicate extreme poverty by 2030. But in sub-Saharan Africa, with virtually no further reduction in the poverty rate, the number of poor people will expand by about 10 percent to reach 500 million by 2030, or about 80 percent of the global population of poor people. Sub-Saharan Africa should clearly be a key priority in the global fight against poverty in the coming 5 to 10 years.

With over 80 percent of the world's extreme poor living in rural areas and nearly two-thirds of them engaged in primary agriculture (UN 2023), agricultural productivity growth has been found to be especially effective at reducing extreme poverty (Christiaensen, Demery, and Kuhl 2011). Such productivity growth might be associated with land productivity (for example, due to improved soil quality) or labor productivity (for example, the effects of education combined with the adoption of better technologies or machinery). Agricultural productivity growth has been shown to be relatively more effective at reducing poverty than equivalent-sized productivity gains in industry or services (Dorosh and Thurlow 2018; Ivanic and Martin 2018), provided product, factor, or credit market failures do not exclude poor farmers from profitable opportunities to grow out of poverty (Dercon 2009). Of course, the benefits of agricultural productivity growth are not restricted to farm households. Household food budget shares in low-income South Asian and sub-Saharan African countries average around 40–50 percent (USDA 2023), with even higher shares for poor households within those countries. Since agricultural productivity gains help lower farm output prices, they can contribute significantly to poverty reduction among rural nonfarm and urban households that consume agricultural products.

Agricultural productivity growth — or agricultural transformation more broadly — provides the impetus for structural change and rural-urban migration (Johnston and Mellor 1961; Timmer 1988), but the net impact of structural change on growth is not always positive (McMillan, Diao, and Verduzco-Gallo 2014), and may even result in urban slums and rising urban poverty (see Chapter 14). Rural-urban migration is also associated with growing demand for processed and convenience foods from retail or food service outlets as opposed to unprocessed farm produce (Barret et al. 2022), such that the share of food processing, packaging, trade, and transport costs in the overall cost of food rises. These dynamics affect the relative effectiveness of on-farm versus off-farm investments in reducing poverty. In the context of Ethiopia, Dorosh et al. (2020) show that investments in nonagriculture sectors become more important for poverty reduction after approximately 10 years of sustained growth and structural transformation. Dorosh and Thurlow (2018), in turn, show that among the nonagriculture sectors, investments in those sectors with strong connections to the food system, such as food processing, trade, or transport, have larger impacts on poverty than those in nonfood manufacturing or service sectors.

The global food system is operating beyond its planetary boundaries (Steffen et al. 2015; Ruggeri et al. 2024). The resulting degradation of environmental systems and greenhouse gas emissions contribute to fragile settings characterized by conflict, disaster, and physical displacement and worsening food security, diet quality, and nutrition outcomes. By 2030, 2.8 billion people will live in fragile settings, up from 1.8 billion in 2020, and 80 percent of them will be poor (GLOPAN 2020). Not only are food systems in urgent need of transformation, but the burden of climate *inaction* will also fall disproportionately on the poor. The urgency of food systems transformation also challenges conceptions around poverty measurement. Poverty lines are traditionally derived from the cost of calories required to sustain human activity. However, food systems should provide more than sufficient calories; they should also ensure that healthy, sustainably produced foods are affordable to poor people (Willet et al. 2019). The global average cost of a healthy diet is estimated at around US$3.30 per day in 2017 prices (FAO 2024), more than 50 percent higher than the global poverty line of US$2.15. Eradicating extreme poverty will not be enough to ensure that all people can afford a healthy diet. More ambitious poverty reduction targets should be adopted if the poor are expected to contribute to more sustainable food systems through their dietary choices.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Foresight analysis can inform the design of food systems policies and investment programs aimed at facilitating transformation and poverty reduction. Investments that raise on-farm productivity in agriculture remain important for driving poverty reduction among the many poor farm households around the world. However, structural change and dietary shifts mean the effectiveness of investments in the off-farm components of the food system, such as food processing, distribution, and food services, will gradually become more important in reducing poverty. Foresight analysis can help policymakers anticipate these changes and adjust their investment allocation decisions across the on- and off-farm components of food systems accordingly.

Potential trade-offs arise across development outcomes. Poverty reduction is not the only development goal of food systems transformation. Others include improved availability and access to healthy foods and the transition toward environmentally sustainable food production practices. Policies that target one development outcome may have unintended consequences for others. For instance, investing in staple crops might be highly effective at reducing extreme poverty but may have adverse implications for diet quality (for example, if it results in overconsumption of calories and lower consumption of healthy foods) or for the environment (for example, because of land use change or increased use of inorganic fertilizer). Likewise, regulations that encourage the adoption of sustainable food production processes (for example, limits on greenhouse gas emissions in food processing or transport) could raise the cost of food, with implications for poverty or diet quality. Foresight analysis can help policymakers identify potential trade-offs associated with the policies they design so that they can implement measures to protect vulnerable households from any adverse impacts.

Trade-offs — or synergies — may also exist between current and future development outcomes. Making quality diets more affordable for poor people today results in a healthier, more productive workforce and higher lifetime earnings. Better diets are also associated with improved learning among school-aged children and better earnings prospects in the future. These future benefits may offset current costs. Conversely, delaying or slowing down the transition toward sustainable food systems may save financial resources today, but the burden of environmental degradation that may follow as a result will be shifted onto future generations of poor people. Foresight analysis can account for future streams of benefits and costs, which in turn can inform optimal budgetary allocations today.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Karl Pauw**, a Senior Research Fellow in the Foresight and Policy Modeling (FPM) Unit at the International Food Policy Research Institute (IFPRI); **Paul Dorosh**, a Senior Research Fellow in FPM at IFPRI; **Wenqian Xu**, a Research Analyst in FPM at IFPRI; and **Jean Balié**, Director of the CGIAR Poverty Reduction, Livelihoods and Jobs Impact Platform.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Pauw, K, P. Dorosh, W. Xu, and J. Balié. 2025. "What Do We Know About the Future of Poverty in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 2. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Damian Ryszawy/Shutterstock

References

Arndt, C., X. Diao, P. Dorosh, K. Pauw, and J. Thurlow. 2023. "The Ukraine War and Rising Commodity Prices: Implications for Developing Countries." *Global Food Security* 36: 100680. https://doi.org/10.1016/j.gfs.2023.100680

Barrett, C.B., T. Reardon, J. Swinnen, and D. Zilberman. 2022. "Agri-Food Value Chain Revolutions in Low- and Middle-Income Countries." *Journal of Economic Literature* 60 (4): 1316–77. https://doi.org/10.1257/jel.20201539

Birdsall, N., J.E.L. Campos, C. Kim, et al. 1993. *The East Asian Miracle: Economic Growth and Public Policy*. World Bank Policy Research Report. Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/975081468244550798/Main-report

Christiaensen, L., L. Demery, and J. Kuhl. 2011. "The (Evolving) Role of Agriculture in Poverty Reduction: An Empirical Perspective." *Journal of Development Economics* 96 (2011): 239–254. https://doi.org/10.1016/j.jdeveco.2010.10.006

Dercon, S. 2009. "Rural Poverty: Old Challenges in New Contexts." *World Bank Research Observer* 24 (1): 1–28. https://doi.org/10.1093/wbro/lkp003

Dorosh, P. and J. Thurlow. 2018. "Beyond Agriculture Versus Non-Agriculture: Decomposing Sectoral Growth–Poverty Linkages in Five African Countries." *World Development* 109 (2018): 440–451. https://doi.org/10.1016/j.worlddev.2016.08.014

Dorosh, P. and J. Thurlow. 2024. "What Do We Know about the Future of Urbanization in Relation to Food System Transformation?" CGIAR Initiative on Foresight. https://www.cgiar.org/news-events/news/what-do-we-know-about-the-future-of-urbanization-food-system-transformation/.

Dorosh, P., J. Thurlow, F. Kebede, T. Ferede, and A. Taffesse. 2020. "Public Investments and Poverty Reduction." In *Ethiopia's Agri-Food System: Past Trends, Present Challenges, and Future Scenarios*, eds. P. Dorosh and B. Minten, 423–460. Washington, DC: IFPRI. https://hdl.handle.net/10568/143243.

FAO (Food and Agriculture Organization of the United Nations). 2024. FAOSTAT: Cost and Affordability of a Healthy Diet. Accessed December 2024. https://www.fao.org/faostat/en/#data/CAHD

GLOPAN (Global Panel on Agriculture and Food Systems for Nutrition). 2020. *Future Food Systems: For People, Our Planet, and Prosperity*. London, UK. https://www.glopan.org/wp-content/uploads/2020/09/Foresight-2.0_Future-Food-Systems_For-people-our-planet-and-prosperity.pdf

Ivanic, M., and W. Martin. 2018. "Sectoral Productivity Growth and Poverty Reduction: National and Global Impacts." *World Development* 109: 429–439. https://doi.org/10.1016/j.worlddev.2017.07.004

Johnston, B., and J. Mellor. 1961. "The Role of Agriculture in Economic Development." *The American Economic Review* 51 (4): 566–593. https://www.jstor.org/stable/1812786

Kharas, H., and M. Dooley. 2022. "The Evolution of Global Poverty, 1990–2030." Brookings Global Working Paper #166 (February), Center for Sustainable Development at Brookings, Washington, DC. https://www.brookings.edu/wp-content/uploads/2022/02/Evolution-of-global-poverty.pdf

McMillan, M., X. Diao, and I. Verduzco-Gallo. 2014. "Globalization, Structural Change, and Productivity Growth, with an Update on Africa." *World Development* 63: 11-32. https://doi.org/10.1016/j.worlddev.2013.10.012

Pauw, K., J. Smart, and J. Thurlow. 2021. "The Short-Run Economic Costs of COVID-19 in Developing Countries in 2020: A Synthesis of Results from a Multi-Country Modeling Exercise." Project Note (June). Washington, DC: IFPRI. https://doi.org/10.2499/p15738coll2.134430

Pingali, P.L. 2012. "Green Revolution: Impacts, Limits, and the Path Ahead." *PNAS* 109 (31): 12302–12308. https://doi.org/10.1073/pnas.0912953109

Ruggeri, C., H. Lotze-Campen, F. DeClerck, et al. 2024. *The Economics of the Food System Transformation. Food System Economics Commission (FSEC), Global Policy Report*. https://foodsystemeconomics.org/wp-content/uploads/FSEC-GlobalPolicyReport-February2024.pdf

Sala-i-Martin, X., and M. Pinkovskiy. 2010. "African Poverty is Falling...Much Faster than You Think!" NBER Working Paper 15775. National Bureau of Economic Research, Cambridge, MA. http://www.nber.org/papers/w15775

Steffen, W., K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, and S. Sörlin. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223): 1259855. https://doi.org/10.1126/science.1259855

Timmer, P. 1988. "The Agricultural Transformation." *Handbook of Development Economics* 1: 275–331. https://doi.org/10.1016/S1573-4471(88)01011-3

UN (United Nations). 2023. *Eradicating Rural Poverty to Implement the 2030 Agenda for Sustainable Development*. Report of the Secretary-General, 23 July. https://documents.un.org/doc/undoc/gen/n23/220/67/pdf/n2322067.pdf

USDA (United States Department of Agriculture). 2023. Lower income countries spend much higher share of expenditures on food than higher income countries. Accessed December 2024. https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=107494

Willett, W., J. Rockström, B. Loken, M. Springmann, T. Lang, S. Vermeulen, and C.J. Murray. 2019. "Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems." *Lancet* 393 (10170): 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

World Bank. 2024a. World Development Indicators. Accessed December 2024. https://databank.worldbank.org/source/world-development-indicators

World Bank. 2024b. *Poverty, Prosperity, and Planet Report 2024: Pathways Out of the Polycrisis*. Washington, DC. https://www.worldbank.org/en/publication/poverty-prosperity-and-planet

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF DIETS AND NUTRITION?

Timothy B. Sulser (IFPRI), Marie Ruel (IFPRI), and Shakuntala H. Thilsted (CGIAR)

Key messages

- Diets continue to evolve and nutrition challenges are changing as diets shift from traditional to more modern ones that are higher in animal-source foods, refined grains, and processed and ultra-processed foods; high in saturated fats, sugar, and salt; and low in fiber.
- Important progress, though uneven, has been made over several decades in improving diets and nutrition, but these trends have reversed or slowed since 2010.
- Undernutrition has decreased over time, while micronutrient deficiencies have not. Overweight and obesity are rapidly rising in all low- and middle-income countries (LMICs) and remain high in high-income countries. Multiple burdens of malnutrition coexist within countries, regions, communities, households, and individuals.
- Nutrition literature increasingly highlights the multiple burdens of malnutrition but rarely looks explicitly at future trajectories for nutritional indicators.
- Simulation studies explore alternative futures explicitly and give a good indication regarding dietary trends but are limited with respect to nutritional outcome trends.
- A critical need and opportunity exist for more work that combines nutrition with foresight modeling, particularly with a focus on LMICs.

RECENT TRENDS AND CHALLENGES

Human nutrition is the result of dietary practices as well as individuals' health and a combination of environmental and societal factors, all of which interact in a dynamic process. Nutrition is inextricably linked to diets, and factors that affect diets influence the resulting nutritional status of individuals, along with many others that determine bioavailability of nutrients from foods consumed and individuals' health status. We focus on the future developments of the diet and nutritional dimensions of this complex topic, especially in low- and middle-income countries (LMICs) and regions in which CGIAR works.

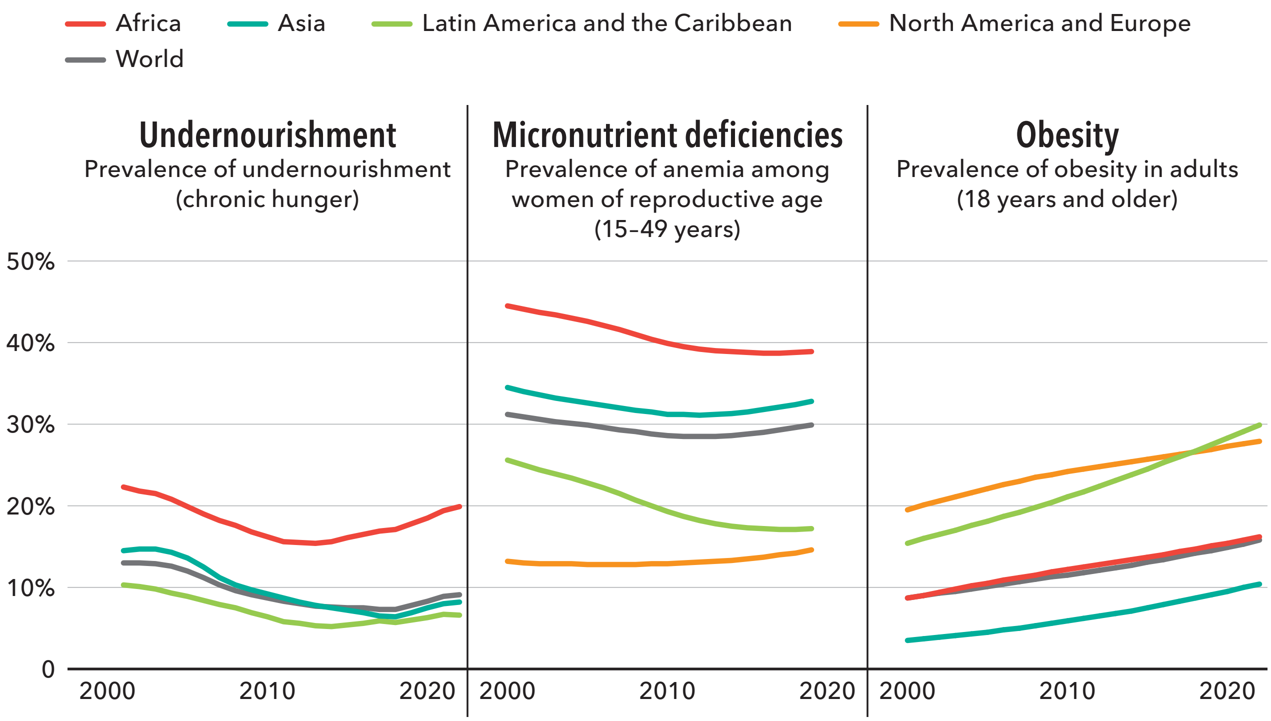
Diets and nutrition are evolving in dynamic ways as technological, agricultural, environmental, and cultural systems change and interact. Diets evolve in response to changing preferences, prices, and incomes and to cultural forces. It is well established that as incomes rise, the share of nutrient-dense foods in the diet increases (Bennett 1941a, 1941b); with near certainty, we can expect this will remain true in the future.

The nutrient content of food evolves due to factors such as breeding, production practices, climate impacts, and processing methods. Societal drivers such as education, health, and sanitation systems also exert a huge influence on the levels of nutrition that are possible with available food and diets.

Malnutrition takes three forms: **undernourishment** (energy deficiency, also referred to as "chronic hunger"), which manifests itself in child wasting or stunting and adult underweight; **micronutrient deficiencies** (also referred to as "hidden hunger"); and **overweight/obesity** and diet-related noncommunicable diseases (Figure 1). Poverty, conflict, and access issues are key drivers in the stalling and reversal of positive trends in hunger and malnutrition.

While undernourishment has decreased over the past several decades, events in recent years have either stalled progress or reversed trends in many regions. The global prevalence of undernourishment dropped 2 to 6 percentage points, depending on the region, between 2000 and 2022. Chronic hunger hit a low point in the 2010s but has been on the rise ever since.

FIGURE 1 Recent nutrition trends



Source: FAOSTAT 2025. https://www.fao.org/faostat/

Note: Chronic hunger is not tracked when it is below 5 percent, as in North America and Europe.

Although little information is available on the prevalence of micronutrient deficiencies globally, anemia—a proxy indicator of iron and potentially other micronutrient deficiencies—has declined since 2000 around the world (except in North America and Europe), but these trends have either slowed or reversed course since the 2010s. Micronutrient deficiencies are driven by a complex mix of factors, some of them related to poverty, unaffordability of nutritious foods, and poor health, and others related to awareness and preferences that cut across income levels.

Overweight/obesity is widespread and increased consistently over the same period in all regions, with prevalence doubling in many regions between 2000 and 2022. Rising incomes, urbanization, and changing food systems are the main drivers of overweight/obesity and the double burden of malnutrition, characterized by the coexistence of multiple forms of malnutrition in the same countries, households, or individuals (Popkin, Corvalan, and Grummer-Strawn. 2020).

LATEST FORESIGHT RESEARCH

A strong literature and research base documents past trends and current status across the various dimensions of diets and nutrition, and many efforts to improve nutrition in the future.

Several current research and development efforts aiming to change the future of nutrition are highly focused on specific improvements that could be achieved in the near term, though in isolation and without consideration of the full agrifood system. Nutritional benefits are foreseen from these types of improvements if and when they can be achieved and scaled up. Some of the most prominent approaches include:

- Improvements in the plants and animals we eat, including biofortification and other management and breeding efforts (Bouis and Saltzman 2017; White and Broadley 2009; Sands et al. 2009; Flax et al. 2023; Boy et al. 2024), as well as improving the mix of food items in the average food basket (Golden et al. 2021; Herforth et al. 2019).

- Supplementation and fortification, including large-scale fortification of staple foods or condiments (for example, salt, bouillon cubes) with essential micronutrients, and micronutrient-fortified products formulated for nutritionally vulnerable groups, such as lipid-based nutrient supplements or micronutrient sprinkles (Dewey et al. 2023; Osendarp et al. 2018).

- Behavior change communication strategies to educate and shape consumer preferences and food choices, as well as interventions to improve the healthiness of food environments (Fretes, Marshall, and Leroy 2024; Kim et al. 2024; Springmann et al. 2016, 2018).

Foresight research that explicitly analyzes the future of nutrition outcomes remains relatively limited, even as dietary projections at the aggregated commodity level are available (Bodirsky et al. 2015; Valin et al. 2014; van Dijk et al. 2021). Some research—such as Tigchelaar et al. (2024) or many of the EAT-Lancet analyses for a planetary health diet—assesses future diets in a quantitative framework without an economic equilibrium. This is important given the pace of change in factors affecting diets and nutrition; the time lags involved in developing approaches to address those changes; and system dynamics, with prices, preferences, and production interacting and changing simultaneously.

Quantitative foresight modeling looks at the complex interplay of drivers to estimate potential trajectories for the agrifood system. This approach provides an estimate of both the supply of and demand for agricultural commodities and many other aspects of the agrifood system. One key component of many foresight studies in the agrifood sector is the evolution of diets in terms of a complex economic equilibrium of demand and availability. Cenacchi, Sulser, and Mishra (2025) provide one example using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model. Using the same set of results, this brief highlights the changes in food availability from different food groups and of nutrients available in the food supply as shown in the projections below.

Nutritional outcomes can be included as part of the projections, depending on the focus of the research. The prevalence of undernourishment—associated with the risk of hunger and a measure of chronic hunger—is the most common metric used in foresight studies (Hasegawa et al. 2019; Sulser et al. 2021b), while hidden hunger is assessed by means of ratios of nutrient availability to recommended levels of intake (Beach et al. 2019;Nelson et al.

2018). Projections of chronic and hidden hunger can be combined into estimates of future trends in disability-adjusted life years (Sulser et al. 2021a). Several quantitative foresight analyses that focus on specific commodities or commodity groups elevate the importance of nutrition derived from particular types of foods, such as from aquatic foods (Chan et al. 2021), livestock (Enahoro et al. 2018), and fruits and vegetables (Mason-D'Croz et al. 2019). Modeling the future of overweight/obesity is estimated by a complex combination of calculations and assumptions (Bodirsky et al. 2020) and has been done by few modeling groups to date. Given the connection of modeling parameters to past trends and estimates of the structural relationships across factors in the agrifood system, the overall outlook is generally a continuation of trends that see improvements in chronic and hidden hunger and a steady increase in overweight/obesity. This broad regional outlook masks details at the country and subnational level, however, as many segments of the population face increasingly challenging situations.

Climate change is a topic of wide interest in relation to diets and nutrition. As temperature and precipitation deviate from historical trends, food production systems must adapt and the transition to new agricultural practices often leads to increased prices and less food availability, particularly in the Global South (Kompas, Nhu Che, and Grafton 2024; Sulser et al. 2021b). At the same time, the nutritional quality of food is projected to change with increasing carbon dioxide, with decreases in protein, minerals, and many vitamins, while enhancing energy content and a few select vitamins (Beach et al. 2019; Loladze 2014; Myers et al. 2014; Zhu et al. 2018). Extreme events and variability lead to additional challenges for nutrition that are often missing from many modeling exercises (Hasegawa et al. 2021).

In general, future changes in population and income are important drivers that far outweigh the climate changes represented in most model-based analyses (Hasegawa et al. 2015; Nelson et al. 2018; Sulser et al. 2021b). Increasing per capita incomes make diverse diets and their nutritional and health benefits more readily available, though concurrently, many negative forces come to the fore, including increased consumption outside the home and preferences for convenience foods that are often unhealthy, with an excess of saturated fats, sugar, and salt. At the same time, increased incomes could curb the overweight and obesity crisis if consumers adopt healthier, more balanced diets. Continued population growth and constrained incomes, on the other hand, lead to challenges for reducing chronic and hidden hunger in many regions. Both over- and undernutrition can occur simultaneously at certain levels of aggregated geographies (Bodirsky et al. 2020; Hawkes et al. 2020; Popkin, Corvalan, and Grummer-Strawn 2020).

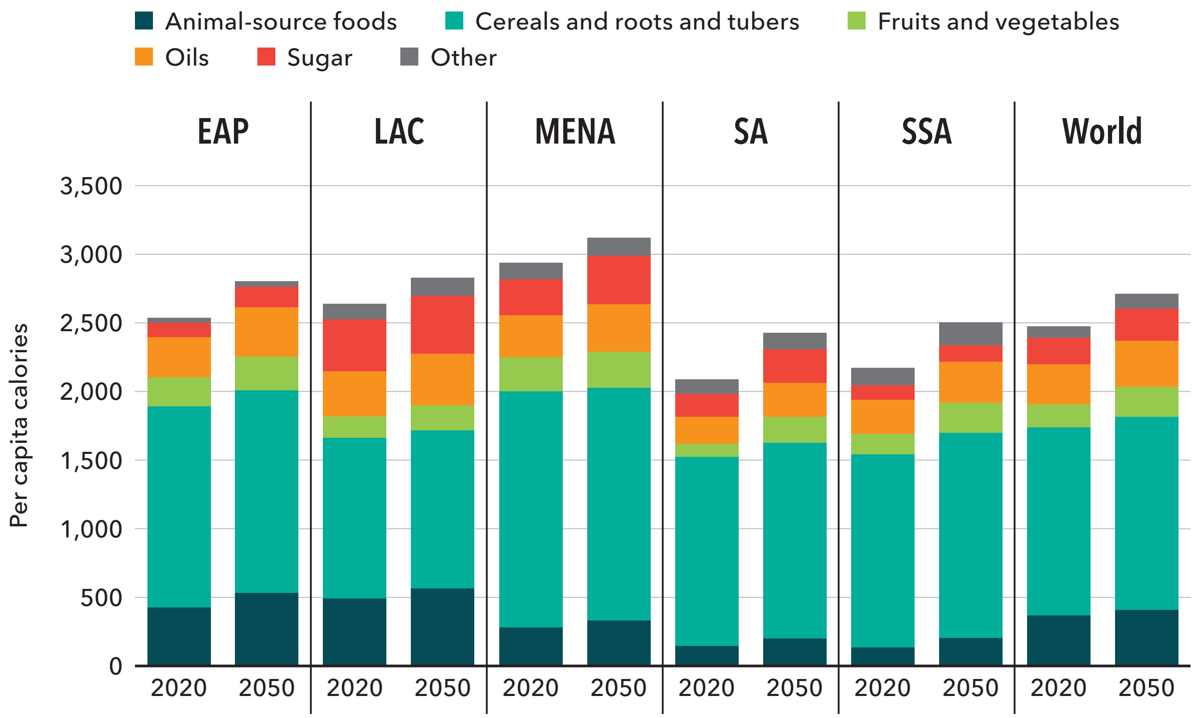
The EAT-Lancet Commission on Food, Planet, and Health (Willet et al. 2019) designed and advocated a planetary health diet that attempts to achieve the goals of healthy diets for all while keeping the agrifood system within sustainable environmental bounds for the future. This effort sparked a great deal of interest, but also skepticism regarding adoption of very low or nonmeat diets and was criticized for its focus on high-income countries and limited applicability elsewhere. Other concerns relate to its nutritional inadequacy for population groups with high nutrient requirements (for example, pregnant or lactating women) and the potentially more costly minimum adequate diet (Beal, Ortenzi, and Fanzo. 2023; Hirvonen et al. 2020). A follow-up to this work (EAT-Lancet 2.0) currently underway aims to update, expand, and strengthen this analysis while addressing some of these critiques (EAT-Lancet 2.0 Commissioners et al. 2023).

Another important development is the work to establish a standard metric of the cost of a healthy diet that ties together nationally developed food-based dietary guidelines with consumer prices, especially in low-income countries (Herforth et al. 2022). This is now incorporated in regular reports by the Food and Agriculture Organization of the United Nations and the World Bank (FAO 2024; World Bank 2024) and is the basis for work that is developing a forward-looking perspective using model projections (Costlow et al. 2025).

Recent projections from the IMPACT model provide a quick look at dietary evolution and nutrition projections (see Chapter 36 in this volume). As an extension to that presentation, Figure 2 shows the change in per capita calorie availability for major food types across regions. Several takeaway messages present themselves:

- The increase in per capita consumption of oils and sugar is clearly shown in East Asia and the Pacific, South Asia, and the Middle East and North Africa, each increasing by over 100 calories combined by 2050. The high-income countries, however, are projected to consume more than 1.5 times more calories from oils and sugars than LMICs.

FIGURE 2 **Per capita calorie availability from major food groups in current and future diets, 2020 and 2050, by region**



Source: IMPACT v3.4, in Rosegrant et al. (2024).

Note: EAP = East Asia and Pacific; LAC = Latin America and Caribbean; MENA = Middle East and North Africa; SA = South Asia; SSA = Sub-Saharan Africa.

- The share of calories from starchy cereals and roots and tubers is declining relative to more nutrient-dense, animal-source foods, fruits and vegetables, and oils and sugars. Some regions even show negative growth trends for calories from starches.
- The increased share of animal-source foods, especially in East Asia and the Pacific and Latin America and the Caribbean, will require careful consideration to focus on healthier options and avoid processed red meat, associated with harmful health outcomes.

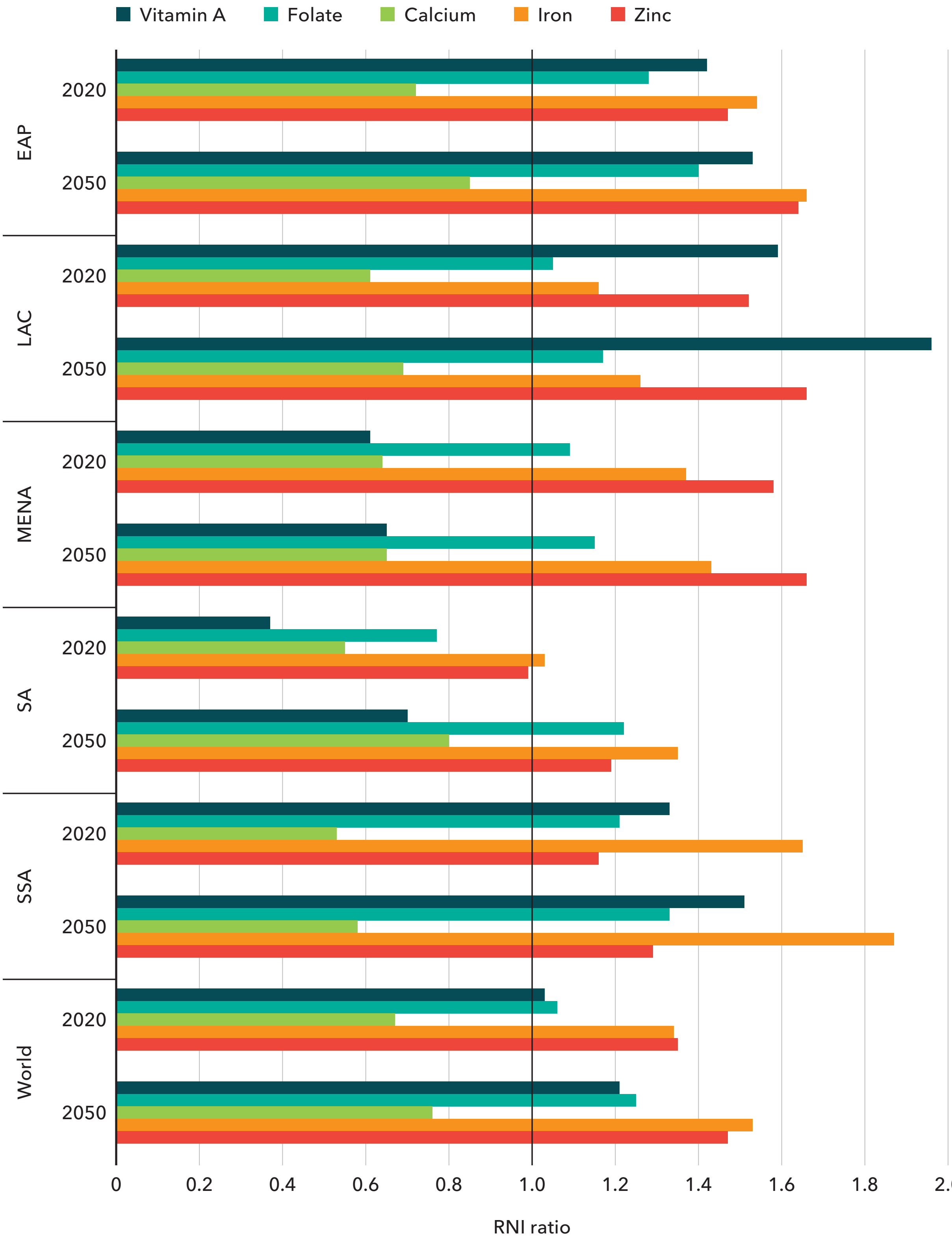
Based on per capita food availability, we compare nutrient availability with recommended nutrient intake levels (RNI ratios), following Beach et al. (2019) and Nelson et al. (2018). RNI ratios close to one mean that the average consumer might be able to meet recommendations while values below one indicate the opposite.

Figure 3 shows the change in regional RNI ratios for five key vitamins and minerals for 2020 and 2050. Calcium supplies are insufficient everywhere to meet dietary requirements. In contrast, iron and zinc have RNI ratios greater than one, indicating that a larger share of the population should have access to adequate supplies of these nutrients though, in practice, many factors could limit their bioavailability. Vitamin A and folate show a pattern similar to iron and zinc in most regions, except the Middle East and North Africa and sub-Saharan Africa, where RNI ratios fall short and few people will be able to achieve adequate levels for a healthy diet.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Looking at complex food systems and the scaling of nutrition interventions and interactions in the longer term is crucial for achieving broad-based, beneficial, and lasting outcomes (Ruel 2024). Understanding the future of diets and nutrition requires connecting nutrition literature and quantitative foresight studies. In general, nutrition literature is essential to understand the many dimensions and

FIGURE 3 **Ratio of nutrient availability from projected diets to recommended nutrient intakes (RNI ratios) for key vitamins and minerals in 2020 and 2050, by region**



Source: IMPACT v3.4, in Rosegrant et al. (2024).

connections between diets and nutrition. This literature, however, relies on analysis of historical data and is limited in looking explicitly at the future in a systematic way.

Meanwhile, simulation studies that look explicitly at future diets are limited in nutritional detail. Studies linking diets, health, and planetary environmental boundaries tend to focus on the Global North, leaving a need and opportunity to combine nutritional depth with foresight modeling and a focus on LMICs. The most robust approach would rely upon "multimodel" ensembles that provide transparent methodologies for their projections of dietary evolution. The range of potential outcomes will reveal either self-reinforcing agreements among models that provide strong evidence of findings or disagreements that flag areas for further research.

A major question for the future of diets and nutrition is how potential demand changes will play out in global agrifood system dynamics. Quantitative foresight modeling of the agrifood sector from an economic equilibrium perspective can help explore this. For example, if a more environmentally conscious diet were to become more widespread—meaning populations avoid increasing their consumption of animal-source foods as incomes increase, while relying more on plant-based foods—foresight modeling could explicitly handle how preference shifts would react to price changes due to changing levels of demand for these different types of commodities, in turn affecting the final purchase of food baskets by different consumers. Joining this with detailed understanding of how food systems work from a nutrition perspective (food environments, nutrition innovations, etc.) can help policymakers make decisions on how to best allocate resources to support a healthy dietary evolution.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Timothy B. Sulser**, a Senior Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); **Marie Ruel**, a Senior Research Fellow in the Nutrition, Diets, and Health Unit at IFPRI; and **Shakuntala H. Thilsted**, Director of the CGIAR Nutrition Impact Platform.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Sulser, T.B., M. Ruel, and S.H. Thilsted. 2025. "What Do We Know About the Future of Diets and Nutrition?" In *What Do We Know About the Future of Food Systems?,* eds. K. Wiebe and E. Gotor, Chapter 3. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Geet Theerawat/Shutterstock

References

Beach, R.H., T.B. Sulser, A. Crimmins, et al. 2019. "Combining the Effects of Increased Atmospheric Carbon Dioxide on Protein, Iron, and Zinc Availability and Projected Climate Change on Global Diets: A Modelling Study." *Lancet Planetary Health* 3 (7): e307–317. https://doi.org/10.1016/S2542-5196(19)30094-4

Beal, T., F. Ortenzi, and J. Fanzo. 2023. "Estimated Micronutrient Shortfalls of the EAT–Lancet Planetary Health Diet." *Lancet Planetary Health* 7 (3): e233–237. https://doi.org/10.1016/S2542-5196(23)00006-2

Bennett, M.K. 1941a. "International Contrasts in Food Consumption." *Geographical Review* 31 (3): 365–376. https://doi.org/10.2307/210172

Bennett, M.K. 1941b. "Wheat in National Diets." *Wheat Studies of the Food Research Institute* 18 (2): 37–76. https://doi.org/10.22004/AG.ECON.142802

Bodirsky, B.L., J.P. Dietrich, E. Martinelli, et al. 2020. "The Ongoing Nutrition Transition Thwarts Long-Term Targets for Food Security, Public Health and Environmental Protection." *Scientific Reports* 10 (1): 19778. https://doi.org/10.1038/s41598-020-75213-3

Bodirsky, B.L., S. Rolinski, A. Biewald, I. Weindl, A. Popp, and H. Lotze-Campen. 2015. "Global Food Demand Scenarios for the 21st Century." *PLOS ONE* 10 (11): e0139201. https://doi.org/10.1371/journal.pone.0139201

Bouis, H.E., and A. Saltzman. 2017. "Improving Nutrition through Biofortification: A Review of Evidence from HarvestPlus, 2003 through 2016." *Global Food Security* 12: 49–58. https://doi.org/10.1016/j.gfs.2017.01.009

Cenacchi, N., T.B. Sulser, and A. Mishra. 2025. "What Do We Know about the Future of Food Demand, Production, and Food Security Based on IMPACT Model Projections?" In What Do We Know About the Future of Food Systems?, eds. K. Wiebe and E. Gotor, Chapter 36. Washington, DC: IFPRI. https://hdl.handle.net/10568/175534

Chan, C.Y., N. Tran, K.C. Cheong, T.B. Sulser, P.J. Cohen, K. Wiebe, and A.M. Nasr-Allah. 2021. "The Future of Fish in Africa: Employment and Investment Opportunities." *PLOS ONE* 16 (12): e0261615. https://doi.org/10.1371/journal.pone.0261615

Costlow, L., A. Herforth, T.B. Sulser, N. Cenacchi, and W.A. Masters. 2025. "Global Analysis Reveals Persistent Shortfalls and Regional Differences in Availability of Foods Needed for Health." *Global Food Security* 44: 100825. https://doi.org/10.1016/j.gfs.2024.100825

Dewey, K.G., C.D. Arnold, K.R. Wessells, and C.P. Stewart. 2023. "Lipid-Based Nutrient Supplements for Prevention of Child Undernutrition: When Less May Be More." *American Journal of Clinical Nutrition* 118 (6): 1133–1144. https://doi.org/10.1016/j.ajcnut.2023.09.007

EAT–Lancet 2.0 Commissioners, J. Rockstrom, S. Thilsted, W. Willett, et al. 2023. "EAT–Lancet Commission 2.0: Securing a Just Transition to Healthy, Environmentally Sustainable Diets for All." *Lancet* 402 (10399): 352–354. https://doi.org/10.1016/S0140-6736(23)01290-4

Enahoro, D., M. Lannerstad, C. Pfeifer, and P. Dominguez-Salas. 2018. "Contributions of Livestock-Derived Foods to Nutrient Supply under Changing Demand in Low- and Middle-Income Countries." *Global Food Security* 19: 1–10. https://doi.org/10.1016/j.gfs.2018.08.002

FAO (Food and Agriculture Organization of the United Nations). 2024. FAOSTAT. https://www.fao.org/faostat/en/#data/CAHD

Flax, V.L., E.A. Ouma, I. Baltenweck, E. Omosa, A. Webb Girard, N. Jensen, and P. Dominguez-Salas. 2023. "Pathways from Livestock to Improved Human Nutrition: Lessons Learned in East Africa." *Food Security* 15 (5): 1293–1312. https://doi.org/10.1007/s12571-023-01382-4

Fretes, G., Q. Marshall, and J.L. Leroy. "Food Environments: Improving Their Healthfulness." In *Global Food Policy Report 2024: Food Systems for Healthy Diets and Nutrition*, 46–52. Washington DC: International Food Policy Research Institute, 2024. https://hdl.handle.net/10568/141887

Golden, C.D., J.Z. Koehn, A. Shepon, et al. "Aquatic Foods to Nourish Nations." *Nature* 598 (7880): 315–20. https://doi.org/10.1038/s41586-021-03917-1

Hasegawa, T., S. Fujimori, K. Takahashi, and T. Masui. 2015. "Scenarios for the Risk of Hunger in the Twenty-First Century Using Shared Socioeconomic Pathways." *Environmental Research Letters* 10 (1): 014010. https://doi.org/10.1088/1748-9326/10/1/014010

Hasegawa, T., P. Havlík, S. Frank, A. Palazzo, and H. Valin. 2019. "Tackling Food Consumption Inequality to Fight Hunger without Pressuring the Environment." *Nature Sustainability* 2 (9): 826–833. https://doi.org/10.1038/s41893-019-0371-6

Hasegawa, T., G. Sakurai, S. Fujimori, K. Takahashi, Y. Hijioka, and T. Masui. 2021. "Extreme Climate Events Increase Risk of Global Food Insecurity and Adaptation Needs." *Nature Food* 2(8): 587–595. https://doi.org/10.1038/s43016-021-00335-4

Hawkes, C., M.T. Ruel, L. Salm, B. Sinclair, and F. Branca. 2020. "Double-Duty Actions: Seizing Programme and Policy Opportunities to Address Malnutrition in All Its Forms." *Lancet* 395 (10218): 142–155. https://doi.org/10.1016/S0140-6736(19)32506-1

Herforth, A., A. Venkat, Y. Bai, L. Costlow, C. Holleman, and W.A. Masters. 2022. *Methods and Options to Monitor the Cost and Affordability of a Healthy Diet Globally. Background Paper for The State of Food Security and Nutrition in the World 2022*. Rome: FAO. https://doi.org/10.4060/cc1169en

Herforth, A., M. Arimond, C. Álvarez-Sánchez, J. Coates, K. Christianson, and E. Muehlhoff. 2019. "A Global Review of Food-Based Dietary Guidelines." *Advances in Nutrition* 10 (4): 590–605. https://doi.org/10.1093/advances/nmy130

Hirvonen, K., Y. Bai, D. Headey, and W.A. Masters. 2020. "Affordability of the EAT–Lancet Reference Diet: A Global Analysis." *Lancet Global Health* 8 (1): e59–66. https://doi.org/10.1016/S2214-109X(19)30447-4

Kim, S.S., N. Koyratty, C.E. Blake, and N. Kumar. 2024. "Demand-Side Approaches: Supporting Healthier Food Choices." In *Global Food Policy Report 2024: Food Systems for Healthy Diets and Nutrition*, 26–35. Washington, DC: International Food Policy Research Institute. https://hdl.handle.net/10568/141884

Kompas, T., T. Nhu Che, and R.Q. Grafton. 2024. "Global Impacts of Heat and Water Stress on Food Production and Severe Food Insecurity." *Scientific Reports* 14 (1): 14398. https://doi.org/10.1038/s41598-024-65274-z

Loladze, I. 2014. "Hidden Shift of the Ionome of Plants Exposed to Elevated CO_2 Depletes Minerals at the Base of Human Nutrition." *ELife* 3: e02245. https://doi.org/10.7554/eLife.02245

Mason-D'Croz, D., J.R. Bogard, T.B. Sulser, N. Cenacchi, S. Dunston, M. Herrero, and K. Wiebe. 2019. "Gaps between Fruit and Vegetable Production, Demand, and Recommended Consumption at Global and National Levels: An Integrated Modelling Study." *Lancet Planetary Health* 3 (7): e318–329. https://doi.org/10.1016/S2542-5196(19)30095-6

Myers, S.S., A. Zanobetti, I. Kloog, et al. 2014. "Increasing CO_2 Threatens Human Nutrition." *Nature* 510 (7503): 139–42. https://doi.org/10.1038/nature13179

Nelson, G., J.R. Bogard, K. Lividini, et al. 2018. "Income Growth and Climate Change Effects on Global Nutrition Security to Mid-Century." *Nature Sustainability* 1 (12): 773–81. https://doi.org/10.1038/s41893-018-0192-z

Osendarp, S.J.M. H. Martinez, G.S. Garrett, L.M. Neufeld, L.M. De-Regil, M. Vossenaar, and I. Darnton-Hill. 2018. "Large-Scale Food Fortification and Biofortification in Low- and Middle-Income Countries: A Review of Programs, Trends, Challenges, and Evidence Gaps." *Food and Nutrition Bulletin* 39 (2): 315–331. https://doi.org/10.1177/0379572118774229

Popkin, B.M., C. Corvalan, and L.M. Grummer-Strawn. 2020. "Dynamics of the Double Burden of Malnutrition and the Changing Nutrition Reality." *Lancet* 395 (10217): 65–74. https://doi.org/10.1016/S0140-6736(19)32497-3

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Ruel, M. 2024. "Supporting and Shaping the Global Nutrition Agenda with Evidence: A Three-Decade Journey of Research and Partnerships for Impact." Presented at the 34th Annual Martin J. Forman Memorial Lecture, Presented at IFPRI. https://hdl.handle.net/10568/158348

Sands, D.C., C.E. Morris, E.A. Dratz, and A.L. Pilgeram. 2009. "Elevating Optimal Human Nutrition to a Central Goal of Plant Breeding and Production of Plant-Based Foods." *Plant Science* 177 (5): 377–389. https://doi.org/10.1016/j.plantsci.2009.07.011

Springmann, M., D. Mason-D'Croz, S. Robinson, et al. 2016. "Global and Regional Health Effects of Future Food Production under Climate Change: A Modelling Study." *Lancet* 387 (10031): 1937–1946. https://doi.org/10.1016/S0140-6736(15)01156-3

Springmann, M., K. Wiebe, D. Mason-D'Croz, T.B. Sulser, M. Rayner, and P. Scarborough. 2018. "Health and Nutritional Aspects of Sustainable Diet Strategies and Their Association with Environmental Impacts: A Global Modelling Analysis with Country-Level Detail." *Lancet Planetary Health* 2 (10): e451–461. https://doi.org/10.1016/S2542-5196(18)30206-7

Sulser, T. B., R.H. Beach, K.D. Wiebe, S. Dunston, and N. K. Fukagawa. 2021. "Disability-Adjusted Life Years Due to Chronic and Hidden Hunger under Food System Evolution with Climate Change and Adaptation to 2050." *American Journal of Clinical Nutrition* 114 (2): 550–563. https://doi.org/10.1093/ajcn/nqab101

Sulser, T.B., K.D. Wiebe, S. Dunston, et al. 2021. "Climate Change and Hunger: Estimating Costs of Adaptation in the Agrifood System." Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/9780896294165

Tigchelaar, M., E.R. Selig, A. Sarhadi, et al. 2025. "Nutrition-Sensitive Climate Risk across Food Production Systems." *Environmental Research Letters* 20 (1): 014046. https://doi.org/10.1088/1748-9326/ad9b3a

Valin, H., R.D. Sands, D. Van Der Mensbrugghe, et al. 2014. "The Future of Food Demand: Understanding Differences in Global Economic Models." *Agricultural Economics* 45 (1): 51–67. https://doi.org/10.1111/agec.12089

Van Dijk, Mi., T. Morley, M.L. Rau, and Y. Saghai. 2021. "A Meta-Analysis of Projected Global Food Demand and Population at Risk of Hunger for the Period 2010–2050." *Nature Food* 2 (7): 494–501. https://doi.org/10.1038/s43016-021-00322-9

White, P.J., and M.R. Broadley. 2009. "Biofortification of Crops with Seven Mineral Elements Often Lacking in Human Diets: Iron, Zinc, Copper, Calcium, Magnesium, Selenium and Iodine." *New Phytologist* 182 (1): 49–84. https://doi.org/10.1111/j.1469-8137.2008.02738.x

Willett, W., J. Rockström, B. Loken, et al. 2019. "Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems." *Lancet* 393 (10170): 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

World Bank. 2023. "Food Prices for Nutrition Database, Version 2.0.". https://doi.org/10.57966/41AN-KY81

Zhu, C., K, Kobayashi, I. Loladze, et al. 2018. "Carbon Dioxide (CO_2) Levels This Century Will Alter the Protein, Micronutrients, and Vitamin Content of Rice Grains with Potential Health Consequences for the Poorest Rice-Dependent Countries." *Science Advances* 4 (5): eaaq1012. https://doi.org/10.1126/sciadv.aaq1012

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF GENDER EQUALITY IN RELATION TO FOOD SYSTEMS?

Elizabeth Bryan (IFPRI), Marilia Magalhaes (IFPRI), Ranjitha Puskur (IRRI), Nicoline de Haan (CGIAR), Els Lecoutere (CGIAR), and Hazel Malapit (IFPRI)

Key messages

- Foresight research has yet to fully explore gender equality as an outcome and a driver of food systems transformation.
- Foresight analysis can assess which food systems investments and interventions are most effective at reducing gender inequalities and increasing women's empowerment.
- Addressing structural inequalities, promoting inclusivity in decision-making, and challenging patriarchal norms can enhance gender equality, social inclusion, and women's empowerment in food systems transformation. Neglecting gender barriers when designing and disseminating food systems innovations may exacerbate gender inequalities and limit women's empowerment.
- Gender equality, women's empowerment, and social inclusion also drive food systems transformation, leading to improved welfare outcomes for all. Foresight research should examine how closing gender gaps in livelihood opportunities, agricultural productivity, and resilience capacities can impact other food systems outcomes, such as poverty reduction, food security, and nutrition.
- While data on gender inequalities in food systems and women's empowerment have increased over the last 10 years, more sex-disaggregated data and impact evaluation studies are needed for rigorous foresight research on gender equality in agrifood systems.

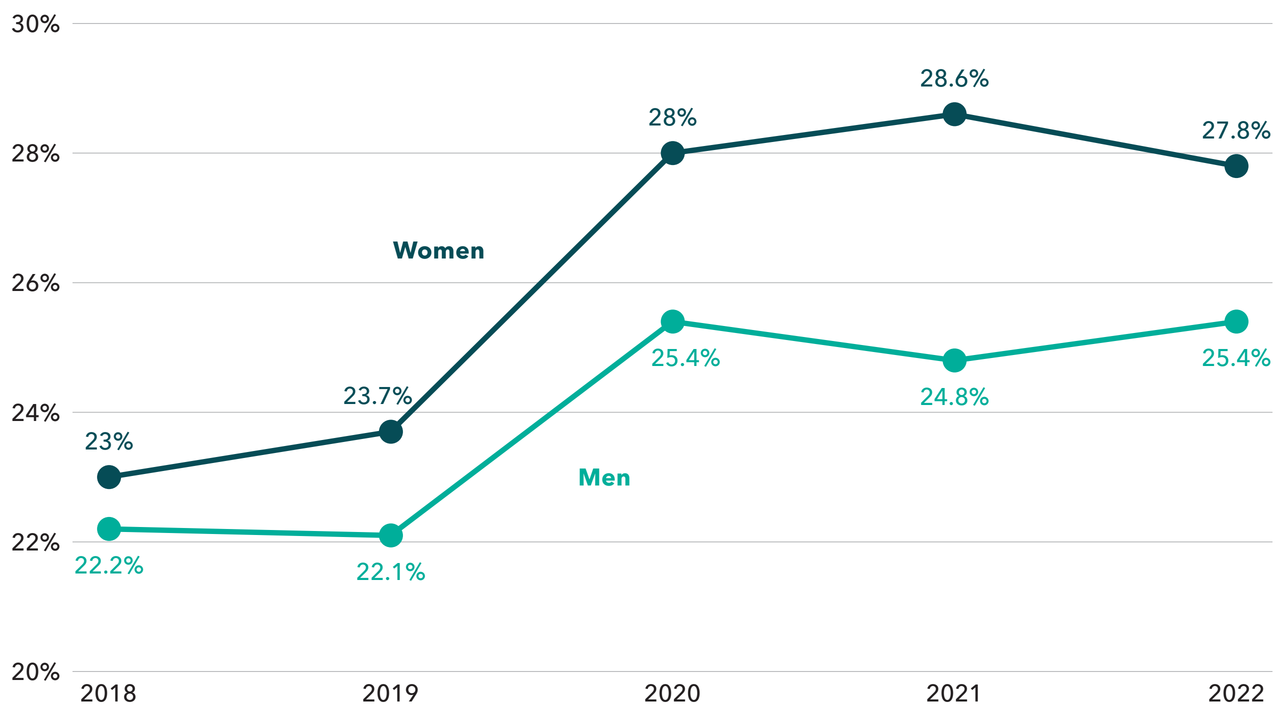
RECENT TRENDS AND CHALLENGES

Only marginal progress has been made in addressing underlying gender inequalities in food systems over the last several decades. Significant challenges remain in closing gender gaps in agricultural productivity, livelihood opportunities, access to resources and services, and wellbeing outcomes. Because of these inequalities, women remain marginalized in agrifood systems and lack opportunities to participate in, benefit from, and exercise agency over food systems transformation.

Some progress has been made in expanding access to information and communication technology, with potential for closing gender gaps in access to information and financial services (Demirgüç-Kunt et al. 2022; GSMA 2023). Progress has also been made in collecting sex-disaggregated data and monitoring progress toward increasing women's empowerment over time and the link with other development outcomes, including food security and nutrition. Gender equality has also received greater emphasis in key policy processes and design in recent years at the global and national levels. However, goals are often not met due to challenges during policy implementation.

The confluence of shocks and stressors over the past few years – including COVID-19, the global food crisis exacerbated by the war in Ukraine, and escalating climate change – have disproportionately affected women and girls, amplifying gender disparities. Women and girls are already more vulnerable to shocks and stressors like climate change, especially in areas where climate impacts are severe and where gender inequalities are greatest (Bryan et al. 2024; Lecoutere et al. 2023; Schipper et al. 2022). Gender gaps in food insecurity, workloads, and specific challenges, such as gender-based violence, are intensified during times of stress (FAO et al. 2023; Kugler et al. 2023; Nico and Azzarri 2022). During the COVID-19 pandemic, the gender gap in food insecurity notably widened to 3.8 percent in 2021 (Figure 1). However, the gap narrowed in 2022 as the pandemic's impact on women's food insecurity eased, both on the global scale and in specific regions including Asia and Latin America. The disproportionate impacts of shocks and stressors on women and girls carry significant implications, impacting their short-term coping abilities and long-term resilience.

FIGURE 1 **Moderate or severe food insecurity (%), worldwide, by gender, 2018–2022**



Source: Data from FAOSTAT 2023.

LATEST FORESIGHT RESEARCH

Lentz (2021) reviews foresight studies on the links between agrifood systems and outcomes related to gender, poverty, and nutrition and concludes that gender equality is the outcome least covered across foresight research. The review finds that many technology-focused studies ignore gender-related barriers to adoption based on differential access to resources and services, as well as gender differences in preferences for technologies. Foresight studies that do consider gender often point to it as a key factor shaping successful transformation of agrifood systems with respect to the other outcomes (Lentz 2021).

The annual report of the World Economic Forum (WEF) tracks and measures gender gaps across four key dimensions: economic participation and opportunity; educational attainment; health and survival; and political empowerment. The latest report shows some small gains in closing gender gaps across these dimensions in 2023, following several years in which progress was disrupted by COVID-19 and other global shocks. WEF now estimates that it will take 131 years to reach gender parity across all four dimensions, largely driven by wider gender gaps in the economic and political dimensions (WEF 2023).

The Food and Agriculture Organization of the United Nations (FAO) also collects data on gender gaps in food insecurity and reports on these in its annual report on the *State of Food and Agriculture* (SOFA) and more recently with other UN agencies in the report on the *State of Food Security and Nutrition in the World*. FAO also recently produced a report on the *Status of Women in Agrifood Systems*, offering updated insights compared to the 2011 SOFA report, which focused on women in agriculture. The 2011 SOFA report made the case for closing gender gaps in access to agricultural assets, inputs, and services not only to address gender inequality but also for the benefit of the agriculture sector and the broader economy (FAO 2011). The report estimated that if women had the same resources as men, they could increase yields on their farms by 20–30 percent — production gains that would increase total agricultural output in low-income countries by 2.5–4.0 percent, thereby reducing the number of hungry people in the world by 12–17 percent.

Moving beyond agriculture, the new *Status of Women in Agrifood Systems* report emphasizes the importance of tackling structural gender inequalities and investing in women's empowerment for the transition toward sustainable and resilient agrifood systems (FAO 2023). It estimates that closing the gender gaps in farm productivity and wages in agrifood systems would increase global gross domestic product (GDP) by at least 1 percent (or nearly US$1 trillion). As a result, global food insecurity would be reduced by at least 2 percentage points, which corresponds to 45 million people coming out of food insecurity (FAO 2023). The report also estimates that "if half of small-scale producers benefited from development interventions which focused on empowering women, it would significantly raise the incomes of an additional 58 million people and increase the resilience of an additional 235 million people." Multiple country-level studies by UN Women support the link between closing the gender gap in agricultural productivity and welfare benefits, including a substantial reduction in poverty — by around 80,000 people in Tanzania, 238,000 people in Malawi, and 119,000 people in Uganda per year over the last 10-year period (UN Women 2015).

While women earn less than men in the agrifood system and economy due to social norms, discrimination, and limited access to resources (FAO 2023), the quantification and implications of closing these gaps remain underexplored. A collaboration between CGIAR's Foresight Initiative and the World Bank's Gender Innovation Lab (GIL) is addressing these issues. Foresight, using IFPRI's RIAPA (Rural Investment and Policy Analysis) model, is assessing the broader implications of narrowing the gender income gap in Nigeria and Ethiopia, highlighting the potential economic gains of closing it (Thurlow and Levy 2024). Other studies are exploring climate change impacts on women farmers in Colombia, emphasizing the need for gender-responsive policies (Escalante and Pineiro 2024).

Another key publication (Njuki et al. 2022) develops a framework illustrating the pathways through which gender equality and women's empowerment can drive food systems transformation. These include: addressing women's differing access to resources; promoting equal and positive gender norms; facilitating women's empowerment; and promoting more equitable policies, institutions, and governance. Much progress has been made over the last 10 years with respect to measurement and data collection on women's empowerment, showing that women's empowerment and gender equality have not only intrinsic value but other social benefits as well, including better agricultural, health, diet, and nutrition outcomes (Quisumbing et al. 2023). In particular, studies show that higher levels of women's empowerment in agriculture are associated with better maternal nutrition and women and children's calorie availability and dietary diversity (Malapit et al. 2015; Sraboni and Quisumbing 2018; Kassie et al. 2020; Bonis-Profumo, Stacey, and Brimblecombe 2021). Projects specifically focused on women's empowerment leading to women's greater decision-making power provide greater benefits for both women and men — including higher incomes, food security, household dietary diversity, and ability to recover from shocks — compared to standard development projects (FAO 2023; Quisumbing et al. 2023).

Scenario-guided foresight processes that engage a broad range of stakeholders and integrate a gender and social inclusion lens are important for informing agricultural policy processes (Marty et al. 2023). In practice, however, many challenges remain to integrating gender and social inclusion in scenario-guided, foresight-driven policy processes, such as power asymmetries among stakeholders (Marty et al. 2023). Recent multistakeholder participatory foresight exercises conducted in two states of India (Uttarakhand and Odisha) demonstrate the potential of participatory approaches (Malhotra et al. 2025). These exercises identified several key driving forces of gender equality in agrifood systems, including the level of cooperation within the household, education of women, agricultural knowledge and skills, women's agency, family support and guidance, women's workloads, access to labor-saving technology, and collective action of women. Participants highlighted the gradual but slow shifts in constraining norms, but also emphasized that significant efforts are needed for more transformative change.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

As noted by Lentz (2021), gender equality has not been adequately explored in foresight research either as a driver of food systems transformation or as an outcome. When projecting outcomes of various scenarios, especially those examining technological interventions and management techniques, it is crucial to consider gender inequalities related to resource and services access, resilience capacities, and restrictive social norms. These factors can significantly impact women's livelihood opportunities and their roles within food systems. Several potential data sources could be used to measure the level of gender inequality at the national or subnational level for foresight work, including nationally representative Labor Force Survey data, the Organisation for Economic Co-operation and Development's Social Institutions and Gender Index, the Global Data Lab's Subnational Gender Development Index, Demographic and Health Surveys, and the Women's Empowerment in Agriculture Index data.

At the same time, foresight analysis can explore drivers of change for greater gender equality and women's empowerment in agrifood systems. In particular, foresight modeling and participatory foresight exercises can help assess which food systems investments and interventions are most effective at reducing gender inequalities and increasing women's empowerment — for example, closing gender gaps in resources, such as land ownership; reaching more women with extension services and finance; or designing interventions to transform gender norms and relations. Foresight research could also explore how reducing gender inequalities may contribute to other positive food systems outcomes, such as greater resilience to climate change, poverty reduction, and food security and nutrition.

Lastly, while data on gender inequalities in food systems and women's empowerment have increased over the last 10 years, more sex-disaggregated data and impact evaluation studies are still needed for rigorous foresight research on gender equality in agrifood systems.

For more information on the topic, check out these resources:

- CGIAR GENDER Impact Platform Resource Hub
- Data2X I Partnering for Better Gender DataData2X
- Africa Gender Innovation Lab
- Launch of the FAO report of "The Status of Women in Agrifood Systems"
- World Economic Forum Gender Gap Report

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Elizabeth Bryan**, a Research Fellow in the Natural Resources and Resilience (NRR) Unit at the International Food Policy Research Institute (IFPRI); **Marilia Magalhaes**, a Senior Research Analyst in NRR at IFPRI; **Ranjitha Puskur**, a Principal Scientist at the International Rice Research Institute (IRRI); **Nicoline de Haan**, Director of the CGIAR Gender Equality and Inclusion Accelerator; **Els Lecoutere**, a Science Officer at the CGIAR Gender Equality and Inclusion Accelerator; and **Hazel Malapit**, a Senior Research Coordinator in the Poverty, Gender, and Inclusion Unit at IFPRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Bryan, E., M. Magalhaes, R. Puskur, N. de Haan, E. Lecoutere, and H. Malapit. 2025. "What Do We Know About the Future of Gender Equality in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 4. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Narendra Shrestha/UN Women

References

Bryan, E., M. Alvi, S. Huyer, and C. Ringler. 2024. "Addressing Gender Inequalities and Strengthening Women's Agency to Create More Climate Resilient and Sustainable Food Systems." *Global Food Security* 40: 100731. https://doi.org/10.1016/j.gfs.2023.100731

Bonis-Profumo, G., N. Stacey, and J. Brimblecombe. 2021. "Measuring Women's Empowerment in Agriculture, Food Production, and Child And Maternal Dietary Diversity in Timor-Leste." *Food Policy* 102: 102102. https://doi.org/10.1016/j.foodpol.2021.102102

Demirgüç-Kunt, A., L. Klapper, D. Singer, and S. Ansar. 2022. *Global Findex Database 2021: Financial Inclusion, Digital Payments, and Resilience in the Age of COVID-19*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/099818107072234182/IDU06a834fe908933040670a6560f44e3f4d35b7

Escalante, L.E., and V. Pineiro. 2024. "Trade-Offs in the Wake of Climate Change: Mitigation Strategies and Their Impact on Poverty, Gender, and Growth." Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=7341

Thurlow, J., and S. Levy. 2024. "Closing Gender Gaps in Developing Countries: Socioeconomic Implications for Poverty, Diets, and Food Security." Presentation. Presented at the CGIAR GENDER Conference From Research to Impact: Towards Just and Resilient Agri-Food Systems." New Delhi, India, 9–12 October 2023. International Food Policy Research Institute. https://hdl.handle.net/10568/137096

FAO (Food and Agriculture Organization of the United Nations). 2011. *The State of Food and Agriculture 2010–11: Women in Agriculture. Closing the Gender Gap for Development*. Rome.

FAO. 2023. *The Status of Women in Agrifood Systems*. Rome. https://doi.org/10.4060/cc5343en

FAO. 2023. FAOSTAT statistical database. Accessed September 5, 2023. https://www.fao.org/faostat/

FAO, IFAD, UNICEF, WFP and WHO. 2023. *The State of Food Security and Nutrition in the World 2023: Urbanization, Agrifood Systems Transformation and Healthy Diets across the Rural–Urban Continuum*. Rome: FAO. https://doi.org/10.4060/cc3017en

GSMA. 2023. *The Mobile Gender Gap Report 2023*. London, UK: GSMA.

Kassie, M., M. Fisher, G. Muricho, and G. Diiro. 2020."Women's Empowerment Boosts the Gains in Dietary Diversity from Agricultural Technology Adoption in Rural Kenya." *Food Policy* 95: 101957. https://doi.org/10.1016/j.foodpol.2020.101957

Kugler, M., M. Viollaz, D. Duque, I. Gaddis, D. Newhouse, A. Palacios-Lopez, and M. Weber. 2023. "How Did the COVID-19 Crisis Affect Different Types of Workers in the Developing World?" *World Development* 170: 106331. https://doi.org/10.1016/j.worlddev.2023.106331

Lecoutere, E., A. Mishra, N. Singaraju et al. 2023. "Where Women in Agri-Food Systems Are at Highest Climate Risk: A Methodology for Mapping Climate–Agriculture–Gender Inequality Hotspots." *Frontiers in Sustainable Food Systems* 7 (November). https://doi.org/10.3389/fsufs.2023.1197809

Lentz, E.C. 2021. "Food and Agriculture Systems Foresight Study: Implications for Gender, Poverty, and Nutrition." *Q Open* 1 (1): qoaa003. https://doi.org/10.1093/qopen/qoaa003

Malapit, H.J., S. Kadiyala, A.R. Quisumbing, K. Cunningham, and P. Tyagi. 2015. "Women's Empowerment Mitigates the Negative Effects of Low Production Diversity on Maternal and Child Nutrition in Nepal." *Journal of Development Studies* 51 (8): 1097–1123. https://doi.org/10.1080/00220388.2015.1018904

Malhotra, A., R. Puskur, A. Anbacha, et al. 2025. *Facilitator's Guide: Participatory Foresight on Gender Equality in Agri-Food Systems*. CGIAR GENDER Impact Platform. Nairobi: CGIAR GENDER Impact Platform. https://hdl.handle.net/10568/175211

Marty, E., A.C. Segnon, S.H.K. Tui, S. Trautman, S. Huyer, L. Cramer, and E. Mapedza. 2023. "Enabling Gender and Social Inclusion in Climate and Agriculture Policy and Planning through Foresight Processes: Assessing Challenges and Leverage Points." *Climate Policy* 24 (8): 1034–1049. https://doi.org/10.1080/14693062.2023.2268042

Nico, G., and C. Azzarri. 2022. "Weather Variability and Extreme Shocks in Africa." IFPRI Discussion Paper 2115. Washington, DC: IFPRI. https://hdl.handle.net/10568/140849

Njuki, J., S. Eissler, H. Malapit, R. Meinzen-Dick, E. Bryan, and A. Quisumbing. 2022. "A Review of Evidence on Gender Equality, Women's Empowerment, and Food Systems." *Global Food Security* 33: 100622. https://doi.org/10.1016/j.gfs.2022.100622

Quisumbing, A., S. Cole, M. Elias et al. 2023. "Measuring Women's Empowerment in Agriculture: Innovations and Evidence." *Global Food Security* 38: 100707. https://doi.org/10.1016/j.gfs.2023.100707

Schipper, E.L.F., A. Revi, B.L. Preston et al. 2022. "Climate Resilient Development Pathways." In *IPCC WGII Sixth Assessment Report. Climate Change 2022: Impacts, Adaptation and Vulnerability*, Ch. 18. IPCC. https://www.ipcc.ch/report/ar6/wg2/

Sraboni, E. and A.R. Quisumbing. 2018. "Women's Empowerment in Agriculture and Dietary Quality across the Life Course: Evidence from Bangladesh." *Food Policy* 81: 21–36. https://doi.org/10.1016/j.foodpol.2018.09.001

UN Women, UNDP, UNEP, and World Bank. 2015. *The Cost of the Gender Gap in Agricultural Productivity in Malawi, Tanzania, and Uganda*. https://africa.unwomen.org/en/digital-library/publications/2015/10/the-cost-of-the-gender-gap-in-agricultural-productivity-in-malawi-tanzania-and-uganda

WEF (World Economic Forum). 2023. *Global Gender Gap Report 2023: Insight Report*. June 2023. Geneva. https://www.weforum.org/publications/global-gender-gap-report-2023/

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF THE ENVIRONMENT AND BIODIVERSITY IN RELATION TO FOOD SYSTEMS?

Elisabetta Gotor (Bioversity International) and Cargele Masso (CGIAR)

Key messages

- The environment's proper functioning is essential for a better life on Earth, including maintaining, enhancing, and restoring biodiversity and ecosystem services. While the environment is driven by external factors and shocks as well as interventions within the global food system, it simultaneously drives the overall health and stability of the planet. This relationship involves complex interactions and tipping points, which foresight research needs to capture in analyzing alternative future pathways for food system transformation.

- A sustainable and resilient environment requires holistic approaches, strategies, and policies to address environmental stresses and promote conservation, regeneration, and coexistence with nature. These include practices that respect ecological boundaries, reduce resource consumption and conflict, foster biodiversity, and enhance ecosystem recovery and adaptability. Foresight research is essential to help decision-makers understand synergies and trade-offs between long-term public goods benefits and short-term private costs from resource use and management.

- Addressing food systems challenges – including root causes of environmental degradation and biodiversity loss – requires sustainable land and soil management, conservation efforts, and food production practices, in addition to economic viability and social inclusion. Foresight analysis can help policymakers, communities, and industries make informed decisions and prioritize and deploy effective and holistic strategies at the biodiversity-climate-society nexus.

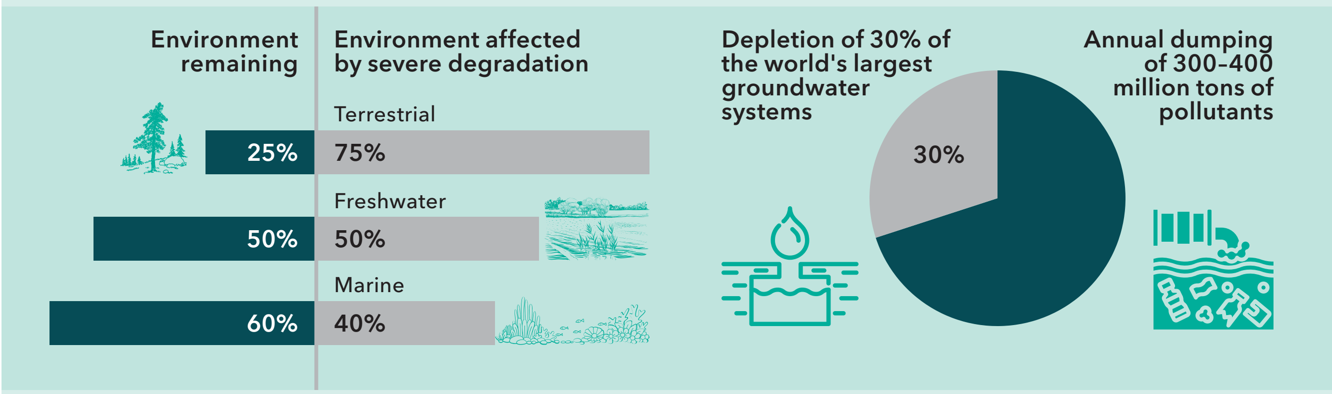
RECENT TRENDS AND CHALLENGES

Responsible natural resource management is urgently needed. The global food system is currently responsible for 21–37 percent of total net greenhouse gas emissions (Olivier et al. 2018), contributing to global warming exceeding 1°C. Projections suggest that by 2050, agricultural land will expand by 400 million hectares, reducing forested and natural land. This loss threatens biodiversity and essential ecosystem services like carbon storage and water regulation provided by forests (IPCC 2021; FAO 2022; FOLU 2019). Figure 1 shows current environmental degradation trends that require action to transition to biodiversity and ecosystem function gains.

Over the past 50 years, population growth — coupled with a 15 percent per-person increase in material consumption since 1980 — has driven alarming surges in biomass extraction, fossil fuel consumption, and mineral and

FIGURE 1 Current environmental degradation trends

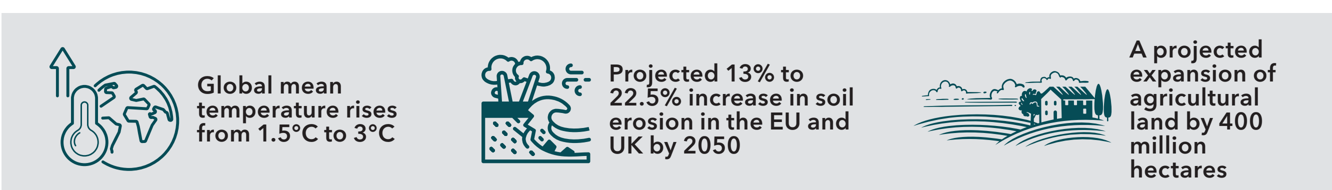
GLOBAL ENVIRONMENTAL DEGRADATION | **POLLUTION AND RESOURCE DEPLETION**



Global environmental degradation:
A figure showing trends in environmental degradation, from a once-robust environment to the current scenario - terrestrial (75%), marine (40%), and freshwater (50%) environments affected by severe degradation - and possible actions to assist, protect, and conserve natural ecosystems and prevent the loss of our planet's endangered biodiversity wildlife in the face of continued climate change (IPCC-IPBES 2021).

Pollution and resource depletion:
An illustration of the annual dumping of 300-400 million tons of pollutants (heavy metals, toxic sludge, etc.) into waters and soils, and the depletion of 30% of the world's largest groundwater systems (UN Water 2021; UNEP 2022).

GLOBAL MULTI-SECTOR RISKS | **SOIL EROSION PROJECTIONS** | **LAND USE CHANGES BY 2050**



Global multi-sector risks:
A representation of the increase in multi-sector risks as global mean temperature rises from 1.5°C to 3°C, with a breakdown of impacts by region, especially focusing on Africa and Asia (Byers et al. 2018).

Soil erosion projections:
A representation of the projected 13% to 22.5% increase in soil erosion in the EU and UK by 2050, with emphasis on rainfall erosivity (Panagos et al. 2021).

Land use changes by 2050:
A projected expansion of agricultural land by 400 million hectares and its effects on forests and biodiversity (FAO 2022; IPCC-IPBES 2021).

Source: CGIAR Environmental Health and Biodiversity Impact Area Platform (EHBIAP).

metal exploitation (IPCC-IPBES 2021). Depletion of the world's largest groundwater systems has reached about 30 percent, and over 80 percent of global wastewater is discharged untreated, exacerbating environmental pollution. Simultaneously, massive amounts of heavy metals, solvents, toxic sludge, and other pollutants — 300 million to 400 million tons annually — are dumped into the world's waters and soils. Coastal ecosystems suffer from extremely low oxygen levels, causing severe ecological degradation in terrestrial and marine environments (UN Water 2021; UNEP 2022).

These environmental impacts are widespread (Figure 1), with 75 percent of the terrestrial environment, 40 percent of the marine environment, and 50 percent of streams experiencing severe degradation, resulting in significant losses of wild animal biomass and plant life (IPCC-IPBES 2021; Tudge et al. 2021). Preserving genetic diversity within crops, animals, and fisheries is crucial for resilient food systems, particularly in terms of pest and disease resistance (FAO 2010, 2020). Alarmingly, global pollinator declines threaten the reliability of pollinator-dependent crop yields, making them less dependable than pollinator-independent crops (Smith et al. 2022). Similar challenges are reported in fisheries, such as the loss of fish diversity in Lake Victoria as a consequence of the introduction of the invasive Nile perch, as well as expansion of invasive plants in terrestrial ecosystems.

LATEST FORESIGHT RESEARCH

Projections for 2050 indicate a high confidence in increased population and income, changes in consumption patterns, and heightened demand for food, feed, and water (van Dijk et al. 2021; IPCC 2019). Demographic and economic factors, dietary shifts (for example, to plant-based diets in affluent countries), innovation, trade, and governance will be key drivers of these changes. While the global goal is to achieve a more sustainable and resilient environment, the diversity in environmental characteristics, motivations, interests, preferences, and values across different regions necessitates localized solutions (Townsend et al. 2020). Therefore, transitioning to a multi-actor and multiscale governance model is deemed vital for creating a sustainable future that addresses the unique challenges and opportunities in different local contexts (Wynberg et al. 2023).

Recent foresight research has highlighted critical challenges, offering insights into water scarcity, "hotspots" across sectors, the delicate balance between population and agricultural productivity, and the environmental impacts of agricultural practices.

Water scarcity, identified as a major concern for specific regions in the future, presents a complex problem with large uncertainties. In their study, Greve et al. (2018) find that median water scarcity and the associated range of uncertainty are generally on the increase worldwide, including for many major river basins. They propose a decision-making framework that identifies four representative clusters of specific water policy challenges and needs. Huang et al. (2021) propose a potential solution through adaptive inner-basin water allocation measures, demonstrating that such interventions could lead to a 12 percent decrease in the global population exposed to water scarcity by 2050. However, they note that adaptive measures may intensify agricultural water scarcity in the upstream area of the basins.

Byers et al. (2018) broaden this perspective, assessing the interactions between climate change risks and socioeconomic development by calculating 14 impact indicators across water, energy, and land sectors. Their study finds that global exposure to multisector risks doubles when the global mean temperature (GMT) increases from 1.5°C to 2°C, doubles again with a 3°C GMT increase, and is approximately six times higher in scenarios characterized by high poverty and inequality. While 85–95 percent of global exposure to multisector risks is concentrated in Asian and African regions, these regions also account for 91–98 percent of the exposed and vulnerable population (depending on the SSP (shared socioeconomic pathway)/GMT combination), with approximately one-half of this population located in South Asia. In higher warming scenarios, a growing proportion of the exposed and vulnerable population is found in African regions. This proportion ranges from 7–17 percent at 1.5 °C, doubles to 14–30 percent at 2 °C, and doubles again to 27–51 percent at 3 °C. Therefore, focusing on reducing poverty, mitigating emissions, promoting adaptation, and achieving targets in the water, energy, and land sectors have the potential to significantly reduce multisector climate risks for vulnerable populations.

A critical aspect addressed by a recent multimodel analysis emphasizes that the balance between changes in population and agricultural productivity is pivotal in determining the pressure for future expansion of crop- and pastureland (Stehfest et al. 2019). However, the authors highlight that land use regulations are underrepresented in models and should receive more attention in future assessments, while modeling is critical to inform effective land use policies and planning. Similarly, Springmann et al. (2018) explore the environmental impacts of increases in agricultural yields and how changes in food management, technology, and transition to healthy diets may help mitigate these impacts. They estimate that implementing these measures — especially those targeting food loss and waste — can reduce environmental pressures on the food system by 25–45 percent compared to the 2050 baseline projection in medium-ambition scenarios, and by 30–60 percent in high-ambition scenarios.

Bergstrom et al. (2021) contribute valuable insights by examining the current state and trajectories of 19 ecosystems across diverse latitudes and environments. Their "3As" framework — awareness, anticipation, and action — guides decision-making in the face of chronic "presses" and acute "pulses" affecting terrestrial and marine ecosystems collapse (for example, loss of services and species). Key recommended policy actions include aligning global climate policies with Paris Agreement targets, enhancing protected area management, incentivizing sustainable land use, adopting adaptive management, integrating Indigenous knowledge, boosting research funding, and fostering international collaboration.

Finally, Panagos et al. (2021) shift the focus to soil erosion by water within the agricultural areas of the European Union and the United Kingdom, projecting a significant increase of 13.0–22.5 percent by 2050 due to a combination of climate change and land use patterns. While a shift to more pastureland could potentially reduce erosion by 3 percent, the projected increases in rainfall erosivity are expected to counteract this effect, leading to overall increases in soil erosion. The study suggests that the most effective strategy is to tie the EU Common Agricultural Policy incentives to environmental performance in a targeted manner. For optimal results, soil conservation measures, such as cover crops and reduced tillage, should be applied to at least 50 percent of erosion hotspots to mitigate both water and wind erosion.

Collectively, these studies paint a comprehensive picture of the challenges we face, but they also offer promising solutions. Proactive policy and investment decisions today can play a crucial role in mitigating resource depletion's impacts and contributing to a more resilient environment. The importance of adaptive and forward-looking strategies in resource management emerges as a recurring theme, underscoring the need for a holistic and proactive approach to address these complex environmental issues on a global scale. In the current climate crisis, models to help decision-makers optimize the synergies among the environmental, agricultural, economic, and social inclusion dimensions of food systems are required more than ever.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Despite significant advances in foresight research on environmental sustainability, several key gaps and questions remain.

First, foresight analysis is needed to identify sustainable practices for land, soil, and water management, especially in developing countries and regions where resource pressures are substantial. However, these practices also remain critical in selected food production systems of developed countries.

Second, both understanding the link between ecosystem functions and services and optimizing trade-offs across sociocultural systems, food systems, and land and water systems are crucial for building resilience (Karki et al. 2018; Panyadee et al. 2018; Rahman et al. 2011; Sharma et al. 2018). In the past, society focused more on provisioning services (that is, increasing agricultural production) at the expense of regulating cultural and supporting services. In the future, there is a need for understanding ecosystem linkages (Walker et al. 2010) and for optimization across the nexus between sociocultural factors, pressures for economic growth, and food, land, soil, and water systems.

Third, future research should focus on enhancing productivity to meet the needs of the growing global population while effectively managing competition for land and water. The impact of both short- and long-term system shocks on the ability to adapt to environmental changes also requires thorough investigation (Benton et al. 2018). The development of early warning systems and recovery measures is essential for effective adaptive strategies (Kramer et al. 2019; Nkiaka et al. 2019; Street et al. 2019).

Finally, understanding the local nuances and factors that influence sustainable practices is critical, necessitating a transition to a contextualized multi-actor and multiscale governance model (Wynberg et al. 2023). Holistically addressing these gaps and questions will contribute to a more comprehensive understanding of the challenges and opportunities for achieving a sustainable and resilient environment and food system.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Elisabetta Gotor**, a Principal Scientist and Lead of the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International; and **Cargele Masso**, with CGIAR, based at the International Livestock Research Institute (ILRI) in Nairobi, Kenya.

The authors would like to thank Chiara Livorno, currently a PhD candidate in Development Economics and Local Systems with the University of Florence, for her contribution to the literature review.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Gotor, E., and C. Masso. 2025. "What Do We Know About the Future of the Environment and Biodiversity in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 5. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Aulia Erlangga/CIFOR

References

Byers, E., M. Gidden, D. Leclère et al. 2018. "Global Exposure and Vulnerability to Multi-Sector Development and Climate Change Hotspots." *Environmental Research* (Letters), 13 (5): 055012. https://doi.org/10.1088/1748-9326/aabf45

Benton, T.G., R. Bailey, A. Froggatt, R. King, B. Lee, and L. Wellesley. 2018. "Designing Sustainable Landuse in a 1.5 °C World: The Complexities of Projecting Multiple Ecosystem Services from Land." *Current Opinion in Environmental Sustainability* 31: 88–95. https://doi.org/10.1016/j.cosust.2018.01.011

Bergstrom, D.M., B.C. Wienecke, J. van den Hoff et al. 2021. "Combating Ecosystem Collapse from the Tropics to the Antarctic." *Global Change Biology* 27 (9): 1692–1703. https://doi.org/10.1111/gcb.15539

FAO (Food and Agriculture Organization of the United Nations). 2010. *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture*. Rome. https://www.fao.org/4/i1500e/i1500e.pdf

FAO. 2020. *The State of the World's Biodiversity for Food and Agriculture*. Rome. https://www.fao.org/state-of-biodiversity-for-food-agriculture/en/

FAO. 2022. *The State of the World's Forests 2022: Forest Pathways for Green Recovery and Building Inclusive, Resilient and Sustainable Economies*. Rome. https://doi.org/10.4060/cb9360en

FOLU (Food and Land Use Coalition). 2019. *Growing Better: Ten Critical Transitions to Transform Food and Land Use*. https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU-GrowingBetter-GlobalReport.pdf

Greve, P., T. Kahil, J. Mochizuki et al. 2018. "Global Assessment of Water Challenges under Uncertainty in Water Scarcity Projections." *Nature Sustainability* 1: 486–494. https://doi.org/10.1038/s41893-018-0134-9

Huang, Z., X. Liu, S. Sun, Y. Tang, X. Yuan, and Q. Tang. 2021. "Global Assessment of Future Sectoral Water Scarcity under Adaptive Inner-Basin Water Allocation Measures." *Science of The Total Environment* 783: 146973. https://doi.org/10.1016/j.scitotenv.2021.146973

IPCC (Intergovernmental Panel on Climate Change). 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781009157988

Karki, R., Hasson, S. ul Hassan, L. Gerlitz et al. 2018. "WRF-Based Simulation of an Extreme Precipitation Event over the Central Himalayas: Atmospheric Mechanisms and Their Representation by Microphysics Parameterization Schemes." *Atmospheric Research* 214 (December): 21–35. https://doi.org/10.1016/J.ATMOSRES.2018.07.016

Kramer, A.A., F. Sebat, and M. Lissauer. 2019. "A Review of Early Warning Systems for Prompt Detection of Patients at Risk for Clinical Decline." *Journal of Trauma and Acute Care Surgery* 87 (1S Suppl 1): S67–S73. https://doi.org/10.1097/TA.0000000000002197

Nkiaka, E., A. Taylor, A.J. Dougill et al. 2019. "Identifying User Needs for Weather and Climate Services to Enhance Resilience to Climate Shocks in Sub-Saharan Africa.: *Environmental Research Letters* 14 (12): 123003. https://doi.org/10.1088/1748-9326/ab4dfe

Oliver, T.H., E. Boyd, K. Balcombe et al. 2018. "Overcoming Undesirable Resilience in the Global Food System." *Global Sustainability* 1: e9. https://doi.org/10.1017/sus.2018.9

Panagos, P., C. Ballabio, M. Himics, S. Scarpa, F. Matthews, M. Bogonos, J. Poesen, and P. Borrelli. 2021. "Projections of Soil Loss by Water Erosion in Europe by 2050." *Environmental Science and Policy* 124 (October): 380–392. https://doi.org/10.1016/j.envsci.2021.07.012

Panyadee, P., H. Balslev, P. Wangpakapattanawong, and A. Inta. 2018. "Karen Homegardens: Characteristics, Functions, and Species Diversity." *Economic Botany* 72 (1): 1–19. https://doi.org/10.1007/s12231-018-9404-8

Rahman, T., A. Skupin, M. Falcke, and C.W. Taylor. 2011. "Rahman et al. reply to H. Vais, J.K. Foskett, and D.-O.D Mak." *Nature* 478: E2-E3. https://doi.org/10.1038/nature10494

Sharma, A., A.F. Hamlet, H.J.S. Fernando, et al.2018. "The Need for an Integrated Land-Lake Atmosphere Modeling System, Exemplified by North America's Great Lakes Region." *Earth's Future* 6 (10): 1366–1379. https://doi.org/10.1029/2018EF000870

Smith, M., N.D. Mueller, M. Springmann et al.. 2022. "Pollinator Deficits, Food Consumption, and Consequences for Human Health: A Modeling Study." I 130 (12). https://doi.org/10.1289/EHP10947

Stehfest, E., W.J. van Zeist, H. Valin et al. 2019. "Key Determinants of Global Land-Use Projections." *Nature Communications* 10 (1): 2166. https://doi.org/10.1038/s41467-019-09945-w

Springmann, M., M. Clark, D. Mason-D'Croz et al. 2018. "Options for Keeping the Food System within Environmental Limits." *Nature* 562 (7728): 519–525. https://doi.org/10.1038/s41586-018-0594-0

Street, R.B., P. Pringle, T.C. Lourenço, and M. Nicolletti. 2019. "Transferability of Decision-Support Tools." *Climatic Change* 153 (4): 523–538. https://doi.org/10.1007/s10584-018-2263-6

Townsend, J., F. Moola, and M.-K. Craig. 2020. "Indigenous Peoples Are Critical to the Success of Nature-Based Solutions to Climate Change." *FACETS* 5: 551–556. https://doi.org/10.1139/facets-2019-0058

Tudge, S.J., A. Purvis, and A. De Palma. 2021. "The Impacts of Biofuel Crops on Local Biodiversity: A Global Synthesis." *Biodiversity and Conservation* 30: 2863–2883. https://doi.org/10.1007/s10531-021-02232-5

UNEP (United Nations Environment Programme). 2022. *Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them*. Geneva. https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/38409/pesticides.pdf

UN Water. 2021. *The United Nations World Water Development Report 2021: Valuing Water*. Paris: UNESCO. https://www.unwater.org/publications/un-world-water-development-report-2021

van Dijk, M., T. Morely, M.L. Rau, and Y. Saghai. 2021. "A Meta-Analysis of Projected Global Food Demand and Population at Risk of Hunger for the Period 2010-2050." *Nature Food* 2: 494–501. https://doi.org/10.1038/s43016-021-00322-9

Walker, B., L. Pearson, M. Harris, K.G. Maler, C.Z. Li, R. Biggs, and T. Baynes. 2010. "Incorporating Resilience in the Assessment of Inclusive Wealth: An Example from South East Australia." *Environmental and Resource Economics* 45 (2): 183–202. https://doi.org/10.1007/s10640-009- 9311-7

Wynberg, R., M. Pimbert, N. Moeller, et al. 2023. "Nature-Based Solutions and Agroecology: Business as Usual or an Opportunity for Transformative Change?" *Environment: Science and Policy for Sustainable Development* 65 (1): 15–22. https://doi.org/10.1080/00139157.2023.2146944

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FOOD SYSTEMS TRANSFORMATION IN RELATION TO CLIMATE CHANGE?

Timothy Thomas (IFPRI) and Aditi Mukherji (CGIAR)

Key messages

- Climate change poses major challenges to agriculture and food systems, but the latest foresight modeling suggests impacts may be more nuanced than previously thought. For example, economic feedback mechanisms affect global average impacts of climate change on yields and important differences arise between the various greenhouse gas (GHG) emissions scenarios and climate models.
- More importantly, global averages mask wide diversity in impacts across geographies, commodities, and people's ability to adapt.
- In addition to long-term impacts of changes in global averages, increasing climate variability is likely to lead to a higher frequency of production shocks from adverse climate events.
- Climate change is expected to lower GDP and therefore increase the number of food-insecure households and increase poverty. It may also slow growth of agricultural productivity, adversely impacting rural households.
- Agriculture and food systems (including diets, energy use, and land use change) play a key role in global emissions and strategies to reach net zero, but these strategies are at cross purposes with meeting food needs under climate change and rising demand for food globally. Foresight modeling can help decision-makers evaluate these trade-offs and ameliorate particularly adverse impacts.

RECENT TRENDS AND CHALLENGES

Climate change is resulting in costlier shocks from extreme events. In 2022 alone, climate change wreaked havoc on agriculture when devastating floods occurred in Pakistan (Otto et al. 2023); the worst heatwave in India took a huge toll on the wheat harvest (Zachariah et al. 2023); the worst drought in 40 years in the Horn of Africa exacerbated food insecurity and caused famine in some places (Kimutai et al. 2025); devastating tropical cyclones destroyed infrastructure and property in places such as Florida (United States) and the Philippines; and landslides from flooding caused destruction and loss of lives in Latin America. Add to this ongoing sea level rise leading to frequent inundation of crops and salinization in the past decades in major river deltas in Bangladesh and Viet Nam, and it is clear how climate change is affecting the entire food system.

Governments worldwide are acknowledging the losses and damages caused by greenhouse gas (GHG)-induced climate change, creating a fund during the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) for assistance or reparations, depending on the perspective one takes. Seneviratne et al. (2021) describe in more detail the mechanisms through which devastating climate events are occurring more frequently.

LATEST FORESIGHT RESEARCH

The primary reference for understanding the latest in climate change research is the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). It is published in three large volumes. The first focuses on the latest research on the physical science related to climate and climate changes (IPCC 2021). The second focuses on the impact of climate change on the systems that people rely on for their well-being (IPCC 2022a). Chapter 5 (Bezner et al. 2022) focuses on agriculture. The third volume of the AR6 focuses on climate change mitigation (IPCC 2022b), with an important chapter on Agriculture, Forestry and Other Land Uses (AFOLU; Nabuurs et al. 2022). Other sources concerning GHG emissions mitigation from the AFOLU sector are Mukherji et al. (2023, 2024). Summaries of the latest research on climate and food can be found in the CGIAR Climate Insights (2025). For a summary of the latest IMPACT foresight model results, see Rosegrant et al. (2024) or Rosegrant et al. (forthcoming).

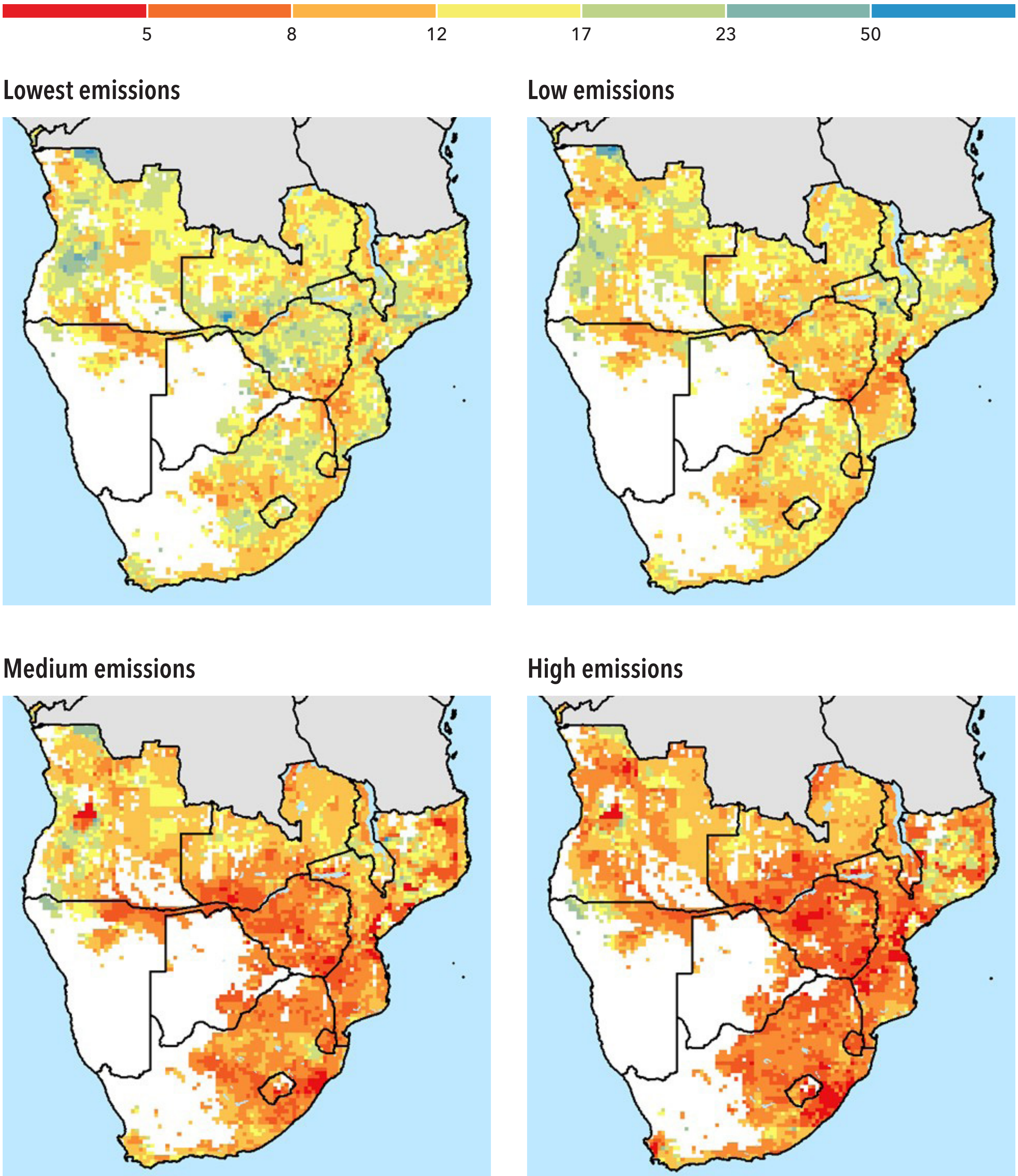
Foresight models generally project modest global average impacts of climate change on agricultural productivity. Several studies of the long-term impact of climate change find modest impacts on aggregate agricultural productivity at the global level (Jägermeyr et al. 2021; Rosegrant et al. 2024), reflecting that losses in some locations and crops are offset by gains in others. For example, Jägermeyr et al. (2021) estimate yield changes from climate change between 1983–2013 and 2069–2099 for the world's four largest crops (using five climate models and 12 crop models, allowing for CO_2 fertilization, and focusing on the low- and high-emissions scenarios, SSP126 and SSP585, but not accounting for changes in technology or markets). Under these scenarios, they project global average yield losses of 6.4–24.1 percent for maize, yield changes of −2.0 to +2.1 percent for soybeans, and yield gains of 1.7–3.4 percent for rice and 8.8–17.5 percent for wheat. Global economic models project that changes in technology and markets will moderate these global average impacts, at least until mid-century (Rosegrant et al. 2024).

Digging deeper reveals important differences in impacts. Global averages conceal important differences between regions, countries, and even locations within a given country. In the process of spatially differentiating climate impact, it is possible to identify "hotspots" — locations where climate change will force major changes in the production systems currently used (Heikonen et al. 2025). More work can be done on this.

In addition to hotspots, a perhaps more significant impact hidden in the global averages is how interannual variability of climate can lead to considerable variability in yields. Extremely low or high rainfall or temperature in a given year can result in very low yields. Global averages offset low-yield years with normal- and high-yield years. Yet because of the devastating effect for farmers and for low-income consumers, years with climate shocks take on great importance.

Foresight analysis thus gives us two complementary messages. First, at the global level, production is projected to roughly keep pace with demand for food, livestock feed,

FIGURE 1 Frequency of 1-in-20-year low maize yield events in southern Africa: Comparing frequency in the 2020s to the 2060s under various emissions scenarios



Source: Thomas et al. (2022b).

and stock for biofuels. And second, in certain locations or in certain years, production shocks will result in hardship, but foresight modeling can help identify risks in advance so that policy interventions can aid in adapting before the shocks are fully realized.

The frequency and impact of extreme events will increase. Thomas et al. (2022a, 2022b) modeled the impact of climate change on climate shocks — 1-in-20-year low-rainfall, high-temperature, or low-yield events in 10 countries of southern Africa — using a distribution of over 500,000 simulated climates (see Figure 1 for impact on low-yield events for maize). The authors noted a large increase in the frequency of low-yield events in most parts of the region (though in relatively small areas, low-yield events actually decreased). Another way of understanding their results is to say that 1-in-20-year low-yield events will have lower yields than before climate change. Other studies that have looked at the interannual variability of yields include Ostberg et al. (2018); Liu, Ye, and Shi (2021); Chen, Zhang, and Tao (2018); Stuch, Alcamo, and Schaldach (2020); Torriani et al. (2007); and Thornton et al. (2009).

Heat stress is projected to adversely affect labor productivity. Nelson et al. (2024) examine the impact of heat stress on manual work in the agriculture sector. They find that under the highest emissions scenario, the productivity of labor will drop from the current level of 86 percent to 70 percent by the end of the century. They also discover that certain regions will experience a much higher effect, and they investigate how much machinery will be required to replace human labor. Heat stress on human labor is currently not accounted for in most foresight modeling and suggests an important cause of productivity declines that should be incorporated in future scenarios (see also Parsons et al. 2021 and Dasgupta and Robinson 2023).

There is little agreement regarding climate's impact on overall productivity growth. Many studies have tried to estimate the impact of climate change on overall agricultural productivity (beyond what process-based models can estimate) and on the economy in general. Dell, Jones, and Olken (2012) suggest that in addition to the direct impact of temperature and precipitation on the level of production, it is theoretically possible that climate might impact the rate of growth of production. However, little agreement exists between studies that have endeavored to investigated this issue: some find very large impacts on agriculture and on the whole economy, while other studies find modest impacts (Dell, Jones, and Olken 2012; Burke, Hsiang, and Miguel 2015; Burke, Davis, and Diffenbaugh 2018; Diffenbaugh and Burke 2019; Casey, Fried, and Goode 2022, 2023; Barrage 2020; Hassler et al. 2019; Golosov et al. 2014; Nordhaus and Boyer 2003; Donadelli et al. 2017; Letta and Tol 2019; Zhang et al. 2018; Chancellor et al. 2021; Ortiz-Bobea et al. 2021; Liang et al. 2017; Xiang et al. 2022; Kotz, Levermann, and Wenz 2024). Studies that impose a growth effect on their analysis (while excluding the level effect) find very large costs due to climate change (Burke, Davis, and Diffenbaugh 2018; Ortiz-Bobea et al. 2021). Despite disagreement concerning the magnitude of the impact of climate change on GDP, it is generally agreed that there is a negative impact of climate change on GDP not accounted for in most if not all foresight modeling scenarios. While the impact on the level effect of agricultural total factor productivity (TFP) is modeled by use of bioeconomic models, if climate exerts a growth effect on agricultural TFP as some research suggests, this is not accounted for in foresight modeling scenarios and could create a much more adverse projection for future agricultural productivity.

CO_2 fertilization reduces nutrients in crops. Finally, despite CO_2 fertilization tending to increase yields (especially of crops other than maize, sorghum, millet, sugarcane, and teff), it also has the effect of reducing protein, vitamin, and mineral content by harvested weight (Myers, Zanobetti, Kloog et al. 2014), and foresight models are able to project the impact on nutrition. Refer to the chapter on diets and nutrition by Sulser et al. in this volume to learn more. Furthermore, some disagreement arises in the scientific literature about the size of the CO_2 fertilization effect (Toreti et al. 2020; Li et al. 2017; Allen et al. 2020; Zhu et al. 2023; Yuan et al. 2019).

Emissions from the food system are large and need to be reduced. Crippa et al. (2021) calculate that 34 percent of the world's GHG emissions are from the food system, including production of fertilizer, land use and land use change, non-CO_2 emissions from enteric fermentation and wet soils, transportation, processing, and retail. Important avenues for getting the global food system to net zero emissions are through afforestation and reforestation, particularly on low-productivity agricultural lands. This often comes with a reduction in livestock production, particularly cattle, which are seen as drivers of deforestation for more pasture and are themselves large methane emitters (a powerful GHG), primarily through enteric fermentation.

Reducing emissions will also require changes in eating habits. Springmann et al. (2018) analyze options for making the global food system both more nutritious and sustainable while staying within planetary boundaries (Rockström et al. 2009a, 2009b), one of which is GHG emissions, but other agriculture-related boundaries include use of nitrogen and phosphorous fertilizers, deforestation, freshwater availability, and biodiversity loss. Springmann et al. (2018) argue that it would be difficult to stay within these boundaries and provide sufficient nutrition to people without major changes to consumer demand for food, including reducing consumption of proteins from livestock. The pushback on this research has primarily dealt with the difficulty of changing consumer behavior and the infeasibility for many people in developing countries of affording the suggested alternative diet, suggesting limits to how much diets will be able to change (Hirvonen et al. 2020).

KEY GAPS AND OPPORTUNITIES FOR FURTHER RESEARCH

The preceding section highlighted some of the latest findings, but also pointed to how those findings could be expanded or included in foresight modeling scenarios, such as including climate impact on GDP or agricultural TFP growth and including the effects of heat stress on labor productivity effects of climate change.

While studies like Thomas et al. (2022a, 2022b) show the impact of climate uncertainty and interannual variability on the frequency of production shocks for southern Africa, more work could be done globally, potentially leading to solutions that mitigate increases in food insecurity and climate shocks that result from climate change. Furthermore, their work examines only the impact of climate uncertainty, but does not examine the impact of increasing climate variability, which could be included in future foresight modeling.

Other climate-related gaps in many foresight models include:

- The impact of climate change on livestock productivity.
- Estimating and accounting for losses from flooding, waterlogging, sea-level rise, storm surge, submersion, and salinization on yields and availability of agricultural land.
- Accounting for the impact of loss of glaciers and reduction in glacier melt for irrigation water.
- Accounting for other large losses of harvests that are increasing under climate change, including wildfires and landslides.
- The effect of climate change on pests and diseases, and how these changes impact crop and livestock productivity.
- Careful analysis of climate change impact by growing season in countries with multiple seasons.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Timothy Thomas**, a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); and **Aditi Mukherji**, Director of the CGIAR Climate Change Adaptation and Mitigation Impact Platform.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Thomas, T., and A. Mukherji. 2025. "What Do We Know About the Future of Food Systems Transformation in Relation to Climate Change?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 6. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: stu.dio/Shutterstock

References

Allen, L.H., B.A. Kimball, J.A. Bunce, et al. 2020. "Fluctuations of CO_2 in Free-Air CO_2 Enrichment (FACE) Depress Plant Photosynthesis, Growth, and Yield." *Agricultural and Forest Meteorology* 284: 107899. https://doi.org/10.1016/j.agrformet.2020.107899

Barrage, L. 2020. "The Fiscal Costs of Climate Change." *AEA Papers and Proceedings* 110: 107–12. https://doi.org/10.1257/pandp.20201082

Bezner Kerr, R., T. Hasegawa, R. Lasco, et al. 2023. "Food, Fibre, and Other Ecosystem Products." In *Climate Change 2022: Impacts, Adaptation and Vulnerability*, eds. H.-O. Pörtner, D.C. Roberts, M. Tignor, et al., 713–906. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/9781009325844.007

Burke, M., W.M. Davis, and N.S. Diffenbaugh. 2018. "Large Potential Reduction in Economic Damages Under UN Mitigation Targets." *Nature* 557: 549–553. https://doi.org/10.1038/s41586-018-0071-9

Burke, M., S.M. Hsiang, and E. Miguel. 2015. "Global Non-Linear Effect of Temperature on Economic Production." *Nature* 527: 235–239. https://doi.org/10.1038/nature15725

Casey, G., S. Fried, and E. Goode. 2022. "Projecting the Impacts of Temperature Change: The Role of Macroeconomic Dynamics." IMF Economic Review Conference, Rabat, June.

Casey, G., S. Fried, and E. Goode. 2023. "Projecting the Impact of Rising Temperatures: The Role of Macroeconomic Dynamics." *IMF Economic Review* 71: 688–718. https://doi.org/10.1057/s41308-023-00203-0

CGIAR. 2025. *CGIAR Climate Insights*. https://hdl.handle.net/10568/138998

Chancellor, W., N. Hughes, S. Zhao, W. Ying Soh, H. Valle, and C. Boult. 2021. "Controlling for the Effects of Climate on Total Factor Productivity: A Case Study of Australian Farms." *Food Policy* 102: 102091. https://doi.org/10.1016/j.foodpol.2021.102091

Chen, Y., Z. Zhang, and F. Tao. 2018. "Impacts of Climate Change and Climate Extremes on Major Crops Productivity in China at a Global Warming of 1.5 and 2.0°C." *Earth System Dynamics* 9 (2): 543–562. https://doi.org/10.5194/esd-9-543-2018

Crippa, M., E. Solazzo, D. Guizzardi, et al. 2021. "Food Systems Are Responsible for a Third of Global Anthropogenic GHG Emissions." *Nature Food* 2: 198–209. https://doi.org/10.1038/s43016-021-00225-9

Dasgupta, S., and E.J.Z. Robinson. 2023. "The Labour Force in a Changing Climate: Research and Policy Needs." *PLOS Climate* 2 (2): e0000131. https://doi.org/10.1371/journal.pclm.0000131

Dell, M., B.F. Jones, and B.A. Olken. 2012. "Temperature Shocks and Economic Growth: Evidence From the Last Half Century." *American Economic Journal: Macroeconomics* 4 (3): 66–95. https://www.aeaweb.org/articles?id=10.1257/mac.4.3.66

Diffenbaugh, N.S., and M. Burke. 2019. "Global Warming Has Increased Global Economic Inequality." *PNAS* 116 (20): 9808–9813. www.pnas.org/cgi/doi/10.1073/pnas.1816020116

Donadelli, M., M. Jüppner, M. Riedel, and C. Schlag. 2017. "Temperature Shocks and Welfare Costs." *Journal of Economic Dynamics and Control* 82: 331–355. https://doi.org/10.1016/j.jedc.2017.07.003

Golosov, M., J. Hassler, P. Krusell, and A. Tsyvinski. 2014. "Optimal Taxes on Fossil Fuel In General Equilibrium." *Econometrica* 82 (1): 41–88. https://doi.org/10.3982/ECTA10217

Hassler, J., P. Krusell, C. Olovsson, and M. Reiter. 2019. *Integrated Assessment in a Multi-Region World With Multiple Energy Sources and Endogenous Technical Change (Preliminary)*. https://www.frbsf.org/wp-content/uploads/Paper-3-2019-11-8-Olovsson-1045AM-1st-paper.pdf

Heikonen, S., M. Heino, M. Jalava, S. Siebert, and M. Kummu. 2025. "Climate Change Threatens Crop Diversity at Low Latitudes." *Nature Food* 6: 331–342. https://doi.org/10.1038/s43016-025-01135-w

Hirvonen, K., Y. Bai, D. Headey, and W.A. Masters. 2020. "Affordability of the EAT–*Lancet* Reference Diet: A Global Analysis." *Lancet Global Health* 8 (1): e59–e66. https://doi.org/10.1016/S2214-109X(19)30447-4

IPCC (Intergovernmental Panel on Climate Change). 2022a. *Climate Change 2022: Impacts, Adaptation and Vulnerability*, eds. H.-O. Pörtner, D.C. Roberts, M. Tignor, et al.. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

IPCC. 2022b. *Climate Change 2022: Mitigation of Climate Change*, eds. P. Shukla, J. Skea, R. Slade, et al. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. UK and New York: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg3/

IPCC. 2023. *Climate Change 2021: The Physical Science Basis*, eds. V. Masson-Delmotte, P. Zhai, A. Pirani, et al. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. UK and New York: Cambridge University Press. https://doi.org/10.1017/9781009157896

Jägermeyr, J., C. Müller, A.C. Ruane, et al. 2021. "Climate Impacts on Global Agriculture Emerge Earlier in New Generation of Climate and Crop Models." *Nature Food* 2: 873–885. https://doi.org/10.1038/s43016-021-00400-y

Kimutai, J., C. Barnes, M. Zachariah, et al. 2025. "Human-Induced Climate Change Increased 2021–2022 Drought Severity in Horn of Africa." *Weather and Climate Extremes* 47: 100745. https://doi.org/10.1016/j.wace.2025.100745

Kotz, M., A. Levermann, and L. Wenz. 2024. "The Economic Commitment of Climate Change." *Nature* 628: 551–557. https://doi.org/10.1038/s41586-024-07219-0

Letta, M., and R.S.J. Tol. 2019. "Weather, Climate and Total Factor Productivity." *Environmental and Resource Economics* 73 (1): 283–305. https://www3.nd.edu/~nmark/Climate/Letta-Tol2019_Article_WeatherClimateAndTotalFactorPr.pdf

Li, P., C. Peng, M. Wang, et al. 2017. "Quantification of the Response of Global Terrestrial Net Primary Production to Multifactor Global Change." *Ecological Indicators* 76: 245–255. https://doi.org/10.1016/j.ecolind.2017.01.021

Liang, X., Y. Wu, R.G. Chambers, et al. 2017. "Determining Climate Effects On US Total Agricultural Productivity." *PNAS* 114 (12): E2285–E2292. https://doi.org/10.1073/pnas.1615922114

Liu, W., T. Ye, and P. Shi. 2020. "Decreasing Wheat Yield Stability on the North China Plain: Relative Contributions from Climate Change in Mean and Variability." *International Journal of Climatology* 41 (S1): E2820–E2833. https://doi.org/10.1002/joc.6882

Mukherji, A., C. Arndt, J. Arango, et al. 2023. *Achieving Agricultural Breakthrough: A Deep Dive Into Seven Technological Areas*. Montpellier, France: CGIAR System Organization. https://hdl.handle.net/10568/131852

Mukherji, A., S. Marshall, J. Arango, et al. 2024. 2024 *Breakthrough Agenda Report: Agriculture*. Montpellier, France: CGIAR. https://agriculture-breakthrough2024.cgiar.org/

Myers, S.S., A. Zanobetti, I. Kloog, et al. 2014. "Increasing CO_2 Threatens Human Nutrition." *Nature* 510: 139–142. https://doi.org/10.1038/nature13179

Nabuurs, G-J., R. Mrabet, A. Abu Hatab, et al. 2022. "Agriculture, Forestry and Other Land Uses (AFOLU)." In *Climate Change 2022: Mitigation of Climate Change*, eds. P.R. Shukla, J. Skea, R. Slade, et al. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. UK and New York: Cambridge University Press. https://doi.org/10.1017/9781009157926.009

Nelson, G.C., J. Vanos, G. Havenith, O. Jay, K. L. Ebi, and R. J. Hijmans. 2024. "Global Reductions in Manual Agricultural Work Capacity Due to Climate Change." *Global Change Biology* 30 (1): e17142. https://doi.org/10.1111/gcb.17142

Nordhaus, W.D. and J. Boyer. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press.

Ortiz-Bobea, A., T.R. Ault, C.M. Carrillo, R.G. Chambers, and D.B. Lobell. 2021. "Anthropogenic Climate Change Has Slowed Global Agricultural Productivity Growth." *Nature Climate Change* 11 (April): 306–312. https://doi.org/10.1038/s41558-021-01000-1

Ostberg, S., J. Schewe, K. Childers, and K. Frieler. 2018. "Changes in Crop Yields and Their Variability at Different Levels of Global Warming." *Earth System Dynamics* 9 (2): 479–496. https://doi.org/10.5194/esd-9-479-2018

Otto, F.E.L., M. Zachariah, F. Saeed, et al. 2023. "Climate Change Increased Extreme Monsoon Rainfall, Flooding Highly Vulnerable Communities in Pakistan." *Environmental Research: Climate*. https://doi.org/10.1088/2752-5295/acbfd5

Parsons, L.A., D. Shindell, M. Tigchelaar, Y. Zhang, and J. T. Spector. 2021. "Increased Labor Losses and Decreased Adaptation Potential in a Warmer World." *Nature Communications* 12: 7286. https://doi.org/10.1038/s41467-021-27328-y

Rockström, J., W. Steffen, K. Noone, et al. 2009a. "A Safe Operating Space for Humanity." *Nature* 461: 472–75. https://doi.org/10.1038/461472a

Rockström, J., W. Steffen, K. Noone, et al. 2009b. "Planetary Boundaries: Exploring the Safe Operating Space for Humanity." *Ecology and Society* 14 (2): 32. http://www. ecologyandsociety.org/vol14/iss2/art32/

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security Under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41 (June). https://doi.org/10.1016/j.gfs.2024.100755

Rosegrant, M.W. et al. Forthcoming. *ADB Report*. Manila: Asian Development Bank.

Seneviratne, S.I., X. Zhang, M. Adnan, et al. 2021. "Weather and Climate Extreme Events in a Changing Climate." In *Climate Change 2021: The Physical Science Basis*, eds V. Masson-Delmotte, P. Zhai, A. Pirani, et al.. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/

Springmann, M., M. Clark, D. Mason-D'Croz, et al. 2018. "Options for Keeping the Food System Within Environmental Limits." *Nature* 562: 519–25. https://doi.org/10.1038/s41586-018-0594-0

Stuch, B., J. Alcamo, and R. Schaldach. 2020. "Projected Climate Change Impacts on Mean and Year-to-Year Variability of Yield of Key Smallholder Crops in Sub-Saharan Africa." *Climate and Development* 13 (3): 268–282. https://doi.org/10.1080/17565529.2020.1760771

Thomas, T.S., C. A. Schlosser, K. Strzepek, R.D. Robertson, and C. Arndt. 2022a. "Using a Large Climate Ensemble to Assess the Frequency and Intensity of Future Extreme Climate Events in Southern Africa." *Frontiers in Climate* 4. https://doi.org/10.3389/fclim.2022.787721

Thomas, T.S., R.D. Robertson, K. Strzepek, and C. Arndt. 2022b. "Extreme Events and Production Shocks for Key Crops in Southern Africa Under Climate Change." *Frontiers in Climate* 4. https://doi.org/10.3389/fclim.2022.787582

Thornton, P., P. Jones, G. Alagarswamy, and J. Andresen. 2009. "Spatial Variation of Crop Yield Response to Climate Change in East Africa." *Global Environmental Change* 19 (1): 54–65. https://doi.org/10.1016/j.gloenvcha.2008.08.005

Toreti, A., D. Deryng, F. Tubiello, et al. 2020. "Narrowing Uncertainties in the Effects of Elevated CO_2 on Crops." *Nature Food* 1: 775–782. https://doi.org/10.1038/s43016-020-00195-4

Torriani, D.S., P. Calanca, S. Schmid, M. Beniston, and J. Fuhrer. 2007. "Potential Effects of Changes in Mean Climate and Climate Variability on the Yield of Winter and Spring Crops in Switzerland." *Climate Research* 34 (1): 59–69. https://doi.org/10.3354/cr034059

Xiang, T., T.H. Malik, J.W. Hou, and J. Ma. 2022. "The Impact of Climate Change on Agricultural Total Factor Productivity: A Cross-Country Panel Data Analysis, 1961–2013." *Agriculture* 12 (12): 2123. https://doi.org/10.3390/agriculture12122123

Yuan, W., Y. Zheng, S. Piao, et al. 2019. "Increased Atmospheric Vapor Pressure Deficit Reduces Global Vegetation Growth." *Science Advances* 5 (8): eaax1396. https://doi.org/10.1126/sciadv.aax1396

Zhang, P., O. Deschenes, K. Meng, and J. Zhang. 2018. "Temperature Effects on Productivity and Factor Reallocation: Evidence From a Half Million Chinese Manufacturing Plants." *Journal of Environmental Economics and Management* 88: 1–17. https://doi.org/10.1016/j.jeem.2017.11.001

Zhu, C., J. Wolf, J. Zhang, W.R.L. Anderegg, J.A. Bunce, and L.H. Ziska. 2023. "Rising Temperatures Can Negate CO_2 Fertilization Effects on Global Staple Crop Yields: A Meta-Regression Analysis." *Agricultural and Forest Meteorology* 342: 109737. https://doi.org/10.1016/j.agrformet.2023.109737

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF AGROBIODIVERSITY IN RELATION TO FOOD SYSTEMS?

Nicola Cenacchi (IFPRI), Elisabetta Gotor (Bioversity International), Athanasios Petsakos (Bioversity International), and Benjamin Schiek (CIAT)

Key messages

- Agrobiodiversity – the diversity of living organisms that underpin agricultural systems – provides numerous critical benefits, from on-farm crop diversity and genetic resources that allow farmers to adapt crops to changing environments to the provision of ecosystem services such as pollination, disease and pest resistance, soil health, and water conservation. These benefits in turn support resilient livelihoods, food security, and diversified, nutritious diets.

- A number of ex ante theoretical and practical approaches have been used to show how greater agricultural biodiversity is connected to higher production and lower risk exposure, and to assess the role that agrobiodiversity plays in supporting agricultural systems resilience. But little has been done to integrate the measurement of agrobiodiversity into foresight modeling, or to apply foresight tools and methods to study long-term effects of agrobiodiversity on socio-economic or environmental outcomes.

- The recent development of the Agrobiodiversity Index and advances in integrated modeling systems provide opportunities for improved scenario analysis focused on agrobiodiversity and informed by agro-ecology and agricultural economics theory.

RECENT TRENDS AND CHALLENGES

It is well established that protecting and investing in greater agrobiodiversity is needed to achieve multiple Sustainable Development Goals (Fowler and Hodgkin 2004; Hajjar, Jarvis, and Gemmill-Herren 2008; Wood et al. 2018; Waha et al. 2022), and that this diversity is threatened by many factors, including climate change, socioeconomic trends, and management decisions that have led to a global homogenization and degradation of both farmland and its genetic resources (IPBES 2019; Purvis et al. 2019; Landis 2017). For example, it is estimated that up to 22 percent of wild crop species may go extinct by 2055 (Brauman et al. 2019; Jarvis, Lane, and Hijmans 2008), and that over 9 percent of domesticated mammal breeds had already become extinct by 2016 (IPBES 2019).

The magnitude of such threats is undermining the future sustainability of agricultural production and the food security and livelihoods of countless producers and consumers: for example, the loss of pollinators has reduced the value of annual global crop production by an estimated US$235 to $577 billion (IPBES 2019; Potts et al. 2016). The large uncertainty inherent in the evolution of global and local drivers of change, and the ensuing challenges, require tools in support of urgent and informed decisions. However, few studies have applied foresight tools to analyze the medium- to long-term effects that investing in agrobiodiversity may have on socioeconomic and ecological outcomes, as well as for adaptation to and mitigation of climate change. Such studies may also be useful to highlight the trade-offs between immediate human needs and the benefits that agrobiodiversity may provide in the long term through the provision of multiple ecosystem services.

LATEST FORESIGHT RESEARCH

A mature literature exists on the farm-level benefits, impact pathways, and nonmarket valuation of agrobiodiversity (Di Falco 2012; Kontoleon, Pascual, and Smale 2009). Linking modeling insights developed at the farm scale with mechanisms and drivers at the ecosystem, national, and global scale remains a challenge, however. A rich literature also addresses the effects that alternative policies or management practices may have on levels of agrobiodiversity (Petsakos et al. 2023). However, to our knowledge, such studies generally lack a time dimension and consideration of other important drivers of change in food systems over the medium to longer term.

Few studies based on scenario analysis have used integrated models to explore the effects of increased agrobiodiversity on farm productivity, incomes, diets, and ecosystem services (Enahoro et al. 2019, 2023; Kozicka et al. 2020, 2022). These studies commonly link a global partial equilibrium model of the agriculture sector to farm models, environmental simulation tools, and models that analyze changes in ecosystem services.

When agrobiodiversity is studied as a driver of change, it is often represented through proxy indicators. For instance, scenario analysis has been used to explore how agroforestry compares to monocropping vis-à-vis the expansion of agricultural land to accommodate growing demand for animal-source foods in Tanzania (Enahoro et al. 2019; Kozicka et al. 2022). In these studies, the two management systems are mainly distinguished in terms of the biomass they are able to produce to meet livestock production needs (for example, yields of maize in monocropping are double the yields of agroforestry), or characterized through parameters relevant to the delivery of specific ecosystem services (for example, above- and below-ground carbon pools).

Foresight work looking at changes in the level of agrobiodiversity is also uncommon. In one example, the Shannon Index was used as a measure of change in agrobiodiversity following three possible scenarios of impacts on farming systems in Uganda (Kozicka et al. 2020).

Study results in Tanzania show that, compared to monocropping, agroforestry-based interventions hold promise for mitigating losses to key ecosystem services; in particular, erosion was halved while increasing production of animal-source foods. However, because more agrobiodiverse systems generate lower yields and greater conversion to cropland, some trade-offs may arise between meeting the demand for animal-source foods and maintaining ecosystem services (Enahoro et al. 2019; Kozicka et al. 2022).

The Uganda case study shows that increasing on-farm crop diversity can improve soil and human health and lead to greater socioeconomic system resilience against both climate shocks and damages from pests and diseases (Kozicka et al. 2020; Kozicka, Groot, and Gotor 2019). However, trade-offs do exist. While greater diversity can boost revenues and could restore dietary vitamin A to close to pre-shock levels, it may also lead to more volatility in revenues.

Similarly, other studies summarize the multiple avenues through which agroforestry interacts with planetary health, note the need for highly context-specific assessments (Rosenstock et al. 2019), and highlight the benefits of agroforestry for household asset accumulation, while also pointing out the difficulties in achieving broad adoption (Hughes et al. 2020).

Crop diversity was the focus of a recent study on durum wheat in Ethiopia, where a GTAP (Global Trade Analysis Project)-derived[1] model was used to test adoption of traditional wheat varieties (TV; those adapted to more extreme agroecological conditions in low-input systems) versus modern high-yielding varieties (MV; those more adapted to high-input monocropping systems) under climate change (Gotor et al. 2024). This study showed that an integrated approach based on the geographically targeted adoption of TV and MV can lead to better adaptation to climate change and boost agricultural production as a result.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

There seems to be a lack of research and application of foresight analysis to either the measurement of agrobiodiversity or its role as a driver of ecosystem services and a key determinant of food security and resilient livelihoods. Factors that may contribute to this situation include (1) confusion around the definition of agrobiodiversity; and (2) the difficulty of capturing in foresight models the causal relationships between socioeconomic factors and their impacts on agrobiodiversity. While these difficulties are not trivial, we see three possible ways of including agrobiodiversity in foresight-type scenario analysis.

First, long-run scenario analysis could be used to estimate across geographies and farming systems how agrobiodiversity may be changing as a result of specific policies and management decisions. The recently published Agrobiodiversity Index (ABDI) (Jones et al. 2021) provides an opportunity for foresight models to systematically measure a broad range of aspects related to agrobiodiversity across both producer and consumer sides of the food system.

Second, agrobiodiversity can be analyzed in terms of the future effects it may have on outcomes, from the provision of ecosystem services to agricultural productivity, incomes and livelihoods, and food security. This area of foresight research is still in its infancy. An additional path may be through development of a feedback loop between a land use change model and an integrated model such as IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) (Robinson et al. 2015), with possible links to biodiversity models.

And third, foresight tools and methods can be used to explore how major global drivers of change — as well as different policies, technologies, and trends — may affect biodiversity in general. These types of analyses are fairly well established from a methodological standpoint, but the emphasis is typically given to extinction risk, abundance, habitat loss and degradation, and changes in species distributions, especially for vascular plants and vertebrates (Flachsbarth et al. 2015; Leclère et al. 2020). But some such studies and methodologies may offer additional insights into impacts on agrobiodiversity.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Nicola Cenacchi**, a Senior Research Analyst in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); **Elisabetta Gotor**, a Principal Scientist and Lead of the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International; **Athanasios Petsakos**, a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International; and **Benjamin Schiek**, a Senior Research Associate in the Performance, Innovation and Strategic Analysis for Impact Program at the International Center for Tropical Agriculture (CIAT).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Cenacchi, N., E. Gotor, A. Petsakos, and B. Schiek. 2025. "What Do We Know About the Future of Agrobiodiversity in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 7. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Tri Saputro/CIFOR

1 https://www.gtap.agecon.purdue.edu

References

Brauman, K.A., L.A. Garibaldi, S. Polasky, et al. 2019. "Status and Trends – Nature's Contributions to People." In *Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, eds. E.S. Brondizio, J. Settele, S. Diaz, and H.T. Ngo, Chapter 2.3. Bonn: IPBES Secretariat. https://doi.org/10.5281/zenodo.3831673

Di Falco, S. 2012. "On the Value of Agricultural Biodiversity." *Annual Review of Resource Economics* 4 (1): 207–223. https://doi.org/10.1146/annurev-resource-110811-114543

Enahoro, D., M. Kozicka, C. Pfeifer, et al. 2019. *Changing Demand for Animal Source Foods and Their Effects on the Provision of Ecosystem Services*. ILRI Research Brief 93. Nairobi: International Livestock Research Institute. https://hdl.handle.net/10568/106431

Enahoro, D., M. Kozicka, C. Pfeifer, et al. 2023. "Linking Ecosystem Services Provisioning with Demand for Animal-Sources Food: An Integrated Modeling Study for Tanzania." *Regional Environmental Change* 23 (48). https://doi.org/10.1007/s10113-023-02038-x

Flachsbarth, I., B. Willaarts, H. Xie, G. Pitois, N.D. Mueller, C. Ringler, and A. Garrido. 2015. "The Role of Latin America's Land and Water Resources for Global Food Security: Environmental Trade-Offs of Future Food Production Pathways." *PLoS ONE* 10 (1): 1–24. https://doi.org/10.1371/journal.pone.0116733

Fowler, C., and T. Hodgkin. 2004. "Plant Genetic Resources for Food and Agriculture: Assessing Global Availability." *Annual Review of Environment and Resources* 29 (1): 143–179. https://doi.org/10.1146/annurev.energy.29.062403.102203

Gotor, E., C. Orecchia, G. Pallante, C. Fadda, and L. Salvatici. 2024. "Agrobiodiversity Conservation Policies: Insights from an Integrated Micro-Macro Economic Model in Ethiopia." *Economia Politica* 42: 91–119. https://doi.org/10.1007/s40888-024-00343-0

Hajjar, R., D.I. Jarvis, and B. Gemmill-Herren. 2008. "The Utility of Crop Genetic Diversity in Maintaining Ecosystem Services." *Agriculture, Ecosystems and Environment* 123 (4): 261–270. https://doi.org/10.1016/j.agee.2007.08.003

Hughes, K., S. Morgan, K. Baylis, J. Oduol, E. Smith-Dumont, T.G. Vågen, and H. Kegode. 2020. "Assessing the Downstream Socioeconomic Impacts of Agroforestry in Kenya." *World Development* 128 (April): 104835. https://doi.org/10.1016/j.worlddev.2019.104835

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2019. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, eds. E.S. Díaz, J. Settele, E. Brondízio, et al. Bonn: IPBES Secretariat. https://doi.org/10.5281/zenodo.3831673

Jarvis, A., A. Lane, and R.J. Hijmans. 2008. "The Effect of Climate Change on Crop Wild Relatives." *Agriculture, Ecosystems and Environment* 126 (1): 13–23. https://doi.org/10.1016/j.agee.2008.01.013

Jones, S.K., N. Estrada-Carmona, S.D. Juventia, M.E. Dulloo, M.-A Laporte, C. Villani, and R. Remans. 2021. "Agrobiodiversity Index Scores Show Agrobiodiversity Is Underutilized in National Food Systems." *Nature Food* 2 (9): 712–723. https://doi.org/10.1038/s43016-021-00344-3

Kontoleon, A., U. Pascual, and M. Smale, eds. 2009. *Agrobiodiversity Conservation and Economic Development*. Routledge Explorations in Environmental Economics. Oxon, UK: Routledge. https://doi.org/10.4324/9780203890127

Kozicka, M., E. Gotor, W. Ocimati, T. de Jager, E. Kikulwe, and J.C.J. Groot. 2020. "Responding to Future Regime Shifts with Agrobiodiversity: A Multi-Level Perspective on Small-Scale Farming in Uganda." *Agricultural Systems* 183 (August):102864. https://doi.org/10.1016/j.agsy.2020.102864

Kozicka, M., J.C.J. Groot, and E. Gotor. 2019. "Can Crop Diversity Strengthen Small-Scale Farmers' Resilience?" In *Agrobiodiversity Index Report 2019: Risk and Resilience*,135–144. Rome: Bioversity International. https://hdl.handle.net/10568/100820

Kozicka, M., S.K. Jones, E. Gotor, and D. Enahoro. 2022. "Cross-Scale Trade-Off Analysis for Sustainable Development: Linking Future Demand for Animal Source Foods and Ecosystem Services Provision to the SDGs." *Sustainability Science* 17 (1): 209–220. https://doi.org/10.1007/s11625-021-01082-y

Landis, D.A. 2017. "Designing Agricultural Landscapes for Biodiversity-Based Ecosystem Services." *Basic and Applied Ecology* 18: 1–12. https://doi.org/10.1016/j.baae.2016.07.005

Leclère, D., M. Obersteiner, M. Barrett, M., et al. 2020. "Bending the Curve of Terrestrial Biodiversity Needs: An Integrated Strategy." *Nature* 585 (7826): 551–556. https://doi.org/10.1038/s41586-020-2705-y

Petsakos, A., P. Ciaian, M. Espinosa, A. Perni, and D. Kremmydas. 2023. "Farm-Level Impacts of the CAP Post-2020 Reform: A Scenario-Based Analysis." *Applied Economic Perspectives and Policy* 45 (2): 1168–1188. https://doi.org/10.1002/aepp.13257

Potts, S.G., V. Imperatriz-Fonseca, H.T. Ngo, et al., 2016. "Safeguarding Pollinators and Their Values to Human Well-Being." *Nature* 540 (7632): 220–229. https://doi.org/10.1038/nature20588

Purvis, A., Z. Molnár, D. Obura, et al. 2019. "Status and Trends – Nature." In *Global Assessment Report of the Intergovernmental Science – Policy Platform on Biodiversity and Ecosystem Services*, eds. E.S. Brondízio, J. Settele, S. Díaz, and H.T. Ngo, Chapter 2.2. Bonn: IPBES Secretariat. https://doi.org/10.5281/zenodo.3831673

Robinson, S., D. Mason d'Croz, S. Islam, et al. 2015. "The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3." IFPRI Discussion Paper 1483. International Food Policy Research Institute (IFPRI), Washington, DC. https://hdl.handle.net/10568/148953

Rosenstock, T.S., I.K. Dawson, E. Aynekulu, et al. 2019. "A Planetary Health Perspective on Agroforestry in Sub-Saharan Africa." *One Earth* 1 (3): 330–344. https://doi.org/10.1016/j.oneear.2019.10.017

Waha, K., F. Accatino, C. Godde, et al. 2022. "The Benefits and Trade-Offs of Agricultural Diversity for Food Security in Low- and Middle-Income Countries: A Review of Existing Knowledge and Evidence." *Global Food Security* 33: 100645. https://doi.org/10.1016/j.gfs.2022.100645

Wood, S.L.R., S.K. Jones, J.A. Johnson, et al. 2018. "Distilling the Role of Ecosystem Services in the Sustainable Development Goals." *Ecosystem Services* 29: 70–82. https://doi.org/10.1016/j.ecoser.2017.10.010

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF CROP PESTS AND DISEASES IN RELATION TO FOOD SYSTEMS?

Athanasios Petsakos (Bioversity International), Carlo Montes (Bioversity International), Diego Pequeno (CIMMYT), Benjamin Schiek (CIAT), and Kai Sonder (CIMMYT)

Key messages

- Crop pests and diseases (P&D) can cause substantial yield losses and pose a threat to global food security. Losses at a regional level can even exceed 40 percent for crops like maize and rice.
- Most studies show that a warmer climate creates a conducive, albeit spatially variable, environment for P&D spread. However, existing foresight research is largely biophysical in nature and focuses on individual pathosystems, examined mostly at the national level. As such, projections of the magnitude of economic impacts of changing patterns of P&D are missing.
- Global assessment of model-based historical and future P&D impacts on food systems remains constrained by the small number of available models that can estimate yield losses under contrasting climate and agroecological conditions.
- Efforts are needed to improve data accessibility, model versatility, and simulation platforms and to establish international observation and modeling networks. Artificial intelligence (AI) and related methods can assist in the development of robust and adaptable models to capture the impacts of P&D on food systems.

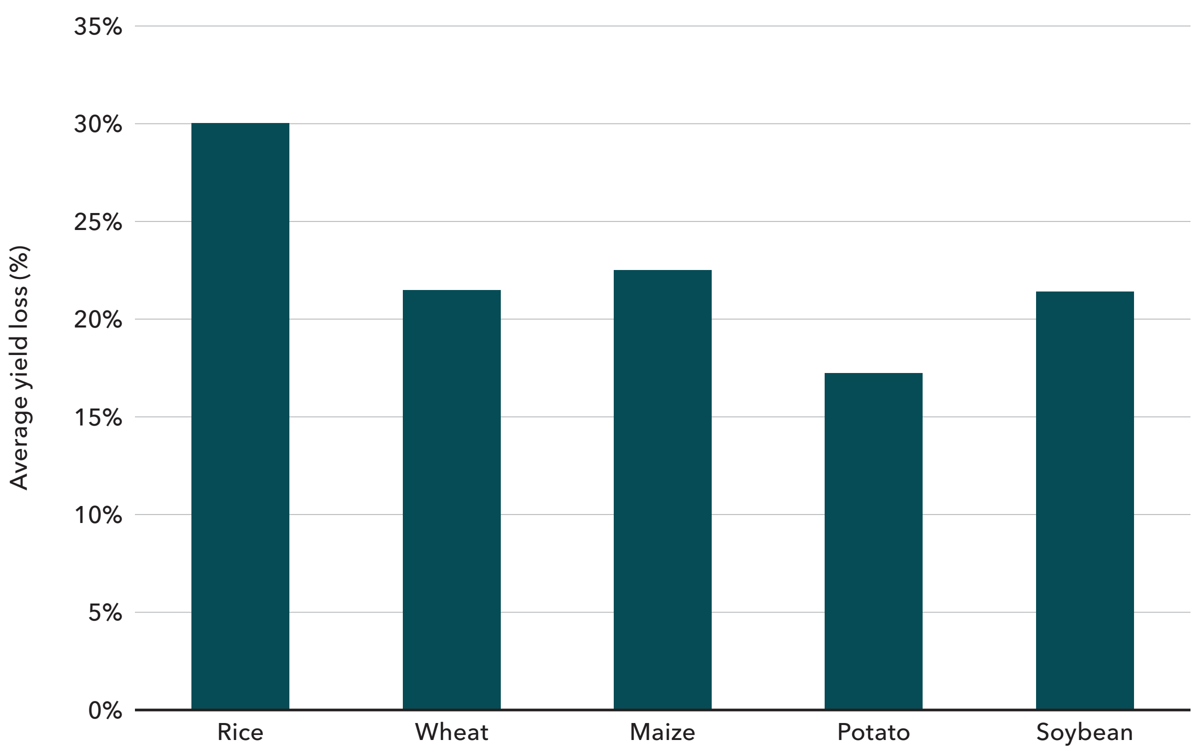
RECENT TRENDS AND CHALLENGES

Pests and diseases (P&D) present a major threat to global food security and have led to several famine events in human history, like the infamous Irish potato famine in the mid-19th century. Latest estimates suggest that current average losses to P&D for wheat, maize, rice, potatoes, and soybeans are in the range of 17–30 percent globally (Figure 1). Losses for maize and rice in the Indo-Gangetic Plains in India even exceed 40 percent (Savary et al. 2019). Without use of pest and disease control, these losses could double (OECD/FAO 2012).

Recent P&D outbreaks and emergencies have put the spotlight on P&D, leading the United Nations to declare 2020 the International Year of Plant Health. Examples of such incidents are abundant: the "Panama" disease, which almost caused a collapse of banana trade in the mid-1900s, is once again threatening banana production worldwide, leading Colombia to declare a national emergency in 2019 and prompting concern about the possible "near-death" of banana cultivation. The recent desert locust outbreak in the Horn of Africa triggered international concerns about food security in the region. Similar concerns are even shared by developed countries that have witnessed a reemergence of the wheat stem rust disease after almost 60 years (Lewis et al. 2018).

Climate is one of the most important factors mediating the impact of P&D on food systems. Climate change is thus expected to affect existing pathosystems, leading to epidemiological and distributional changes in existing P&D (Bebber, Castillo, and Gurr 2016; Garrett et al. 2006). It can also facilitate the establishment of new pathogens, especially when combined with increased trade between countries, as happened recently in the case of the wheat blast disease, introduced to Bangladesh in 2016 via international wheat trade. The disease is now threatening wheat production in South Asia, especially those regions where climate conditions are most suitable for its development (Montes, Hussain, and Krupnik 2022; Pequeno et al. 2024).

FIGURE 1 Estimated global yield losses to pests and diseases based on expert opinion, average over 2010–2014



Source: Data drawn from Savary et al. (2019).

LATEST FORESIGHT RESEARCH

Many studies have assessed the potential impacts of climate change on future threats associated with P&D, often examining one pathosystem at a time and at varying spatial scales. Juroszek et al. (2022) reviewed 143 studies performing model-based projections of potential disease infection risks for 30 different crops. The review reveals that more than 60 percent of them project an increase of infection risks in the future, but results are associated with high uncertainty and exhibit considerable spatial variability.

Chaloner, Gurr, and Bebber (2021) found that projections (to the late 21st century) of climate-induced yield changes for 12 crops exhibited positive spatial correlations with infection risks from 80 crop pathogens. These results suggest that while climate may become more suitable for crop growth over some areas in the future, it will also be conducive to pathogen development. Their analysis reveals that the number of pathogens developing under suitable climate conditions (pathogen richness) will likely increase in higher latitudes for most crops except rice, for which an increase in pathogens is projected across all latitudes. For instance, Europe, China, and Peru are expected to face the greatest overall pressure from P&D in the future because of increased pathogen richness and large changes in the composition of pathogen assemblages.

Deutsch et al. (2018) studied the global impact of increasing temperatures on grain losses from insect pests by 2050. Their analysis shows that a warmer climate can lead to up to 25 percent higher yield losses globally per degree of temperature increase. The United States, China, and Europe are likely to face the largest increase in yield losses for wheat (>60 percent) and maize (>40 percent), whereas China and South Asia are expected to register up to almost 30 percent higher losses for rice.

Several authors (Liu and Van der Fels-Klerx 2021; Moretti, Pascale, and Logrieco 2019) highlight the increased risks of aflatoxin contamination with climate change and the expansion of current risk areas (mainly in tropical and subtropical zones) to Europe, the United States, and southern latitude countries like Argentina and Australia. Increased CO_2, elevated temperatures, drought, and the combination of these factors are expected to increase crops' susceptibility to pathogens. Among the major staples, maize has been found to be more susceptible to infection, with aflatoxin-producing pathogens leading to high aflatoxin levels when grown under very dry and warm conditions in combination with drought. These climate conditions are expected to be more frequent in the future. Forecasting models have been developed in combination with crop phenology models to calculate the aflatoxin risk index (ARI) under current and future conditions to determine critical levels of infection (Alvito and Assunção 2021). Given the increasing high risk of aflatoxin contamination for humans and livestock, especially in tropical areas, more forward-looking analyses are required to inform policy decisions and assess the economic viability of potential long-term agroecological solutions for aflatoxin biocontrol, such as Aflasafe (Atehnkeng et al. 2022).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Quantifying the future pressure of P&D on food systems remains a challenge. The difficulty in modeling P&D stems from the complexity of simulating the various processes related to P&D dynamics, which is exacerbated by the existence of multiple pathosystems, the uncertainty related to model parameterization, and the limited availability of the data needed for model validation and calibration.

Among existing P&D models, only a few have been implemented at the regional or global scale, considering long-term climate trends (Juroszek et al. 2022). The number of models that quantify the impact of P&D on yields is equally small, and mostly focused on the main grain crops such as wheat, maize, and rice (for example, Batchelor et al. 2020; Willocquet et al. 2002, 2022).

The difficulty in quantifying losses to P&D and in accounting for socioeconomic conditions currently presents a major obstacle in linking P&D models with existing integrated foresight modeling frameworks to assess potential P&D pressures on food production systems and food security in the future. As such, current foresight work largely focuses on how climate change affects biophysical processes for specific P&D, and future changes in risk of infection. However, the link to crop yield responses and to food security is missing. Attempts to combine P&D with economic models to address food security issues are still at an embryonic stage, with current research limited to "what if" analyses of the economic impacts from potential epidemics of specific crop diseases (Godfray, Mason-D'Croz, and Robinson 2016; Petsakos et al. 2023).

The need to link epidemiological and crop simulation models to quantify the impacts of P&D on crop development and yield has long been considered one of the priorities for P&D modeling, but also an important challenge (Cunniffe et al. 2015; Donatelli et al. 2017). Recent research on coupling crop modeling with generic P&D modeling (Batchelor et al. 2020; Pequeno et al. 2024), along with the expressed need to create multidisciplinary communities of practice, reveals opportunities for improving existing tools and enhancing our understanding of the future impacts of P&D on food systems.

Given the complexity of agronomic system interactions, AI techniques offer a promising alternative and complement to traditional crop and P&D modeling approaches. AI-driven methods, particularly machine learning and deep learning algorithms, excel at identifying nonlinear patterns and relationships that may elude conventional modeling techniques. AI has the potential to overcome existing modeling limitations by integrating cause-and-effect relationships from diverse and complex data sources, including satellite imagery, sensor data, and historical records. This integration could not only improve model accuracy but also expand applicability across various agricultural scenarios. By leveraging these capabilities, researchers can develop more robust and adaptable models that capture the intricate dynamics of P&D impacts on crops and can be easily used to inform integrated foresight modeling frameworks.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Athanasios Petsakos**, a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International; **Carlo Montes**, a Climate Scientist in Climate Action at Bioversity International; **Diego Pequeno**, a Scientist and Wheat Crop Modeler in the Sustainable Agrifood Systems Program at the International Maize and Wheat Improvement Center (CIMMYT); **Benjamin Schiek**, a Senior Research Associate in the Performance, Innovation and Strategic Analysis for Impact Program at the International Center for Tropical Agriculture (CIAT); and **Kai Sonder**, Head of the Geographic Information System Unit in the Sustainable Agrifood Systems Program at CIMMYT.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Petsakos, A., C. Montes, D. Pequeno, B. Schiek, and K. Sonder, K. 2025. "What Do We Know About the Future of Crop Pests and Diseases in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, K. Wiebe and E. Gotor, Chapter 8. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Neil Palmer/CIAT

References

Alvito, P., and R. Assunção. 2021. "Climate Change and the Impact on Aflatoxin Contamination in Foods: Where Are We and What Should be Expected?: In K.R. Hakeem, C. A. F. Oliveira, & A. Ismail, eds., *Aflatoxins in Food. A Recent Perspective*, 275–288. Springer. https://doi.org/10.1007/978-3-030-85762-2

Atehnkeng, J., P.S. Ojiambo, A. Ortega-Beltran, J. Augusto, P.J. Cotty, and R. Bandyopadhyay. 2022. "Impact of Frequency of Application on the Long-Term Efficacy of the Biocontrol Product Aflasafe in Reducing Aflatoxin Contamination in Maize." *Frontiers in Microbiology* 13. https://doi.org/10.3389/fmicb.2022.1049013

Batchelor, W.D., L.M. Suresh, X. Zhen, Y. Beyene, M. Wilson, G. Kruseman, and B. Prasanna. 2020. "Simulation of Maize Lethal Necrosis (MLN) Damage Using the CERES-Maize Model." *Agronomy* 10 (5): 710. https://doi.org/10.3390/agronomy10050710

Bebber, D.P., A.D. Castillo, and S.J. Gurr. 2016. "Modelling Coffee Leaf Rust Risk in Colombia with Climate Reanalysis Data." *Philosophical Transactions of the Royal Society B: Biological Sciences* 371 (1709): 20150458. https://doi.org/10.1098/rstb.2015.0458

Chaloner, T.M., S.J. Gurr, and D.P. Bebber. 2021. "Plant Pathogen Infection Risk Tracks Global Crop Yields under Climate Change." *Nature Climate Change* 11 (8): 710–715. https://doi.org/10.1038/s41558-021-01104-8

Cunniffe, N.J., B. Koskella, C.J.E. Metcalf, S. Parnell, T.R. Gottwald, and C.A. Gilligan. 2015. "Thirteen Challenges in Modelling Plant Diseases." *Epidemics* 10: 6–10. https://doi.org/10.1016/j.epidem.2014.06.002

Deutsch, C.A., J.J. Tewksbury, M. Tigchelaar, D.S. Battisti, S.C. Merrill, R.B. Huey, and R.L. Naylor. 2018. "Increase in Crop Losses to Insect Pests in a Warming Climate." *Science* 361 (6405): 916–919. https://doi.org/10.1126/science.aat3466

Donatelli, M., R.D. Magarey, S. Bregaglio, L. Willocquet, J.P.M. Whish, and S. Savary. 2017. "Modelling the Impacts of Pests and Diseases on Agricultural Systems." *Agricultural Systems* 155: 213–224. https://doi.org/10.1016/j.agsy.2017.01.019

Garrett, K.A., S.P. Dendy, E.E. Frank, M.N. Rouse, and S.E. Travers. 2006. "Climate Change Effects on Plant Disease: Genomes to Ecosystems." *Annual Review of Phytopathology* 44 (1): 489–509. https://doi.org/10.1146/annurev.phyto.44.070505.143420

Godfray, H.C.J., D. Mason-D'Croz, and S. Robinson. 2016. "Food System Consequences of a Fungal Disease Epidemic in a Major Crop." *Philosophical Transactions of the Royal Society B: Biological Sciences* 371 (1709): 20150467. https://doi.org/10.1098/rstb.2015.0467

Juroszek, P., Bartsch, L., Fontaine, J. F., Racca, P., & Kleinhenz, B. (2022). Summary of the worldwide available crop disease risk simulation studies that were driven by climate change scenarios and published during the past 20 years. *Plant Pathology*, 71 (9): 1815–1838. https://doi.org/10.1111/ppa.13634

Lewis, C.M., A. Persoons, D.P. Bebber et al. 2018. "Potential for Re-emergence of Wheat Stem Rust in the United Kingdom." *Communications Biology* 1 (1): 13. https://doi.org/10.1038/s42003-018-0013-y

Liu, C., and H.J. Van der Fels-Klerx. 2021. "Quantitative Modeling of Climate Change Impacts on Mycotoxins in Cereals: A Review." *Toxins* 13 (4): 276. https://doi.org/10.3390/toxins13040276

Montes, C., Sk.G. Hussain, and T.J. Krupnik. 2022. "Variable Climate Suitability For Wheat Blast (*Magnaporthe oryzae* pathotype Triticum) in Asia: Results from a Continental-Scale Modeling Approach." *International Journal of Biometeorology* 66 (11): 2237–2249. https://doi.org/10.1007/s00484-022-02352-9

Moretti, A., M. Pascale, and A.F. Logrieco. 2019. "Mycotoxin Risks under a Climate Change Scenario in Europe." *Trends in Food Science & Technology* 84: 38–40. https://doi.org/10.1016/j.tifs.2018.03.008

OECD/FAO (Organisation for Economic Co-operation and Development/Food and Agriculture Organization of the United Nations). (2012). *OECD-FAO Agricultural Outlook 2012-2021*. OECD Publishing. https://doi.org/10.1787/agr_outlook-2012-en

Pequeno, D.N.L., T.B. Ferreira, J.M.C. Fernandes et al. 2024. "Production Vulnerability to Wheat Blast Disease under Climate Change." *Nature Climate Change* (February). https://doi.org/10.1038/s41558-023-01902-2

Petsakos, A., M. Kozicka, G. Blomme, J.N. Nakakawa, W. Ocimati, and E. Gotor. 2023. "The Potential Impact of Banana Xanthomonas Wilt on Food Systems in Africa: Modeling Scenarios of Policy Response and Disease Control Measures." *Frontiers in Sustainable Food Systems* 7. https://doi.org/10.3389/fsufs.2023.1207913

Savary, S., L. Willocquet, S.J. Pethybridge, P. Esker, N. McRoberts, and A. Nelson. 2019. "The Global Burden of Pathogens and Pests on Major Food Crops." *Nature Ecology & Evolution* 3: 430–439. https://doi.org/10.1038/s41559-018-0793-y

Willocquet, L., V. Rossi, and S. Savary. 2022. "Simulation Modelling of Yield Losses Caused by Wheat Stem Rust." *Plant Pathology* 71 (3): 544–555. https://doi.org/10.1111/ppa.13488

Willocquet, L., S. Savary, L. Fernandez et al. 2002. "Structure and Validation of RICEPEST, a Production Situation-Driven, Crop Growth Model Simulating Rice Yield Response to Multiple Pest Injuries for Tropical Asia." *Ecological Modelling* 153 (3): 247–268. https://doi.org/10.1016/S0304-3800(02)00014-5

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF LAND IN RELATION TO FOOD SYSTEMS?

Ricky Robertson (IFPRI), Nicola Cenacchi (IFPRI), and Abhijeet Mishra (IFPRI)

Key messages

- The total amount of cropland across the globe is likely to expand over the next three decades due to rising demand for food along with feed for livestock.
- Pasture will likely be stable or contract as livestock production continues to shift away from grazing and toward intensive use of feed and transported fodder.
- Climate change will increase the overall challenge and drive additional cropland expansion by generally reducing potential yields, although some crops and locations will benefit (typically higher latitudes and, to a lesser extent, higher elevations).
- Natural land will be displaced by cropland in some areas. In particular, forests in the tropics are at greater risk of conversion than in other regions. Beyond cropland incursion, the types, mixes, and footprints of natural vegetation may be affected by climate change.

RECENT TRENDS AND CHALLENGES

Land continues to be transformed by human activities. With the growing human population and higher incomes, demand for land has risen, driven by the need for housing, crop cultivation, livestock rearing, and timber production. Within the global trend, local dynamics can feature diverse patterns of land use change that partially cancel each other out when looking at worldwide figures (Winkler et al. 2021).

Cropland is the major human-managed land cover, covering an estimated 12 percent of the global ice-free land surface (Shukla et al. 2019). Despite the increasing accuracy of Earth observation systems, estimates of the precise 2020 cropland area, and 2000–2020 expansion rates, are still uncertain, largely due to differing land use definitions across maps (Tubiello et al. 2023). The FAOSTAT database continues to be the primary starting point for understanding global trends in cropland (Tubiello et al. 2023). The country-level values reported in the database are for harvested areas of crops during the reported year in each country, which can then be aggregated to the entire world. The corresponding actual space taken up on the ground (the physical area) will be smaller because some locations support multiple harvests in a single year, whether of the same crop or different crops using the same fields.

Reported harvested areas have consistently trended upward. Currently, about 290 million hectares (Mha) of land area are harvested. Since 2002, harvested area has increased at a rate of approximately 14.5 Mha/year, while prior to 2002 this rate was much lower, at about 5.4 Mha/year (FAOSTAT). The main crops associated with the post-2002 acceleration are maize and soybeans, but these only account for 40 percent of the acceleration (Cassman and Grassini 2020). Oil palm, sesame seed, cassava, and rape/colza seed have also made important contributions, showing high area growth compared to their 2002 levels. Geographically, major cropland expansion has occurred in South America and Africa.

The trends in reported pasture areas are the opposite of those in cropland, declining over the last two decades (Ritchie 2022). The shift arises from the interplay among changes in demand for animal products, intensification of animal production (which decreases the need for pasture by shifting to other sources of feed/fodder instead of pasture-based forage, which in turn requires more cropland), and the challenges within the reporting process. The aggregate numbers show a global decline of about 4.5 Mha/year of pasture recently.

The total extent of cropland and pastures together has leveled off or is possibly decreasing when considering both the intensification of livestock production and the different regional dynamics of cropland extensification and intensification to produce the additional feed (Ritchie 2022).

Forests are the most visible of the natural ecosystems. Much like with cropland and pastures, forest gains have occurred in some regions (primarily the temperate zones) and losses in others (largely in the tropics). The bulk of forest losses are associated with agricultural expansion (with cropland consistently expanding and pasture moving or expanding in forest regions, despite pasture's overall downward trend; Pendrill et al. 2022). Overall forest area appears to be declining at a rate of about 4.75 Mha/year.

LATEST FORESIGHT RESEARCH

Although a wealth of research is available on land use change, crop distribution, and natural ecosystems, global-scale analyses in these areas are relatively infrequent. Integrated assessment models that address these issues often bring together climate, hydrology, natural ecosystems, agriculture, and socioeconomic drivers. Typically, the economics and agriculture components determine the amount of cropland, which then interacts with the natural ecosystem component to predict where and how much of the different types of land will prevail. The effects of climate change and water availability exert their influence throughout the process.

Schmitz et al. (2014) brought together the results from 11 economic models of global agriculture to compare projections to 2050 using a particular shared socioeconomic pathway (SSP2, as defined for climate change studies). Without climate change, they found a median increase (from 2005 to 2050) of around 193 Mha of cropland (although ranging from −100 to +420 Mha), implying an overall annual average increase of about 4.3 Mha/year. When applying climate change, this increased to 317 Mha (or 7 Mha/year), meaning climate change increased the amount of cropland needed by 125 Mha (an additional 2.7 Mha/year above the no climate change case).

Similarly, Popp et al. (2017) brought five integrated assessment models together to evaluate the effects of climate change along with all five of the SSPs from 2005 to 2100. In addition to cropland, they reported projections for all land types, including pasture, forests, and other natural land. For the unmitigated climate change baseline case with SSP2, the median of the cropland projections showed an increase of about 150 Mha by 2050 and 231 Mha by 2100 (about 3.3 Mha/year before 2050 and 1.6 Mha/year after 2050). Pasture is projected to be fairly stable. For the baseline case, forest coverage continues to decline by about 83 Mha in 2050 (averaging 1.8 Mha/year), but then stabilizes and somewhat recovers by 2100. Of course, a great diversity of outcomes arise depending on the SSP and climate change assumptions, some of which result in much greater cropland expansion and forest losses and others that show the opposite.

Stehfest et al. (2019) similarly assessed six models, focusing on cropland, pasture, and the aspects of the modeling process that have the greatest influence on various outcomes. Their models showed an increase in cropland area under SSP2 of about 200 Mha by 2050 (about 5 Mha/year between 2010 and 2050) but much less agreement concerning pasture, with estimates ranging from decreases of roughly 200 Mha to increases of 200 Mha (in contrast to the fairly clear decline seen in the recent past).

The role of land in the food system is entangled in varying degrees with climate, the water cycle, biodiversity, technology developments, consumer preferences, and energy policy. In 2021, the UN Climate Change Conference in Glasgow (COP26) declaration to end deforestation by 2030 was one of the highlights. Land use modeling results show that if this declaration is fully implemented globally, about 167 Mha of deforestation could be avoided by 2050. However, avoided deforestation and associated emissions could come at the cost of strongly increased conversion of unprotected nonforested land to agricultural land (Mishra et al. 2024).

Integrated assessment models (which include land use components) have been used in combination with sectoral models to explore (1) how carbon taxes on emissions from land use change may increase food prices and negatively impact food security (Hasegawa et al. 2018); (2) the crucial effect of alternative land use policies on future biodiversity extinction risk and other indicators (Leclère et al. 2020); and (3) the effects that changes in livestock species may have on emissions (Cheng et al. 2022). Developing these links is an important activity in foresight research and requires refining the techniques employed in land use research.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Several key opportunities exist for refining foresight research on how cropland, pasture, and natural ecosystems will interact in the future. First, the underlying data on land cover need to be improved. In fact, disparities persist between the reported cropland/pasture/natural areas from administrative sources and those derived from satellite images. Both sources present challenges. Foresight modeling would benefit from better data to provide more accurate initial conditions for simulations. A recent exploration of these challenges can be found in Potapov et al. (2022, 2023).

Second, it is essential to establish connections across scales to enable global models to benefit from local information and local models to benefit from the global context, thus more effectively informing policymakers. Responding to the need for more granular information, Čengić et al. (2023) developed a methodology based on artificial neural networks that could be used to downscale the projections of global land change models and obtain more fine-grained maps of potential agricultural expansion.

The third opportunity involves the representation of natural ecosystems. Most integrated assessment models currently show that changes in forest area (and to a lesser extent, other natural ecosystems) closely mirror changes in cropland area. Similarly, strong relationships exist between nonforest ecosystems and assumptions about bioenergy crops, where appropriate. However, it is likely that the dynamics among land types in existing studies primarily occur through conversion to or from human-managed land, with limited interconversion between natural land types. But in the face of climate change-induced temperature variations and altered precipitation patterns, the stability of natural land appears uncertain (for example, concerning boreal forests, refer to Reich et al. 2022). Consequently, understanding the evolution of natural vegetation patterns becomes crucial for assessing habitat loss, degradation, and ultimately the challenges and opportunities for future biodiversity (Robertson, De Pinto, and Cenacchi 2023). This area thus warrants more research.

Last, progress on the aforementioned points must be continually integrated to better capture the links between biophysical conditions and economic mechanisms.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Ricky Robertson**, a Research Fellow in the Foresight and Policy Modeling (FPM) Unit at the International Food Policy Research Institute (IFPRI); **Nicola Cenacchi**, a Senior Research Analyst in FPM at IFPRI; and **Abhijeet Mishra**, an Associate Research Fellow in FPM at IFPRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Robertson, R., N. Cenacchi, and A. Mishra. 2025. "What Do We Know About the Future of Land?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 9. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Aulia Erlangga/CIFOR

References

Cassman, K.G., and P. Grassini. 2020. "A Global Perspective on Sustainable Intensification Research." *Nature Sustainability* 3 (4): 262–268. https://doi.org/10.1038/s41893-020-0507-8

Čengić, M., Z.J.N. Steinmann, P. Defourny, et al. 2023. "Global Maps of Agricultural Expansion Potential at a 300 m Resolution." *Land* 12 (3): 579. https://doi.org/10.3390/land12030579

Cheng, L., X. Zhang, S. Reis, C. Ren, J. Xu, and B. Gu. 2022. "A 12% Switch from Monogastric to Ruminant Livestock Production Can Reduce Emissions and Boost Crop Production for 525 Million People." *Nature Food* 3 (12): 1040–1051. https://doi.org/10.1038/s43016-022-00661-1

d'Annunzio, R., M. Sandker, Y. Finegold, and Z. Min. 2015. "Projecting Global Forest Area Towards 2030." *Forest Ecology and Management* 352: 124–133. https://doi.org/10.1016/j.foreco.2015.03.014

FAOSTAT. Food and Agricultural Commodities Production. Food and Agricutlture Organization of the United Nations. http://faostat.fao.org/

Hasegawa, T., S. Fujimori, P. Havlík, et al. 2018. "Risk of Increased Food Insecurity under Stringent Global Climate Change Mitigation Policy." *Nature Climate Change* 8 (8): 699–703. https://doi.org/10.1038/s41558-018-0230-x

Leclère, D., M. Obersteiner, M. Barrett, et al. 2020. "Bending the Curve of Terrestrial Biodiversity Needs an Integrated Strategy." *Nature* 585 (7826): 551–556. https://doi.org/10.1038/s41586-020-2705-y

Mishra, A., F. Humpenöder, C.P. Reyer, F. Beier, H. Lotze-Campen, and A. Popp. 2024. "Emission Savings Through the Cop26 Declaration of Deforestation Could Come at the Expense of Non-Forest Land Conversion." *Environmental Research Letters* 19 (5): 054058. https://doi.org/10.1088/1748-9326/ad42b4

Pendrill, F., T.A. Gardner, P. Meyfroidt, et al. 2022. "Disentangling the Numbers Behind Agriculture-Driven Tropical Deforestation." *Science* 377 (6611): p.eabm9267. https://doi.org/10.1126/science.abm9267

Popp, A., K. Calvin, S. Fujimori, et al. 2017. "Land-Use Futures in the Shared Socio-Economic Pathways." *Global Environmental Change* 42: 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002

Potapov, P., M.C. Hansen, S. Turubanova, et al. 2023. "Reply to: Measuring the World's Cropland Area." *Nature Food* 4: 33–44. https://doi-org.ifpri.idm.oclc.org/10.1038/s43016-022-00668-8

Potapov, P., S. Turubanova, M.C. Hansen, et al. 2022. "Global Maps of Cropland Extent and Change Show Accelerated Cropland Expansion in the Twenty-First Century." *Nature Food* 3: 19–28. https://doi.org/10.1038/s43016-021-00429-z

Reich, P.B., R. Bermudez, R.A. Montgomery, R.L. Rich, K.E. Rice, S.E. Hobbie, and A. Stefanski. 2022. "Even Modest Climate Change May Lead to Major Transitions in Boreal Forests." *Nature* 608 (7923): 540–545. https://doi.org/10.1038/s41586-022-05076-3

Ritchie, H. 2022. "After Millennia of Agricultural Expansion, the World Has Passed 'Peak Agricultural Land'." Our World in Data. https://ourworldindata.org/peak-agriculture-land

Robertson, R.D., A. De Pinto, and N. Cenacchi. 2023. "Assessing the Future Global Distribution of Land Ecosystems as Determined by Climate Change and Cropland Incursion." *Climatic Change* 176 (8): 108. https://doi.org/10.1007/s10584-023-03584-3.

Schmitz, C., H. van Meijil, P. Kyle, et al. 2014. "Land-Use Change Trajectories Up to 2050: Insights from a Global Agro-Economic Model Comparison." *Agricultural Economics* 45: 69–84. https://doi.org/10.1111/agec.12090

Shukla, P.R., J. Skea, R. Slade, et al. 2019. "Technical Summary." In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*, eds. P.R. Shukla, J. Skea, E. Calvo Buendia, et al. New York: Cambridge University Press.

Stehfest, E., W.J. van Zeist, H. Valin, et al. "Key Determinants of Global Land-Use Projections." 2019. *Nature Communications* 10: 2166. https://doi.org/10.1038/s41467-019-09945-w

Tubiello, F.N., G. Conchedda, L. Casse, et al. 2023. "Author Correction: Measuring the World's Cropland Area." *Nature Food* 4 (1): 125. https://doi.org/10.1038/s43016-023-00697-x

Winkler, K., R. Fuchs, M. Rounsevell, et al. 2021. "Global Land Use Changes Are Four Times Greater than Previously Estimated." *Nature Communications* 12 (2501). https://doi.org/10.1038/s41467-021-22702-2

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF WATER IN FOOD SYSTEMS?

Claudia Ringler (IFPRI), Matthew McCartney (IWMI), and Mohsin Hafeez (IWMI)

Key messages

- Demand is growing while supply is uncertain: Globally, the demand for water in agriculture and food systems is growing, alongside competing needs in other sectors. Freshwater consumption is projected to increase by 17 percent between 2020 and 2050, most of it for irrigation, and almost all of it in low- and middle-income countries. At the same time, water availability is becoming increasingly uncertain due to climate extremes, long-term climate change, pollution, and land use changes such as deforestation and wetland degradation. The rising variability and scarcity contribute to competition among different water users.
- The water supply-demand gap must be addressed: As the gap between water supply and demand increases, both tested and new technologies, policies, and institutions are needed to improve water productivity and efficiency. At the same time, more research is needed to identify solutions that mitigate the negative impacts of water shortages, pollution, and poor water management on food systems as well as to curb the adverse impacts arising from inefficient and wasteful food systems on water resources and the environment. Agriculture and food systems drive many of the pressures on freshwater ecosystems. According to the IUCN Red List, 25 percent of freshwater species are threatened with extinction (IUCN 2024). This loss of biodiversity threatens not only the species themselves but also the vital services they and their ecosystems provide to humanity.

- With water a connector across sectors, new approaches to management are critical: With rising water scarcity, decisions in areas such as climate, nutrition, energy, and trade policy will increasingly shape the future of water in food systems. To improve water management in food systems, a more integrated, forward-looking approach is needed that considers the broader implications of policies and investments across multiple sectors. In addition, strengthening governance and institutions and empowering farmers, as key stewards of water resources, are essential for sustainable outcomes.

RECENT TRENDS AND CHALLENGES

Water is essential for human life and ecosystems. People use water in multiple ways: for food production, processing, preparation, and consumption; for other domestic uses, such as bathing, cleaning, and sanitation; for energy production; and for industrial processes (Figure 1). Estimates suggest that water withdrawals by humans increased nearly eightfold between 1900 and 2010, from around 500 cubic kilometers (km^3) to 4,000 km^3. Currently, more than 3 billion people live in areas with high or very high levels of water stress (FAO 2020).

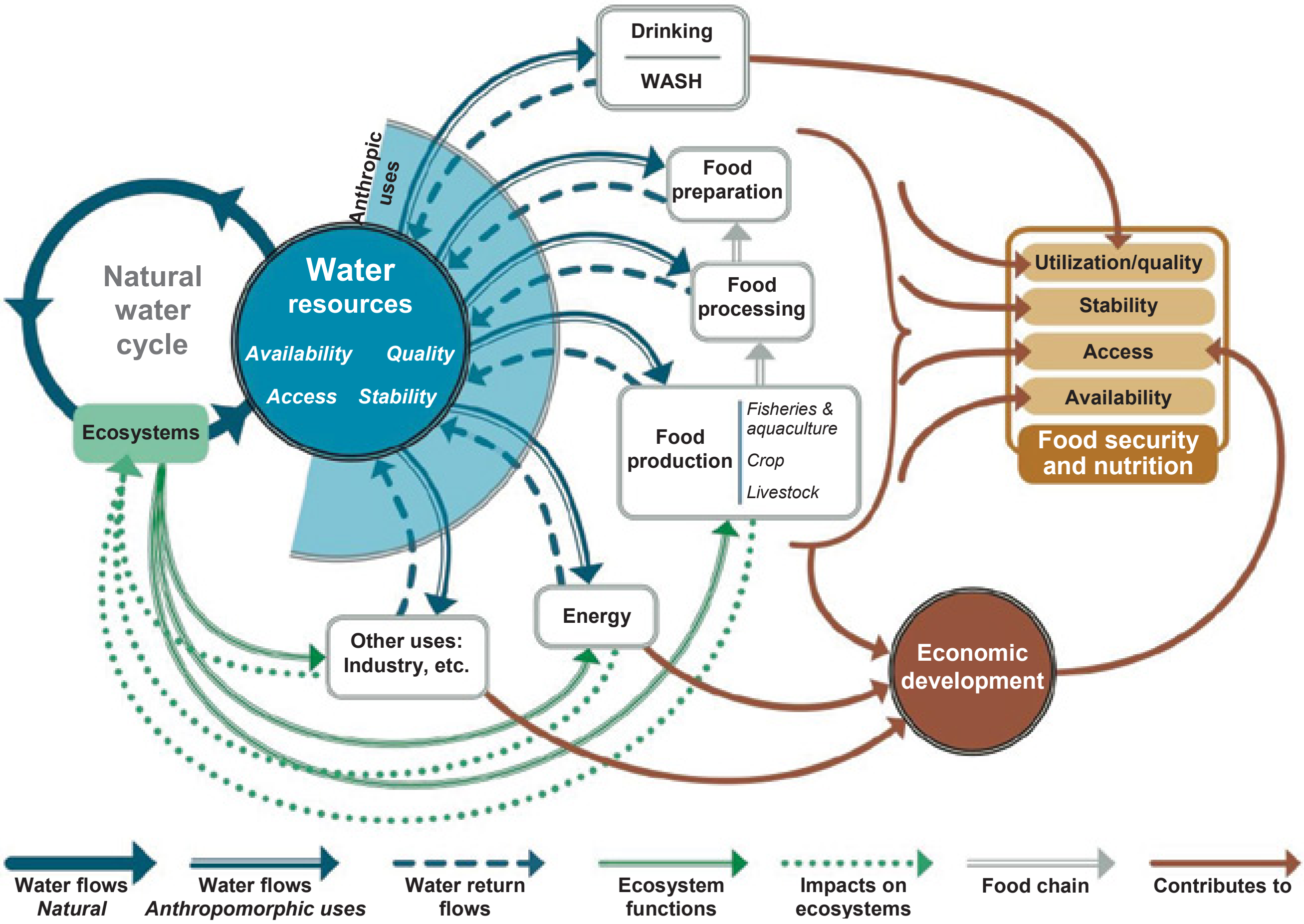
While freshwater ecosystems cover less than 1 percent of the Earth's surface area, they provide vital habitat for 10 percent of all species and one-third of all vertebrate species (Strayer and Dudgeon 2010). The widespread degradation of wetlands, rivers, lakes, and aquifers has led to significant biodiversity loss and negatively impacted water resources that are critical for a wide range of anthropogenic uses, including food systems. Since 1700, an estimated 21 percent of wetlands have been lost (Fluet-Choinard et al. 2023), and freshwater vertebrate species populations have declined by an alarming 85 percent since 1970 (WWF 2024). Environmental degradation is one of the major causes of reduced water storage across landscapes. The cumulative reduction in global terrestrial water storage from 1971 to 2020 is estimated to be on the order of 27,000 km^3, far more than the annual total global freshwater use by humans (McCartney et al. 2022).

Around 70 percent of water withdrawn by humans is used to irrigate food crops, in particular rice and wheat, as well as nonfood crops such as cotton. While the global share of water withdrawals used for agriculture slowly declined over the last three decades — because of the faster growth in withdrawals for domestic and industrial uses — absolute withdrawals for agrifood systems continue to increase. A recent study calculated that the area equipped for irrigation increased by 11 percent between 2000 and 2015 to 330 million hectares, and that slightly more than one-half of the increase occurred in areas that were already water-stressed (Mehta et al. 2024).

Climate change — characterized by higher temperatures; unpredictable precipitation; shorter, more intense rains; and prolonged dry seasons — is severely straining water resources in a rising number of regions. This is intensifying competition for water across sectors, especially between agrifood systems and other uses. Fundamental changes are occurring in freshwater systems worldwide, as a result of which many river systems are experiencing longer periods of below-normal flow (WMO 2024). These disruptions have large negative impacts on aquatic ecosystems and human livelihoods. At the same time, glacier melt has accelerated, particularly in North America and Europe. Peak glacier melt — the maximum melt rate of retreating glaciers — has occurred in these regions, reducing water storage and availability in the long term (WMO 2024).

Growing climate variability is driving increased demand for irrigation. Without it, crop and livestock production are becoming riskier and less profitable in more and more places. Much of the rise in irrigation water demand is being met with groundwater, which has become more accessible due to advances in well-drilling and pump technologies, as well as the availability of free or heavily subsidized electricity in some places. Groundwater now accounts for approximately 40 percent of irrigation globally (Siebert et al. 2010). The greater availability of low-cost solar-powered irrigation pumps that remove the need for electricity or diesel to extract water might accelerate groundwater depletion — the extraction of groundwater beyond the level of recharge (Balasubramanya et al. 2024; Perez et al. 2024).

FIGURE 1 Water use, food security, and nutrition



Source: HLPE (2015).

Water pollution from industrial, domestic, and agricultural sources is also harming water systems, particularly as their capacity to dilute contaminants is diminishing due to growing water shortages. Water pollution poses a significant threat to human and aquatic life. Poor water quality is estimated to cause more than 1 million human deaths annually, although exact figures are not available (Fuller et al. 2022; Schwarzenbach et al. 2010).

LATEST FORESIGHT RESEARCH

Initial water simulations and foresight studies focused on better understanding future availability of surface water resources and the global water cycle at a coarse resolution (Arnell 1999; Vorosmarty et al. 2000). The granularity of global hydrological models has since improved (for example, Sutanudjaja et al. 2018). Attention is growing on improving the representation of groundwater in foresight studies (de Graaf et al. 2015; Wada et al. 2010; Perez et al. 2024) and on modeling water pollution at different scales (Xie and Ringler 2017). Some studies have explored the potential for unconventional water resources, such as saline and (recycled) wastewater, to meet increasing human needs (Thebo et al. 2017). The untapped potential for wastewater reuse – particularly in irrigation, where nutrients can be recycled – is around 320 km^3 per year; this resource is 10 times the level of the current global desalination capacity (UNEP 2023).

Over time, attention has shifted from only understanding water supply to examining future water demand and the critical interlinkages between future supply and demand. Good examples of this include Cai and Rosegrant (2002), Alcamo et al. (2003), Shen et al. (2008), and Wada et al. (2016). Agricultural water demand remains a central focus, as it represents the largest share of human water withdrawals and is easier to estimate and model than either industrial or environmental water use.

Water–food simulations typically differentiate between rainfed and irrigated systems and incorporate data on seasonal, monthly, or even daily availability of rainfall and other water for crops and production systems. Although the quantity and quality of data on agricultural production systems has improved over the last few decades, no consensus exists on likely future changes in irrigated area and irrigation water demand. Projections suggest both declines and increases depending on underlying assumptions in population and economic growth, climate change, diets, and cropping patterns. Discrepancies also arise in how crop water use is modeled, such as in the representation of deficit irrigation, the effects of rising atmospheric carbon dioxide on crop water use, the modeling of paddy irrigation, and the incorporation of climate extremes. Nevertheless, a larger number of studies suggest that irrigated area and irrigation water use will continue to increase over the coming decades (Cai and Rosegrant 2002; Nechifor and Winning 2017; Perez et al. 2024). Perez et al. (2024) project freshwater consumption will increase by close to 400 km^3, or 17 percent, between 2020 and 2050. Irrigation is projected to remain the largest consumptive use of withdrawn freshwater, but its share is expected to decline from 85 percent to 81 percent. Almost all of the projected increase is concentrated in the group of low- and middle-income countries.

As a result of limited supplies and growing demands for water resources, an increasing number of studies have found challenges to meeting future food demand with traditional water management practices. The expansion of freshwater supplies is limited, and the combined pressures of climate change and growing demand will require innovative solutions (Cai and Rosegrant 2002; Hanjra and Qureshi 2010; Rockstrom et al. 2009; UNEP 2023). As an example, foresight studies indicate that a growing number of locations will experience seasonal or annual water shortages, driven in part by climate change, which amplifies the evaporative demand of irrigation water. In the Himalayas, peak glacier melt is expected to reduce water supply in the Brahmaputra, Ganges, Indus, and Yangtze Rivers, threatening the functioning of some of the world's largest irrigation systems (Immerzeel, van Beek, and Bierkens 2010).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

To better understand how rapidly worsening water availability and quality is affecting food systems, more attention is needed on modeling the interactions between climate and water, with a particular focus on simulating the impacts of climate extremes. This is particularly important because rainfed and irrigation systems respond differently and complement each other differently under varying climatic conditions. Additionally, different irrigation technologies, systems, and management practices have varying degrees of resilience to different types of climate extremes; these must be better reflected in foresight studies.

A more comprehensive representation of the interactions between water and food systems is also needed, given the multiple feedback loops that exist between the two systems. For example, while increased irrigation development can boost food production and improve nutrition by expanding the availability of fruits and vegetables, it can also negatively affect water availability and quality for domestic uses, including drinking water. This, in turn, can lead to poorer nutrition and health outcomes, even as food diversity improves. Similarly, water pollution from food processing can kill aquatic life, reducing access to fish and other aquatic resources by poor people dependent on common-pool water systems. Expanding irrigation in areas previously reliant on rainfed agriculture can shrink grazing areas for pastoralists, reducing access to milk and livestock products. At the same time, irrigation systems in some places can serve as sources of aquaculture production and of energy production using the flow of water in canals, and they are a key source of domestic water for many rural households.

Existing economic models often fail to account for feedback loops between land use change — including irrigation, wetland degradation, and deforestation — and climate change. The lack of integration of water pollution and groundwater systems in many foresight analyses also limits the accuracy and usefulness of projections. In addition, more research is needed to assess the water needs of ecosystems and the implications of the degradation of freshwater ecosystems for food systems.

Foresight analyses should, moreover, broaden the scope of policy interventions for improving water management in agriculture. Rather than focusing solely on advanced irrigation systems, there is a need to consider institutional changes that can improve water governance. In addition, the distributional impacts of alternative interventions in water–food systems should be considered. For example, while water pricing can improve water use efficiency, it may disproportionately affect poorer farmers, making it harder for them to continue to farm. Similarly, subsidies for advanced irrigation technologies may not reach poorer farmers, who need them most. On the other hand, paying farmers to adopt water-saving practices, such as shifting cropping patterns in water-scarce areas, could incentivize more sustainable water use, including for poorer farmers. Given that farmers are responsible for the majority of global water withdrawals, supporting them to manage water more efficiently is crucial for ensuring the long-term sustainability of food systems and ultimately benefits everyone.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Claudia Ringler**, Director of the Natural Resources and Resilience Unit at the International Food Policy Research Institute (IFPRI); **Matthew McCartney**, Research Group Leader in Sustainable Water Infrastructure and Ecosystem at the International Water Management Institute (IWMI); and **Mohsin Hafeez**, Strategic Program Director of Water, Food and Ecosystems at IWMI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Ringler, C., M. McCartney, and M. Hafeez. 2025. "What Do We Know About the Future of Water in Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 10. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Martchan/Shutterstock

References

Alcamo, J., P. Doell, T. Henrichs, F. Kaspar, et al. 2003. "Development and Testing of the WaterGAP 2 Global Model of Water Use and Availability." *Hydrological Sciences Journal* 48 (3): 317–337. https://doi.org/10.1623/hysj.48.3.317.45290

Arnell, N.W. 1999. "Climate Change and Global Water Resources." *Global Environmental Change* 9: S31–S49. https://doi.org/10.1016/S0959-3780(99)00017-5

Balasubramanya, S., D. Garrick, N. Brozovic, C. Ringler, et al. 2024. "Solar-Powered Groundwater Irrigation for Sustainable Development." *Science* 383 (6680): 256–258. https://doi.org/10.1126/science.adi9497

Cai, X., and M.W. Rosegrant. 2002. "Global Water Demand and Supply Projections: Part 1: A Modeling Approach." *Water International* 27 (2): 159–169. https://doi.org/10.1080/02508060208686989

de Graaf, I.D., E.H. Sutanudjaja, L.P.H. van Beek, and M.F.P. Bierken. 2015. "A High-Resolution Global-Scale Groundwater Model." *Hydrology and Earth System Sciences* 19 (2): 823–837. https://doi.org/10.5194/hess-19-823-2015

FAO (Food and Agriculture Organization of the United Nations). 2020. *The State of Food and Agriculture 2020: Overcoming Water Challenges in Agriculture*. Rome. https://doi.org/10.4060/cb1447en

Fluet-Chouinard, E., B.D. Stocker, Z. Zhang, et al. 2023. "Extensive Global Wetland Loss over the Past Three Centuries." *Nature* 614: 281–286. https://doi.org/10.1038/s41586-022-05572-6

Fuller, R., P. J. Landrigan, K. Balakrishnan, et al. 2022. "Pollution and Health: A Progress Update." *Lancet Planetary Health* 6 (6): e535–e547. https://doi.org/10.1016/

Hanjra, M.A., and M.E. Qureshi. 2010. "Global Water Crisis and Future Food Security in an Era of Climate Change." *Food Policy* 35 (5): 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006

HLPE (High Level Panel of Experts on Food Security and Nutrition). 2015. *Water for Food Security and Nutrition*. Report by the High -Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Report No. 9. Rome: FAO.

Immerzeel, W.W., L.P.H. van Beek, and M.F.P. Bierkens. 2010. "Climate Change Will Affect the Asian Water Towers." *Science* 328 (5984): 1382–1385. https://doi.org/10.1126/science.1183188

IUCN (International Union for the Conservation of Nature). 2024. "The IUCN Red List of Threatened Species." Version 2024-1. https://www.iucnredlist.org/

McCartney, M., W. Rex, W. Yu, S. Uhlenbrook, and R. von Gnechten. 2022. "Change in Global Freshwater Storage." IWMI Working Paper 202. International Water Management Institute (IWMI), Colombo, Sri Lanka. https://doi.org/10.5337/2022.204

Mehta, P., S. Siebert, M. Kummu, et al. 2024. "Half of Twenty-First Century Global Irrigation Expansion Has Been in Water-Stressed Regions." *Nature Water* 2: 254–261. https://doi.org/10.1038/s44221-024-00206-9

Nechifor, V., and M. Winning. 2017. "Projecting Irrigation Water Requirements across Multiple Socio-economic Development Futures: A Global CGE Assessment." *Water Resources and Economics* 20 (October): 16–30. https://doi.org/10.1016/j.wre.2017.09.003

Perez, N., V. Singh, C. Ringler, H. Xie, T. Zhu, E.H. Sutanudjaja and K. Villholth. 2024. "Ending Groundwater Overdraft without Affecting Food Security." *Nature Sustainability* 7: 1007–1017. https://doi.org/10.1038/s41893-024-01376-w

Rockstrom, J., M. Falinmark, L. Karlberg, H. Hoff, S. Rost, and D. Gerten. 2009. "Future Water Availability for Global Food Production: The Potential of Green Water for Increasing Resilience to Global Change." *Water Resources Research* 45 (7). https://doi.org/10.1029/2007WR006767

Schwarzenbach, R.P., T. Egli, T.B. Hofstetter, U. von Gunten and B. Wehrli. 2010. "Global Water Pollution and Human Health." *Annual Review of Environment and Resources* 35: 109–136. https://doi.org/10.1146/annurev-environ-100809-125342

Shen, Y., T. Oki, N. Utsumi, S. Kanae, and N. Hanasaki. 2008. "Projection of Future World Water Resources under SRES Scenarios: Water Withdrawal/Projection des ressources en eau mondiales futures selon les scénarios du RSSE: prélèvement d'eau." *Hydrological Sciences Journal* 53 (1): 11–33. https://doi.org/10.1623/hysj.53.1.11

Siebert, S., J. Burke, J.M. Faures, K. Frenken, J. Hoogeveen, P. Doell, and F.T. Portmann. 2010. "Groundwater Use for Irrigation: A Global Inventory." *Hydrology and Earth Systems Sciences* 14: 1863–1880. https://doi.org/10.5194/hess-14-1863-2010

Strayer, D.L., and D. Dudgeon. 2010. "Freshwater Biodiversity Conservation: Recent Progress and Future Challenges." *Journal of the North American Benthological Society* 29 (1). https://doi.org/10.1899/08-171.1

Sutanudjaja, E.H., R. van Beek, N. Wanders et al. 2018. "PCR-GLOBWB 2: A 5 Arcmin Global Hydrological and Water Resources Model." *Geoscientific Model Development* 11 (6): 2429–2453. https://doi.org/10.5194/gmd-11-2429-2018

Thebo, A.L., P. Drechsel, E.F. Lambin, and K.L. Nelson. 2017. "A Global, Spatially-Explicit Assessment pf Irrigated Croplands Influenced by Urban Wastewater Flows." *Environmental Research Letters* 12 (7): 074008. https://doi.org/10.1088/1748-9326/aa75d1

UNEP (United Nations Environment Programme). 2023. *Wastewater: Turning Problem to Solution. A UNEP Rapid Response Assessment*. Nairobi. https://doi.org/10.59117/20.500.11822/43142

Vorosmarty, C.J., P. Gren, J. Salisbury, and R.B. Lammers. 2000. "Global Water Resources: Vulnerability from Climate Change and Population Growth." *Science* 289 (5477): 284–288. https://doi.org/10.1126/science.289.5477.284

Wada, Y., L.P.H. van Beek, C.M. van Kempen, et al. 2010. "Global Depletion of Groundwater Resources." *Geophysical Research Letters* 37: L20402. https://doi.org/10.1029/2010GL044571

Wada, Y., M. Flörke, N. Hanasaki, et al. 2016. "Modeling Global Water Use for the 21st Century: The Water Futures and Solutions (WFaS) Initiative and Its Approaches." *Geoscientific Model Development* 9 (1): 175–222. https://doi.org/10.5194/gmd-9-175-2016

WMO (World Meteorological Organization). 2024. *State of Global Water Resources Report 2023*. WMO-No. 1362. Geneva. https://library.wmo.int/records/item/69033-state-of-global-water-resources-report-2023

WWF (World Wildlife Fund). 2024. *Living Planet Report 2024: A System in Peril*. Gland, Switzerland. https://www.worldwildlife.org/publications/2024-living-planet-report

Xie, H., and C. Ringler. 2017. "Agricultural Nutrient Loadings to the Freshwater Environment: The Role of Climate Change and Socioeconomic Change." *Environmental Research Letters* 12: 104008. https://doi.org/10.1088/1748-9326/aa8148

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF ENERGY AND FOOD SYSTEMS?

Channing Arndt (Purdue University)

Key messages

- The global energy transition currently in process involves increases in variable renewable energy generation and ongoing electrification of transport and industrial processes, leading to the possibility of absolute declines in the use of coal and petroleum before 2030.
- This transition creates both opportunities and risks for agri-food systems.
- Trade will be an important impact channel for net exporters and net importers of fossil fuels, with impacts spilling into the agri-food sector.
- Improvements in energy technology, particularly solar generation, have broad applications with potentially large implications for agri-food systems.

RECENT TRENDS AND CHALLENGES

A large-scale global energy transition is underway. In 2023, global investment in solar power alone exceeded investment in all other forms of electricity generation combined (IEA 2024a). Currently, investment in renewable energy is approximately twice that of investment in fossil fuels (IEA 2024a). This transition is extending rapidly into transport. In 2023, 18 percent of all new light vehicles sold worldwide were electric (EVs), up from about 2 percent in 2018 and 4 percent in 2020 (IEA 2024b).

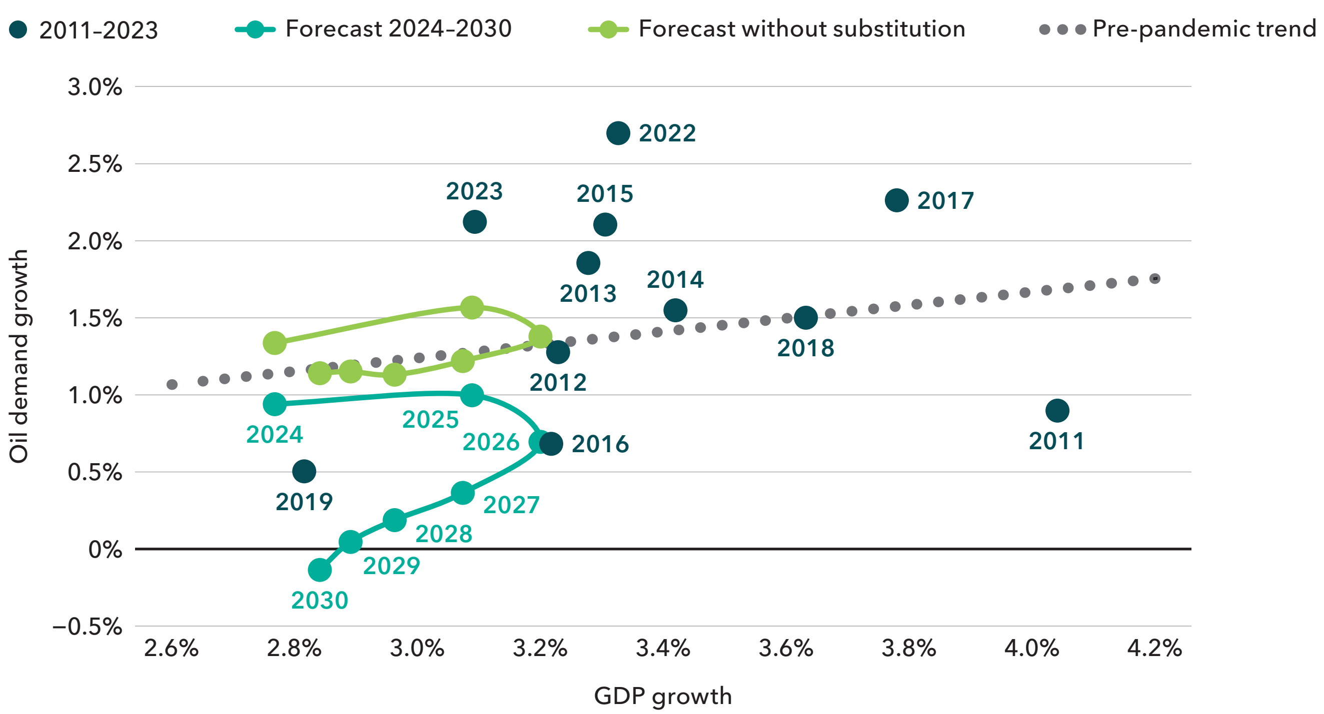
A key point is that the sectors leading this energy transition are no longer small. From 2017 to 2022, the share of power generated by solar and wind doubled, from about 6 percent to 12 percent. From these larger bases, the next doubling brings the share of solar and wind to about 24 percent of generation and the share of EVs in light vehicle sales to about 36 percent. These larger absolute values imply a greater and more noticeable force of change, with concomitantly larger direct and indirect implications, including for agrifood systems.

LATEST FORESIGHT RESEARCH

Let us begin with fuel. As a result of the abovementioned structural factors, the International Energy Agency's (IEA) most recent forecasts predict a decline in global oil demand in 2030 (IEA 2024c). Figure 1 shows the forecast for oil demand to 2030 and relates oil demand to gross domestic product (GDP) growth. Prior to the COVID-19 pandemic, simple regression analysis illustrates a standard trend (shown in the dashed line) whereby oil demand increases with GDP. However, this relationship has weakened over time, and the IEA now expects it to break down altogether in the latter half of this decade. This occurs because "substitution away from oil in transport and power generation pushes oil demand growth towards zero, and eventually into decline" (IEA 2024c, 13).

As these structural factors are expected to persist, an unprecedented long-run decline in oil demand is expected to commence from a peak in 2029. Even though other forecasters, such as the Organization of Petroleum Exporting Countries (OPEC 2024), expect peak oil demand to occur much farther into the future, the

FIGURE 1 Growth in global oil demand and GDP, 2011–2030



Source: IEA (2024c, 12).

IEA forecast merits attention for two principal reasons. First, oil has traditionally been viewed as a nonrenewable resource whose supply would eventually be exhausted. In this view, accessible oil in the ground is an asset whose value is likely to grow with time. However, a world with declining oil demand opens the possibility that much of the oil currently in the ground will stay there and may eventually become worthless. This creates incentives to extract sooner. Second, incentives to extract sooner notwithstanding, a long-run decline in oil demand must be accompanied by a long-run compression of supply.

Because a sustained decline in global oil demand has never occurred in the industrial era, how exactly the combination of increasing incentives to extract sooner and a necessary compression in supply will unfold is unknown. Nevertheless, it is clear that as demand declines, low-cost producers have incentives to force high-cost producers out of the market by allowing oil prices to drop low enough for long enough to induce a sufficient volume of permanent shutdown. This puts high-cost oil producers at risk. At the same time, these periods of low prices will generate significant terms-of-trade gains for net importers of fuels (Arndt et al. 2019).

Turning to electricity generation, for almost anywhere sunny, solar power is likely to be the least-cost generation option at the margin. This is most likely to hold for grids with relatively low penetration rates of variable renewable energy (because other generating units can accommodate the variability) and in (sunny) locations where service from the grid is poor or nonexistent. Nevertheless, to date, solar investment has been concentrated in the developed world plus China. However, given the cost advantages that solar generation now possesses, it is reasonable to expect rapidly growing investment in solar generation in the developing world, both at grid scale and for bespoke uses in locations that are off grid or have unreliable grid service.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

The implications of these trends are vast. The potential implications of the predicted structural decline in demand for oil and of ongoing technical advance in generation technologies, notably solar, are described briefly below.

Oil and derived products represent a significant share of global trade, and the share of oil and derived products in total trade tends to be higher in lower-income settings. For example, for sub-Saharan Africa (SSA), oil and derived products represented about 25 percent of total exports and imports in 2022 (WITS 2024). While nearly all countries in SSA tend to import large volumes of fuel, exports of petroleum products tend to be concentrated among a few producers.

For major net exporters, particularly those with relatively high extraction costs, the implications of declining global oil demand are potentially profound. Consider Nigeria, which is both the largest economy in SSA and the most populous nation on the continent. Despite decades of rhetoric about diversification of the Nigerian economy, Nigeria still counts on oil and derived products for more than 80 percent of export revenue (Pauw, Randiamamonjy, and Thurlow 2024). And while exact figures are not known, Nigeria is widely viewed as a relatively high-cost oil producer and is not known as an easy place to do business (Economist 2024; ITA 2023). Hence, Nigeria could confront, in the not-too-distant future, a period of low oil prices that is designed specifically to force higher-cost producers permanently out of the market. If Nigerian petroleum-related export revenues decline due to a combination of lower prices and volumes, this would oblige Nigeria to enter an intense period of structural adjustment to raise nonoil export revenues. More generally, to meet foreign currency needs, higher-cost oil-exporting countries facing both lower prices and volumes must stage a nonoil export push.

Even for low-cost net exporters of fuels, the incentives to diversify exports have likely never been greater. Unfortunately, especially for low- and middle-income countries (LMICs), breaking into new export markets is distressingly difficult (Forge, Garred, and Kwon 2024). For countries with little experience exporting anything other than oil for a generation or more, the difficulties are likely to be pronounced. While it is not easy to break into global food markets, agrifood products seem very likely to figure prominently in an export diversification push in many country cases (Nigeria not least). Achieving much greater export diversification through very rapid expansion of exports in agrifood and other products, notably for high-cost oil producers, is a very important topic for research.

Net importers of fuels are in a much more favorable position. Periods of low prices represent a substantial terms-of-trade gain. For net fuel importers, lower fuel prices combined with ongoing electrification of transport (resulting in lower fuel import volumes) typically drive a real exchange rate appreciation (an increase in the price of nontradable goods relative to tradable goods), signaling a reduced need to export and/or an expanded scope to import products other than fuel. Because agrifood products are often traded globally and because LMICs frequently export and import substantial volumes of agrifood commodities, declining oil demand will very likely influence agrifood production and trade patterns, perhaps significantly. An intriguing possibility is that lower fuel prices facilitate a shift toward healthier diets because the components of a healthy diet (fresh foods) are typically less tradable. More generally, for net importers of fossil fuels, tracking the likely benefits of reduced dependence on volatile fossil fuel markets should inform policies related to the pace of electrification of transport and industrial processes and the accompanying policies/investments that build upon this structural transformation.

Turning to electricity generation, the massive declines in the cost of solar generation combined with ongoing declines in battery prices create large opportunities for developing countries, many of which are well-endowed with sun, to generate electricity at scale, almost anywhere, and at low cost. Agrifood systems will be crucial to realizing the considerable upside that the ongoing energy transition offers to LMICs; however, realizing the gains and avoiding pitfalls will not be easy. Increased attention to energy in foresight research on agrifood systems is needed to ensure a reasonably smooth and fair transition that benefits marginalized populations, including those with limited access to modern energy. Research into the policies and institutions necessary to avoid pitfalls — such as excessive water withdrawals due to very low marginal costs of pumping from solar-powered systems — is also important.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The author of this chapter is **Channing Arndt**, Director and Research Professor of Global Trade Analysis in the Department of Agricultural Economics at Purdue University, and formerly Senior Director of Transformation Strategies at the International Food Policy Research Institute (IFPRI).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Arndt, C. 2025. "What Do We Know About the Future of Energy and Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 11. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Hussain Warraich/Shutterstock

References

Arndt, C., D. Arent, F. Hartley, B. Merven, and A.H. Mondal. 2019. "Faster Than You Think: Renewable Energy and Developing Countries." *Annual Review of Resource Economics* 11 (1): 149–168. https://doi.org/10.1146/annurev-resource-100518-093759

Economist. 2024. "Nigeria's High-Cost Oil Industry Is in Decline." May 21. https://www.economist.com/middle-east-and-africa/2024/03/21/nigerias-high-cost-oil-industry-is-in-decline.

Forge, F., J. Garred, and K.L. Kwon. 2024. "When Are Tariff Cuts Not Enough? Heterogeneous Effects of Trade Preferences for the Least Developed Countries." *Journal of International Economics* 152 (November): 103971. https://doi.org/10.1016/j.jinteco.2024.103971

IEA (International Energy Agency). 2024a. *World Energy Investment 2024*. Paris. https://www.iea.org/reports/world-energy-investment-2024

IEA. 2024b. *Global EV Outlook 2024: Moving Towards Increased Affordability*. Paris. https://www.iea.org/reports/global-ev-outlook-2024

IEA. 2024c. *Oil 2024: Analysis and Forecast to 2030*. Paris. https://www.iea.org/reports/oil-2024

ITA (International Trade Administration). 2023. *Nigeria Investment Climate Statement*. https://www.trade.gov/country-commercial-guides/nigeria-investment-climate-statement

OPEC (Organization of Petroleum Exporting Countries). 2024. *World Oil Outlook*. Vienna. https://www.opec.org/opec_web/en/publications/340.htm

Pauw, K., J. Randriamamonjy, and J. Thurlow. 2024. "2021 Social Accounting Matrix for Nigeria: A Nexus Project SAM." Data Paper. Washington, DC: International Food Policy Research Institute. https://hdl.handle.net/10568/137911

World Integrated Trade Solutions (WITS). 2024. https://wits.worldbank.org/CountryProfile/en/Country/SSF/Year/2022/TradeFlow/Import/Partner/all/Product/27-27_Fuels.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS INNOVATION?

Daniel Mason-D'Croz (Cornell University), Mario Herrero (Cornell University), Cody Kugler (Independent), Rosaline Remans (Bioversity International), Philip Thornton (ILRI, Cornell University, Clim-Eat, and University of Edinburgh), and Heather Zornetzer (Bioversity International)

Key messages

- Innovations have been and will continue to be critical drivers of food systems and societal change.
- Predicting "game-changing" technology ahead of time is not possible, and silver bullets do not exist.
- Novel innovations can alleviate some challenges, but unintended consequences always arise.
- Foresight research can help to identify undesirable outcomes early on and align investments and incentives with social and environmental objectives.

RECENT TRENDS AND CHALLENGES

Innovations have been critical to shaping the food systems we know today, contributing to many historical food system transitions as new technologies, practices, and food products have redefined humanity's connection to food and food production (Herrero et al. 2020, 2021; Loboguerrero et al. 2020). Food systems innovation, industrialization, and infrastructure have been intertwined and self-reinforcing, with increasing agricultural productivity acting as an important driver of past transformational sociopolitical and economic change (Gollin, Parente, and Rogerson 2002).

Agricultural productivity growth has been critical to allow food systems to respond to the growing global population while increasing food availability and affordability, as the risk of hunger has been falling for decades, despite recent increases (Barrett et al. 2020, 2022). Nevertheless, sustained productivity growth is being challenged, with evidence suggesting that agricultural productivity growth is slowing (Fuglie 2018a) and that it is getting harder to develop groundbreaking innovations (Bloom et al. 2020; Chu and Evans 2021; Park, Leahey, and Funk 2023), while climate change is eroding past gains (Mbow, Rosenzweig, et al. 2019).

All innovations, revolutionary or incremental, come with unintended consequences (Merton 1936; Baert 1991), which can be both positive and negative. The industrialization of food systems has been accompanied by many undesired consequences, including unbalanced and unhealthy diets and unsustainable environmental practices (IPBES 2019; IPCC 2019; Swinburn et al. 2019; Willett et al. 2019).

Innovations are needed to help respond to these undesired outcomes, including development of more climate-resilient agriculture, as well as a shift toward more holistic approaches to food systems that consider the social, environmental, and health consequences of innovation. The call for a "Great Food System Transformation" (Vermeulen et al. 2020; Béné 2022) highlights the need for more responsible or mission-oriented innovation in food systems, to more systematically consider power dynamics and potential unintended consequences to better assess potential winners and losers. Reviews of historical food system innovations have highlighted that successful adoption of innovations requires a range of social processes, such as establishing permission, developing a fostering enabling environment, and enacting active and adaptive policies in the face of unintended consequences (Thornton et al. 2024). This suggests that future innovation will need to more intentionally embed social processes in the technological development process to contribute to more sustainable food systems (Barrett et al. 2022). Figure 1 highlights a framework for accelerating more responsible innovation that identified 10 accelerators and enablers for food systems innovation.

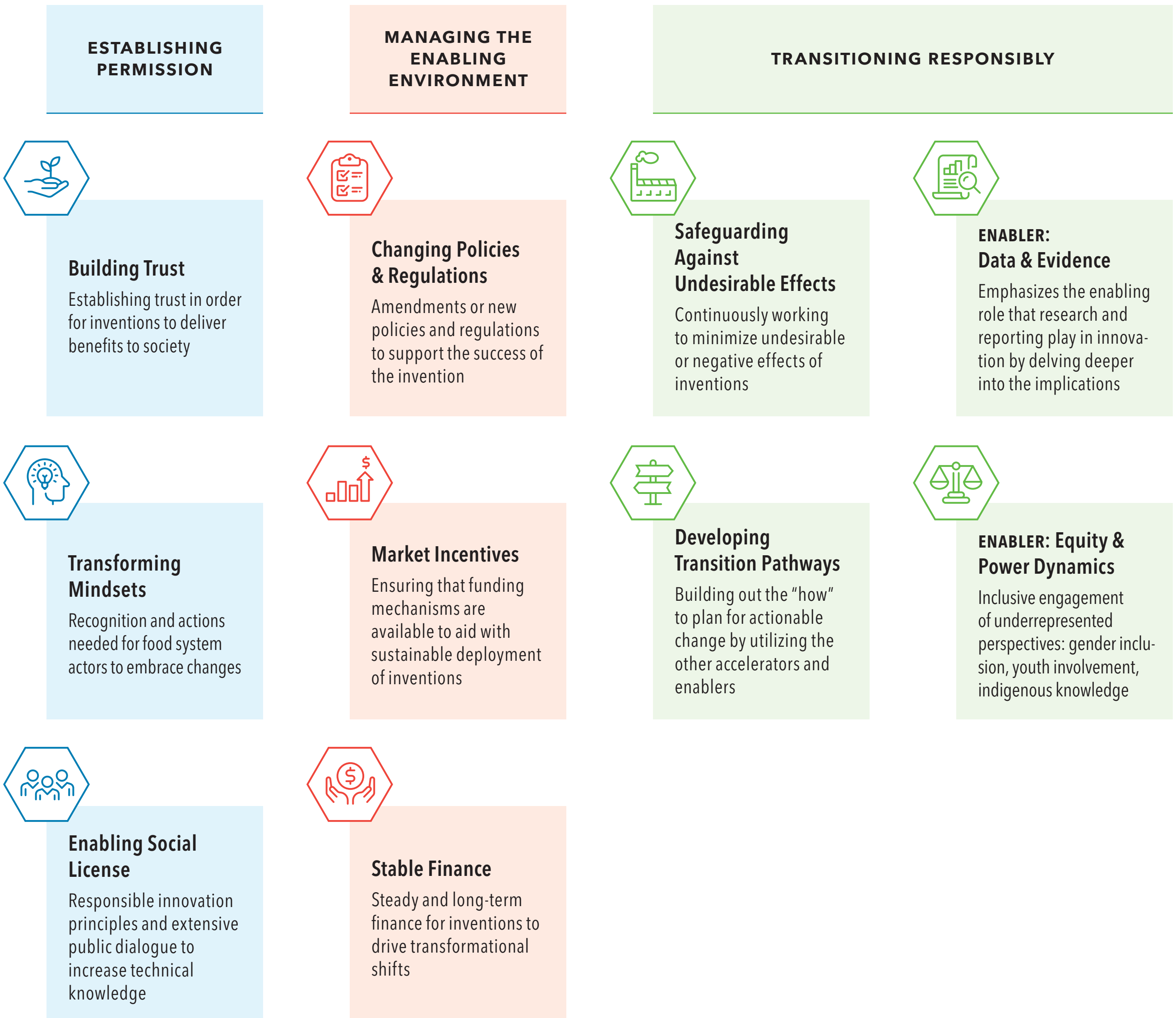
Recent policy shifts toward more activist industrial policy (Aiginger and Rodrik 2020) offer new potential opportunities for more mission-oriented research and development (R&D). However, without an intentional approach to innovation policy and a rebalancing of the food system to align incentives with desired environmental, social, and health outcomes — for example, True Costing of Food (Baker et al. 2020; FAO 2023; Kennedy et al. 2023) — increased public sector involvement in the innovation process will not ensure that future innovation contributes to healthier and more sustainable food systems.

LATEST FORESIGHT RESEARCH

Food systems innovation is a complex sociotechnical process. Foresight research focusing on food systems innovation seeks to better understand how these processes function and could be improved, as well as how their outcomes can contribute to positive and/or negative change. Much of the research assessing the potential of food systems innovation focuses on assessing specific technologies (or combinations of technologies) or the consequences of novel policies. Additionally, a growing body of literature considers how sociocultural changes can alter consumer preferences as well as paradigms of what is valued by society. Figure 2 summarizes some of the broad areas of foresight research focused on food systems innovation.

The spatial scale of foresight analysis can range from the individual/firm level to the global level. More microanalysis has tended to focus primarily on private benefits and costs and the adoption process, exploring questions of how and why individuals and firms choose to adopt new technologies and practices. Various methods are applied in this area including agent-based (for example, Bell 2017;

FIGURE 1 Accelerators and enablers of innovation



Source: Mason-D'Croz et al. (2023), adapted from Herrero et al. (2020, 2021).

Giabbanelli and Crutzen 2017; Kaaronen and Strelkovskii 2020; Marvuglia et al. 2022) and system dynamic models (for example, Dizyee, Baker, and Rich 2017; Varia et al. 2017; Dizyee et al. 2021). More macro studies tend to explore somewhat different questions, focusing on questions of R&D investment (for example, Mason-D'Croz et al. 2019) or policies to encourage more innovation (for example, Sodano 2019; Moberg et al. 2021). Some studies explore the role of various actors in the innovation ecosystem (for example, NARS vs CGIAR), often with a goal of better understanding the process of technology diffusion (for example, Aghion and Jaravel 2015; Fuglie 2018b). This work often implicitly frames technology in terms of Pareto efficiency (that is, adopted innovations move the technological frontier out, or help to move us closer to the frontier), and that knowledge generation occurs in core countries nearest the technological frontier, with catchup and diffusion assumed for peripheral countries farther from this frontier. National and global studies also assess potential unintended consequences of adoption at scale, particularly with respect to negative environmental or social consequences (for example, UNEP 2023).

FIGURE 2 Examples of food systems innovation foresight research

R&D systems

Improve the representation of the innovation process to inform innovation policy

For example:

- Endogenizing technological development [1]
- Linking R&D investments to productivity [2]
- Reorienting R&D systems [3]

Technological

Assess impacts of adopting, scaling up, and/or combining technologies and policies

For example:

- Impact of alternative proteins [4]
- Climate resilient agriculture [5]
- Mitigation potential [6]
- Circularity [7]

Governance

Assess impacts of policy innovations targeting the food system

For example:

- Fiscal policies [8]
- Trade policies [9]
- Land-use and climate policies [10]
- Poverty alleviation and social safety nets [11]

Socio-cultural

Assess impacts of changes in norms and consumer preferences

For example:

- Dietary transitions [12]
- Degrowth [13]

Selection of sources:

1. Baker and Shittu 2008; Dietrich et al. 2014; Hong et al. 2014.
2. Rosegrant et al. 2017; Mason-D'Croz et al. 2019; Sulser et al. 2021.
3. Nordmann 2014; Hall and Dijkman 2019; Conti et al. 2024.
4. Gerhardt et al. 2020; Humpenöder, et al. 2022b; Mason-D'Croz et al. 2022; Kozicka et al. 2023; UNEP 2023.
5. Sulser et al. 2010; Rosegrant et al. 2014; Ignaciuk, Mason-D'Croz, and Islam 2015; Robinson et al. 2015; Islam et al. 2016.
6. Havlík et al. 2014; Frank et al. 2017, 2018.
7. Parodi et al. 2018; van Selm et al. 2022.
8. Springmann et al. 2017; Springmann, et al. 2018a; Laborde et al. 2021; Springmann and Freund 2022.
9. Siriwardana, Meng, and McNeill 2017; Bellora and Fontagné 2020; Janssens et al. 2022.
10. Cohn et al. 2014; Dixon et al. 2016; Tabeau et al. 2017; Henderson et al. 2018; Roe et al. 2021; Humpenöder, et al. 2022a.
11. Laborde et al. 2016; Chichaibelu et al. 2021.
12. Stehfest et al. 2009; Springmann et al. 2016; Searchinger et al. 2018; Springmann, et al. 2018b; Eker, Reese, and Obersteiner 2019; Willett et al. 2019; Humpenöder et al. 2024.
13. Bodirsky et al. 2022; Li et al. 2023.

The scope of innovation foresight research can be sector-specific or economywide. Economywide analysis allows for assessing potential spillover effects from one sector to another, spurring economic growth more broadly, but the wider scope of analysis tends to come with more stylized representation of innovations.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Predicting future groundbreaking innovations is impossible (King and Baatartogtokh 2015; Fink et al. 2017; Hall and Dijkman 2019; FAO 2022; Thornton et al. 2024), but growing calls for a food system transformation (Webb et al. 2020) and the need for responsible (Nordmann 2014; Brier et al. 2020) and mission-oriented innovation (Klerkx and Begemann 2020) highlight a critical role for foresight research. Such research will be fundamental to helping better orient the application of science to solving critical environmental, economic, and human wellbeing challenges, while emphasizing the potential undesired consequences of transformation.

While improvements in modeling capability and data collection on innovation (including how to apply artificial intelligence approaches) are critical to improve our understanding of the process of innovation as well as its consequences, we focus our key gaps on research and scenario design. To date, much of foresight analysis on food systems innovation has focused on "What If" questions to consider the impacts of the wide-scale adoption of an innovation, for example: What if alternative proteins displaced conventional meat?; What if investments in R&D increased?; or What if a paradigm shift led to healthy diets? This valuable first step helps to highlight potential innovations worthy of consideration and investment but leaves several key questions unanswered, as follows.

1. ***How do innovations compete with and complement each other?*** The innovation ecosystem is highly dynamic and volatile. Yet most foresight studies explore individual innovations as one-offs or, if in a bundle, in a very stylized way. Relatively limited exploration exists of how innovations coevolve, and what these implications might mean for designing bundles of innovations and appropriate policies.

2. ***What is the theory of change?*** Relatively few foresight studies have explored in detail innovation and transition roadmaps, instead focusing more on the ends than the means. However, historical experience reveals that the impacts of innovations are path-dependent, and the sociotechnical interface of adoption and obsolescence largely determines the winners and losers of innovation. Exploring such roadmaps will require greater engagement with multiscale and multidisciplinary research to better understand how innovation processes scale and diffuse. It also will require developing or adapting new modelling tools to simulating plausible pathways across relevant time and spatial scales.

3. ***What role can low- and middle-income countries (LMICs) play in spurring innovation?*** Technology development and diffusion is represented too simplistically (that is, core-periphery and Pareto efficiency), with novel technologies developed predominantly in advanced economies and then spread to the rest of the world. Foresight research needs to consider more pluralistic futures (Mangnus et al. 2019), reexamining what is meant by progress in varying regional and cultural contexts (Ritzer 2003; Pereira et al. 2021). It should explore how innovation processes can be started in LMICs and potentially spread to high-income countries (for example, frugal innovation) (Hossain, Simula, and Halme 2016).

4. ***Can we build consensus on desirable futures?*** Food systems are complex and fractal. Micro and macro analyses highlight the fundamental complexity and unknowability of the whole system. Nevertheless, foresight approaches can help to highlight different stakeholder perspectives and facilitate dialogue across alternative and potentially competing visions of the future (for example, group-based model building [Gerritsen et al. 2020; Anastasiou et al. 2023] or participatory scenarios [Chaudhury et al. 2013; Mason-D'Croz et al. 2016; Aguiar et al. 2020]), a critical first step for collective action.

Answering these questions requires developing more nuanced scenarios that simulate the innovation process in a less linear fashion. Greater application of foresight methods such as backcasting (Holmberg and Robert 2000; Robinson 2003) and three horizons (Sharpe et al. 2016) could help enrich scenario development that feeds into quantitative analyses of food systems innovation. This will provide not just a quantification of an endpoint but of the pathway between the present and an alternative future. It should also incorporate growing literature on innovation readiness and scaling (Herrero et al. 2020; Sartas et al. 2020; List 2022; Woltering et al. 2024). Achieving this will require broader and larger scenario sets and a wider range of foresight models to better capture key relationships and feedbacks, learning and expanding on previous multimodel efforts not only to understand model uncertainty (Nelson et al. 2014) but also to allow representation of a wider range of behaviors described in these more pluralistic scenarios. Failing to do this will reduce the applicability of future foresight research to inform strategic decision-making, such as in the design of innovation bundles (that is, prioritization and investment).

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Daniel Mason-D'Croz**, a Senior Research Associate in the Department of Global Development at Cornell University and a PhD Candidate with the Agricultural Economics and Rural Policy Group at Wageningen University and Research; **Mario Herrero**, Professor, Cornell Atkinson Scholar, and Nancy and Peter Meinig Family Investigator in the Life Sciences in the Department of Global Development at Cornell University; **Cody Kugler**, an independent agri-food innovation and sustainability consultant; **Roseline Remans**, an Honorary Research Fellow at Bioversity International; **Philip Thornton**, an Emeritus Fellow at the International Livestock Research Institute (ILRI), a visiting professor at Cornell University, a Research and Innovation Strategist with Clim-Eat, and an Honorary Professor in the School of Geosciences at the University of Edinburgh; and **Heather Zornetzer**, Coordinator of the Innovative Food System Solutions (IFSS) Portal at Bioversity International.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Mason-D'Croz, D., M Herrero, C. Kugler, R. Remans, P. Thornton, and H. Zornetzer. 2025. "What Do We Know About the Future of Food Systems Innovation?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 12. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Georgina Smith/CIAT

References

Aghion, P., and X. Jaravel. 2015. "Knowledge Spillovers, Innovation and Growth." *The Economic Journal* 125 (583): 533–573. https://doi.org/10.1111/ecoj.12199

Aguiar, A.P.D., D. Collste, Z.V. Harmáčková, et al. 2020. "Co-Designing Global Target-Seeking Scenarios: A Cross-Scale Participatory Process for Capturing Multiple Perspectives on Pathways to Sustainability." *Global Environmental Change* 65: 102198. https://doi.org/10.1016/j.gloenvcha.2020.102198

Aiginger, K., and D. Rodrik. 2020. "Rebirth of Industrial Policy and an Agenda for the Twenty-First Century." *Journal of Industry, Competition and Trade* 20 (2): 189–207. https://doi.org/10.1007/s10842-019-00322-3

Anastasiou, K., P. Baker, G.A. Hendrie, et al. 2023. "Conceptualising the Drivers of Ultra-Processed Food Production and Consumption and their Environmental Impacts: A Group Model-Building Exercise." *Global Food Security* 37: 100688. https://doi.org/10.1016/j.gfs.2023.100688

Baert, P. 1991. "Unintended Consequences: A Typology and Examples." *International Sociology* 6 (2): 201–210. https://doi.org/10.1177/026858091006002006

Baker, E., and E. Shittu. 2008. "Uncertainty and Endogenous Technical Change in Climate Policy Models." *Energy Economics* 30 (6): 2817–2828. https://doi.org/10.1016/j.eneco.2007.10.001

Baker, L., G. Castilleja, A. De Groot Ruiz, and A. Jones. 2020. "Prospects for the True Cost Accounting of Food Systems." *Nature Food* 1 (12): 765–767. https://doi.org/10.1038/s43016-020-00193-6

Barrett, C.B., T.G. Benton, K.A. Cooper, et al. 2020. "Bundling Innovations to Transform Agri-Food Systems." *Nature Sustainability* 3 (12): 974–976. https://doi.org/10.1038/s41893-020-00661-8

Barrett, C.B., T. Benton, J. Fanzo, et al. 2022. *Socio-Technical Innovation Bundles for Agri-Food Systems Transformation*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-88802-2

Bell, A.R., 2017. "Informing Decisions in Agent-Based Models—A Mobile Update." *Environmental Modelling & Software* 93: 310–321. https://doi.org/10.1016/j.envsoft.2017.03.028

Bellora, C., and L. Fontagné. 2020. *Carbon Border Adjustment and Alternatives*. Paris: CEPII.

Béné, C. 2022. "Why the Great Food Transformation May Not Happen—A Deep-Dive into our Food Systems' Political Economy, Controversies and Politics of Evidence." *World Development* 154: 105881. https://doi.org/10.1016/j.worlddev.2022.105881

Bloom, N., C.I. Jones, J. Van Reenen, and M. Webb. 2020. "Are Ideas Getting Harder to Find?" *American Economic Review* 110 (4): 1104–1144. https://doi.org/10.1257/aer.20180338

Bodirsky, B.L., D.M.-C. Chen, I. Weindl, et al. 2022. "Integrating Degrowth and Efficiency Perspectives Enables an Emission-Neutral Food System by 2100." *Nature Food* 3 (5): 341–348. https://doi.org/10.1038/s43016-022-00500-3

Brier, D., C.R. Eastwood, B.T. Dela Rue, and D.W. Viehland. 2020. "Foresighting for Responsible Innovation Using a Delphi Approach: A Case Study of Virtual Fencing Innovation in Cattle Farming." *Journal of Agricultural and Environmental Ethics* 33 (3–6): 549–569. https://doi.org/10.1007/s10806-020-09838-9

Chaudhury, M., J. Vervoort, P. Kristjanson, et al. 2013. "Participatory Scenarios as a Tool to Link Science and Policy on Food Security under Climate Change in East Africa." *Regional Environmental Change* 13 (2): 389–398. https://doi.org/10.1007/s10113-012-0350-1

Chichaibelu, B.B., M. Bekchanov, J. von Braun, and M. Torero. 2021. "The Global Cost of Reaching a World without Hunger: Investment Costs and Policy Action Opportunities." *Food Policy* 104: 102151. https://doi.org/10.1016/j.foodpol.2021.102151

Chu, J.S.G., and J.A. Evans. 2021. "Slowed Canonical Progress in Large Fields of Science." *Proceedings of the National Academy of Sciences* 118 (41): e2021636118. https://doi.org/10.1073/pnas.2021636118

Cohn, A.S., A. Mosnier, H. Valin, et al. 2014. "Cattle Ranching Intensification in Brazil can Reduce Global Greenhouse Gas Emissions by Sparing Land from Deforestation." *Proceedings of the National Academy of Sciences* 111 (20): 7236–7241. https://doi.org/10.1073/pnas.1307163111

Conti, C., A. Hall, H. Percy, et al. 2024. "What Does the Agri-Food Systems Transformation Agenda Mean for Agricultural Research Organisations? Exploring Organisational Prototypes for Uncertain Futures." *Global Food Security* 40: 100733. https://doi.org/10.1016/j.gfs.2023.100733

Dietrich, J.P., C. Schmitz, H. Lotze-Campen, et al. 2014. "Forecasting Technological Change in Agriculture—An Endogenous Implementation in a Global Land Use Model." *Technological Forecasting and Social Change* 81: 236–249. https://doi.org/10.1016/j.techfore.2013.02.003

Dixon, P.B., H. van Meijl, M. Rimmer, et al. 2016. "RED versus REDD: Biofuel Policy versus Forest Conservation." *Economic Modelling* 52: 366–374. https://doi.org/10.1016/j.econmod.2015.09.014

Dizyee, K., J. Aboah, S. Bahta, et al. 2021. *Regional Integrated Livestock Value Chain Simulation Model for Economic, Equity, and Environment Policy Assessment*. ILRI Research Report 93. Nairobi, Kenya: ILRI. https://hdl.handle.net/10568/117460

Dizyee, K., D. Baker, and K.M. Rich. 2017. "A Quantitative Value Chain Analysis of Policy Options for the Beef Sector in Botswana." *Agricultural Systems* 156: 13–24. https://doi.org/10.1016/j.agsy.2017.05.007

Eker, S., G. Reese, and M. Obersteiner. 2019. "Modelling The Drivers of a Widespread Shift to Sustainable Diets." *Nature Sustainability* 2: 725–735. https://doi.org/10.1038/s41893-019-0331-1

FAO (Food and Agriculture Organization of the United Nations). 2022. *Introducing the Agrifood Systems Technologies and Innovations Outlook (ATIO)*. Rome. https://doi.org/10.4060/cc2506en

FAO. 2023. *The State of Food and Agriculture 2023: Revealing The True Cost Of Food To Transform Agrifood Systems*. Rome. https://doi.org/10.4060/cc7724en

Fink, T.M.A., M. Reeves, R. Palma, and R.S. Farr. 2017. "Serendipity and Strategy in Rapid Innovation." *Nature Communications* 8 (1): 2002. https://doi.org/10.1038/s41467-017-02042-w

Frank, S., P. Havlík, J.-F. Soussana, et al. 2017. "Reducing Greenhouse Gas Emissions in Agriculture without Compromising Food Security?" *Environmental Research Letters* 12 (10): 105004. https://doi.org/10.1088/1748-9326/aa8c83

Frank, S., P. Havlík, H. Valin, et al. 2018. "Structural Change as a Key Component for Agricultural Non-CO_2 Mitigation Efforts." *Nature Communications* 9 (1): 1060. https://doi.org/10.1038/s41467-018-03489-1

Fuglie, K. 2018a. "Is Agricultural Productivity Slowing?" *Global Food Security* 17: 73–83. https://doi.org/10.1016/j.gfs.2018.05.001

Fuglie, K. 2018b. "R&D Capital, R&D Spillovers, and Productivity Growth in World Agriculture." *Applied Economic Perspectives and Policy* 40 (3): 421–444. https://doi.org/10.1093/aepp/ppx045

Gerhardt, C., et al. 2020. "How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry?" *Industrial Biotechnology* 16 (5): 262–270. https://doi.org/10.1089/ind.2020.29227.cge

Gerritsen, S., G. Suhlmann, F. Ziemßen, et al. 2020. "Community Group Model Building as a Method for Engaging Participants and Mobilising Action in Public Health." *International Journal of Environmental Research and Public Health* 17 (10): 3457. https://doi.org/10.3390/ijerph17103457

Giabbanelli, P.J., and R. Crutzen. 2017. "Using Agent-Based Models to Develop Public Policy about Food Behaviours: Future Directions and Recommendations." *Computational and Mathematical Methods in Medicine* 1: 5742629. https://doi.org/10.1155/2017/5742629

Gollin, D., S. Parente, and R. Rogerson. 2002. "The Role of Agriculture in Development." *American Economic Review* 92 (2): 160–164. https://doi.org/10.1257/000282802320189177

Hall, A., and J. Dijkman. 2019. *Public Agricultural Research in an Era of Transformation: The Challenge of Agri-Food System Innovation*. Rome and Canberra: CGIAR ISPC Secretariat and CSIRO. https://iaes.cgiar.org/isdc/publications/public-agricultural-research-era-transformation-challenge-agri-food-system

Havlík, P., et al. 2014. "Climate Change Mitigation through Livestock System Transitions." *Proceedings of the National Academy of Sciences* 111 (10): 3709–3714. https://doi.org/10.1073/pnas.1308044111

Henderson, B., et al. 2018. "The Power and Pain of Market-Based Carbon Policies: A Global Application to Greenhouse Gases from Ruminant Livestock Production." *Mitigation and Adaptation Strategies for Global Change* 23 (3): 349–369. https://doi.org/10.1007/s11027-017-9737-0

Herrero, M., et al. 2020. "Innovation Can Accelerate the Transition Towards a Sustainable Food System." *Nature Food* 1 (5): 266–272. https://doi.org/10.1038/s43016-020-0074-1

Herrero, M., et al. 2021. "Articulating the Effect of Food Systems Innovation on the Sustainable Development Goals." *The Lancet Planetary Health* 5 (1): e50–e62. https://doi.org/10.1016/S2542-5196(20)30277-1.

Holmberg, J., and K.H. Robert. 2000. "Backcasting—A Framework for Strategic Planning." *International Journal of Sustainable Development & World Ecology* 7 (4): 291–308. https://doi.org/10.1080/13504500009470049

Hong, C., et al. 2014. "Validation of an R&D-Based Computable General Equilibrium Model." *Economic Modelling* 42: 454–463. https://doi.org/10.1016/j.econmod.2014.07.014

Hossain, M., H. Simula, and M. Halme. 2016. "Can Frugal Go Global? Diffusion Patterns of Frugal Innovations." *Technology in Society* 46: 132–139. https://doi.org/10.1016/j.techsoc.2016.04.005

Humpenöder, F., A. Popp, et al. 2022. "Overcoming Global Inequality is Critical for Land-Based Mitigation in Line with the Paris Agreement." *Nature Communications* 13 (1): 7453. https://doi.org/10.1038/s41467-022-35114-7

Humpenöder, F., B.L. Bodirsky, et al. 2022. "Projected Environmental Benefits of Replacing Beef with Microbial Protein." *Nature* 605 (7908): 90–96. https://doi.org/10.1038/s41586-022-04629-w

Humpenöder, F., et al. 2024. "Food Matters: Dietary Shifts Increase the Feasibility of 1.5°C Pathways in Line with the Paris Agreement." *Science Advances* 10 (13): eadj3832. https://doi.org/10.1126/sciadv.adj3832

Ignaciuk, A., D. Mason-D'Croz, and S. Islam. 2015. "Better Drip than Flood: Reaping the Benefits of Efficient Irrigation." *EuroChoices* 14 (2): 26–32. https://doi.org/10.1111/1746-692X.12088

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2019. *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany. https://doi.org/10.5281/ZENODO.3831673

IPCC (Intergovernmental Panel on Climate Change). 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva. Edited by P.R. Shukla et al.

Islam, S., et al. 2016. "Structural Approaches to Modeling the Impact of Climate Change and Adaptation Technologies on Crop Yields and Food Security." *Global Food Security* 10: 63–70. https://doi.org/10.1016/j.gfs.2016.08.003

Janssens, C., et al. 2022. "A Sustainable Future for Africa through Continental Free Trade and Agricultural Development." *Nature Food* 3 (8): 608–618. https://doi.org/10.1038/s43016-022-00572-1

Kaaronen, R.O., and N. Strelkovskii. 2020. "Cultural Evolution of Sustainable Behaviors: Pro-Environmental Tipping Points in an Agent-Based Model." *One Earth* 2 (1): 85–97. https://doi.org/10.1016/j.oneear.2020.01.003

Kennedy, E.T., M.A. Torero, D. Mozaffarian, et al. 2023. "Beyond the Food Systems Summit: Linking Recommendations to Action—The True Cost of Food." *Current Developments in Nutrition* 7 (5): 100028. https://doi.org/10.1016/j.cdnut.2023.100028

King, A.A., and B. Baatartogtokh. 2015. "How Useful is the Theory of Disruptive Innovation?" *MIT Sloan Management Review* 57 (1): 77–90. https://sloanreview.mit.edu/article/how-useful-is-the-theory-of-disruptive-innovation/

Klerkx, L., and S. Begemann. 2020. "Supporting Food Systems Transformation: The What, Why, Who, Where and How of Mission-Oriented Agricultural Innovation Systems." *Agricultural Systems* 184: 102901. https://doi.org/10.1016/j.agsy.2020.102901

Kozicka, M., et al. 2023. "Feeding Climate and Biodiversity Goals with Novel Plant-Based Meat and Milk Alternatives." *Nature Communications* 14 (1): 5316. https://doi.org/10.1038/s41467-023-40899-2

Laborde, D., L. Bizikova, T. Lallemant, and C. Smaller. 2016. *Ending Hunger: What Would it Cost?* Winnipeg, Canada: International Institute for Sustainable Development. https://hdl.handle.net/10568/147550

Laborde, D., A. Mamun, W. Martin, et al. 2021. "Agricultural Subsidies and Global Greenhouse Gas Emissions." *Nature Communications* 12 (1): 2601. https://doi.org/10.1038/s41467-021-22703-1

Li, M., L. Keyßer, J.S. Kikstra, et al. 2023. "Integrated Assessment Modelling of Degrowth Scenarios for Australia." *Economic Systems Research* 36 (4): 545–575. https://doi.org/10.1080/09535314.2023.2245544

List, J.A. 2022. *The Voltage Effect: How to Make Good Ideas Great and Great Ideas Scale*. New York: Crown Currency.

Loboguerrero, A.M., P. Thornton, J. Wadsworth, et al. 2020. "Perspective Article: Actions to Reconfigure Food Systems." *Global Food Security* 26: 100432. https://doi.org/10.1016/j.gfs.2020.100432

Mangnus, A.C., J.M. Vervoort, S.R. McGreevy, et al. 2019. "New Pathways for Governing Food System Transformations: A Pluralistic Practice-Based Futures Approach using Visioning, Back-Casting, and Serious Gaming." *Ecology and Society* 24 (4): 2. https://doi.org/10.5751/ES-11014-240402

Marvuglia, A., A. Bayram, P. Baustert, et al. 2022. "Agent-Based Modelling to Simulate Farmers' Sustainable Decisions: Farmers' Interaction and Resulting Green Consciousness Evolution." *Journal of Cleaner Production* 332: 129847. https://doi.org/10.1016/j.jclepro.2021.129847

Mason-D'Croz, D., J. Vervoort, A. Palazzo, et al. 2016. "Multi-Factor, Multi-State, Multi-Model Scenarios: Exploring Food and Climate Futures for Southeast Asia." *Environmental Modelling & Software* 83: 255–270. https://doi.org/10.1016/j.envsoft.2016.05.008

Mason-D'Croz, D., T.B. Sulser, K. Wiebe, et al. 2019. "Agricultural Investments and Hunger in Africa Modeling Potential Contributions to SDG2–Zero Hunger." *World Development* 116: 38–53. https://doi.org/10.1016/j.worlddev.2018.12.006

Mason-D'Croz, D., A. Barnhill, J. Bernstein, et al. 2022. "Ethical and Economic Implications of the Adoption of Novel Plant-Based Beef Substitutes in the USA: A General Equilibrium Modelling Study." *The Lancet Planetary Health* 6 (8): e658–e669. https://doi.org/10.1016/S2542-5196(22)00169-3

Mason-D'Croz, D., et al. 2023. *Wild Futures—Innovations for Food Systems Transformations: Project Summary Report*. Project Report. Ithaca, NY: Cornell Food Systems and Global Change.

Mbow, C., C. Rosenzweig, L.G. Barioni, et al. 2019. "Chapter 5:Food Security—Special Report on Climate Change and Land." In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva: IPCC. https://www.ipcc.ch/srccl/chapter/chapter-5/

Merton, R.K. 1936. "The Unanticipated Consequences of Purposive Social Action." *American Sociological Review* 1 (6): 894. https://doi.org/10.2307/2084615

Moberg, E., E.H. Allison, H.K. Harl, et al. 2021. "Combined Innovations in Public Policy, the Private Sector and Culture Can Drive Sustainability Transitions in Food Systems." *Nature Food* 2 (4): 282–290. https://doi.org/10.1038/s43016-021-00261-5

Nelson, G.C., H. Valin, R.D. Sands, et al. 2014. "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks." *Proceedings of the National Academy of Sciences* 111 (9): 3274–3279. https://doi.org/10.1073/pnas.1222465110

Nordmann, A. 2014. "Responsible Innovation, the Art and Craft of Anticipation." *Journal of Responsible Innovation* 1 (1): 87–98. https://doi.org/10.1080/23299460.2014.882064

Park, M., E. Leahey, and R.J. Funk. 2023. "Papers and Patents are Becoming Less Disruptive over Time." *Nature* 613 (7942): 138–144. https://doi.org/10.1038/s41586-022-05543-x

Parodi, A., A. Leip, I.J.M. De Boer, et al. 2018. "The Potential of Future Foods for Sustainable and Healthy Diets." *Nature Sustainability* 1 (12): 782–789. https://doi.org/10.1038/s41893-018-0189-7

Pereira, L., G.R. Asrar, R. Bhargava, et al. 2021. "Grounding Global Environmental Assessments through Bottom-Up Futures Based on Local Practices and Perspectives." *Sustainability Science* 16: 1907–16922. https://doi.org/10.1007/s11625-021-01013-x

Ritzer, G. 2003. "Rethinking Globalization: Glocalization/Grobalization and Something/Nothing." *Sociological Theory* 21 (3): 193–209. https://doi.org/10.1111/1467-9558.00185

Robinson, J. 2003. "Future Subjunctive: Backcasting as Social Learning." *Futures* 35 (8): 839–856. https://doi.org/10.1016/S0016-3287(03)00039-9

Robinson, S., D. Mason-D'Croz S. Islam, et al. 2015. "Climate Change Adaptation in Agriculture: Ex Ante Analysis of Promising and Alternative Crop Technologies Using DSSAT and IMPACT." IFPRI Discussion Paper 1469. IFPRI, Washington, DC.

Roe, S., C. Streck, R. Beach, et al. 2021. "Land- Based Measures to Mitigate Climate Change: Potential and Feasibility by Country." *Global Change Biology* 27 (23): 6025–6058. https://doi.org/10.1111/gcb.15873

Rosegrant, M.W., J. Koo, N. Cenacchi, et al. 2014. "Food Security in a World of Natural Resource Scarcity." *Monographs of the Society for Research in Child Development* 79 (1): 134–137. https://doi.org/10.1111/mono.12084

Rosegrant, M.W., T.B. Sulser, D. Mason-D'Croz, et al. 2017. *Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio*. Project Report for USAID. Washington, DC: IFPRI. https://hdl.handle.net/10568/148186

Sartas, M., M. Schut, C. Proietti, G. Thiele, and C. Leeuwis. 2020. "Scaling Readiness: Science and Practice of an Approach to Enhance Impact of Research for Development." *Agricultural Systems* 183: 102874. https://doi.org/10.1016/j.agsy.2020.102874

Searchinger, T., R. Waite, C. Hanson, and J. Ranganathan. 2018. *Creating a Sustainable Food Future. A Menu of Solutions to Feed Nearly 10 Billion People by 2050: Synthesis Report*. Washington, DC: World Resources Institute.

Sharpe, B., A. Hodgson, G. Leicester, et al. 2016. "Three Horizons: A Pathways Practice for Transformation." *Ecology and Society* 21 (2): 47. https://doi.org/10.5751/ES-08388-210247

Siriwardana, M., S. Meng, and J. McNeill. 2017. "Border Adjustments Under Unilateral Carbon Pricing: The Case of Australian Carbon Tax." *Journal of Economic Structures* 6: 34. https://doi.org/10.1186/s40008-017-0091-x

Sodano, V. 2019. "Innovation Trajectories and Sustainability in the Food System." *Sustainability* 11 (5): 1271. https://doi.org/10.3390/su11051271

Springmann, M., D. Mason-D'Croz, S. Robinson, et al. 2016. "Global and Regional Health Effects of Future Food Production Under Climate Change: A Modelling Study." *The Lancet* 387 (10031): 1937–1946. https://doi.org/10.1016/S0140-6736(15)01156-3

Springmann, M., D. Mason-D'Croz, S. Robinson, et al. 2017. "Mitigation Potential and Global Health Impacts from Emissions Pricing of Food Commodities." *Nature Climate Change* 7 (1): 69–74. https://doi.org/10.1038/nclimate3155

Springmann, M., D. Mason-D'Croz, et al. 2018a. "Health-Motivated Taxes on Red and Processed Meat: A Modelling Study on Optimal Tax Levels and Associated Health Impacts." *PLOS ONE* 13 (11): e0204139. https://doi.org/10.1371/journal.pone.0204139

Springmann, M., M. Clark, et al. 2018b. "Options for Keeping the Food System within Environmental Limits." *Nature* 562 (7728): 519–525. https://doi.org/10.1038/s41586-018-0594-0

Springmann, M., and F. Freund. 2022. "Options for Reforming Agricultural Subsidies from Health, Climate, and Economic Perspectives." *Nature Communications* 13 (1): 82. https://doi.org/10.1038/s41467-021-27645-2

Stehfest, E., L. Bouwman, D.P. van Vuuren, et al. 2009. "Climate Benefits of Changing Diet." *Climatic Change* 95 (1–2): 83–102.

Sulser, T., K.D. Wiebe, S. Dunston, et al. 2021. *Climate Change and Hunger: Estimating Costs of Adaptation in the Agrifood System*. Food Policy Report June 2021. Washington, DC: IFPRI. https://doi.org/10.2499/9780896294165

Sulser, T.B., C. Ringler, T. Zhu, et al. 2010. "Green and Blue Water Accounting in the Ganges and Nile Basins: Implications for Food and Agricultural Policy." *Journal of Hydrology* 384 (3–4): 276–291. https://doi.org/10.1016/j.jhydrol.2009.10.003

Swinburn, B.A., V.IK. Kraak, S. Allender, et al. 2019. "The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission Report." *The Lancet* 393 (10173): 791–846. https://doi.org/10.1016/S0140-6736(18)32822-8

Tabeau, A., H. van Meijl, K.P. Overmars, and E. Stehfest. 2017. "REDD Policy Impacts on the Agri-Food Sector and Food Security." *Food Policy* 66: 73–87. https://doi.org/10.1016/j.foodpol.2016.11.006

Thornton, P., D. Mason-D'Croz, C. Kugler, et al. 2024. "Enabling Food System Innovation: Accelerators for Change." *Global Food Security* 40: 100738. https://doi.org/10.1016/j.gfs.2023.100738

UNEP. 2023. *Frontiers 2023. What's Cooking? An Assessment of the Potential Impacts of Selected Novel Alternatives to Conventional Animal Products*. Nairobi: United Nations Environment Programme (UNEP). https://doi.org/10.59117/20.500.11822/44236

van Selm, B., A. Frehner, I.J.MN. de Boer, et al. 2022. "Circularity in Animal Production Requires a Change in the EAT-Lancet Diet in Europe." *Nature Food* 3 (1): 66–73. https://doi.org/10.1038/s43016-021-00425-3

Varia, F.,G.D. Guccione, D. Macaluso, and D. Marandola. 2017. "System Dynamics Model to Design Effective Policy Strategies Aiming at Fostering the Adoption of Conservation Agriculture Practices in Sicily." *Chemical Engineering Transactions* 58: 763–768. https://doi.org/10.3303/CET1758128

Vermeulen, S.J., T. Park, C.K. Khoury, and C. Béné. 2020. "Changing Diets and the Transformation of the Global Food System." *Annals of the New York Academy of Sciences* 1478 (1): 3–17. https://doi.org/10.1111/nyas.14446

Webb, P., lT.G. Benton, J. Beddington, et al. 2020. "The Urgency of Food System Transformation is Now Irrefutable." *Nature Food* 1 (10): 584–585. https://doi.org/10.1038/s43016-020-00161-0

Willett, W., J. Rockström, B. Loken, et al. 2019. "Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems." *The Lancet* 393 (10170): 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Woltering, L., E.M. Valencia Leñero, M. Boa-Alvarado, et al. 2024. "Supporting a Systems Approach to Scaling for All; Insights from Using the Scaling Scan Tool." *Agricultural Systems* 217: 103927. https://doi.org/10.1016/j.agsy.2024.103927

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FOOD TRADE?

Joseph Glauber (IFPRI) and Sherwin Gabriel (IFPRI)

Key messages

- Trade in agriculture and food products increased dramatically over the past 20 years, driven by population and income growth that resulted in consumption exceeding production in many countries. Productivity growth grew as well, allowing countries with surplus production to meet global import demand. Reforms in the global trading system have reduced import barriers, also encouraging trade.

- As a result, imports as a percentage of total consumption have increased steadily (particularly in low-income countries) and forecasts for the near term (next 10 years) as well as longer-term projections (to 2050) suggest that these trends will continue.

- Climate change will pose continued challenges as production shifts due to increased temperatures and more variable rainfall. Trade will be necessary to help mitigate the impacts of these changes, so the global trading system must remain open and free of harmful distortions.

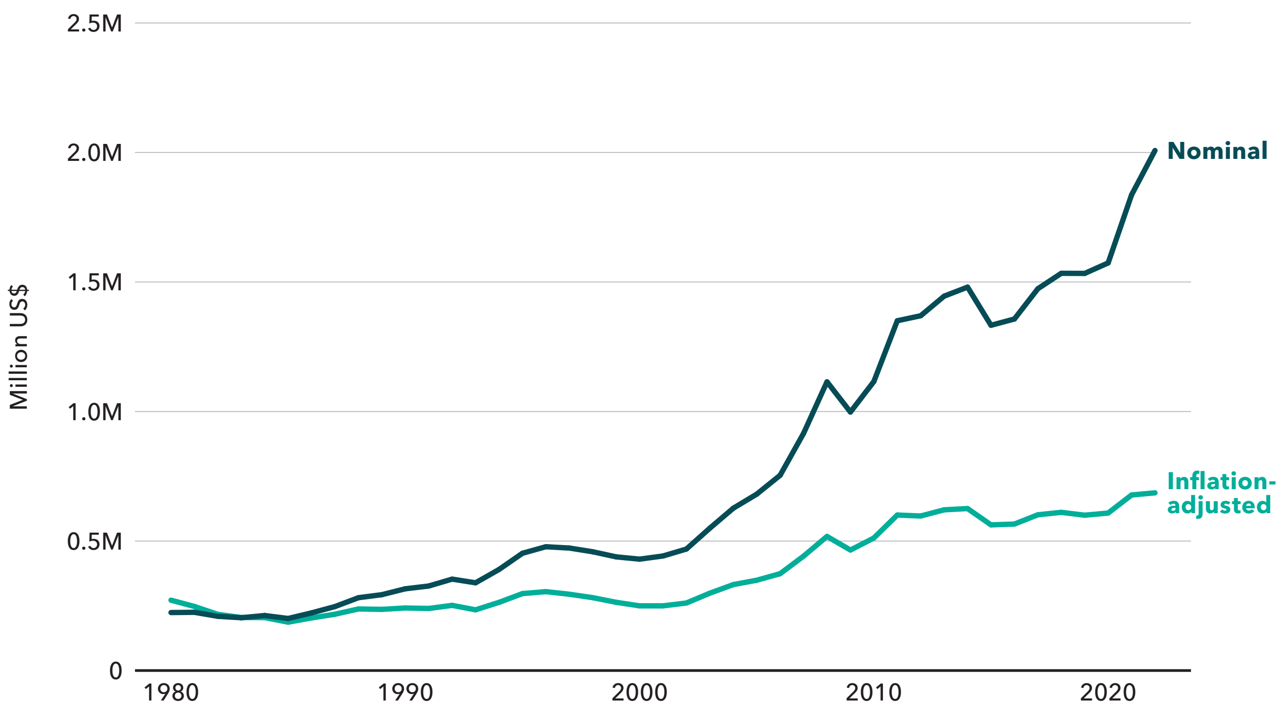
RECENT TRENDS AND CHALLENGES

Global trade in food products exceeded a record US$2 trillion in 2022 (WTO 2024). Over the past 20 years, global food trade more than tripled in nominal value and, accounting for inflation, more than doubled in real terms (Figure 1).

Developing countries are now playing a far larger role in global trade than they did 25 years ago (Figure 2). In 1995, developing countries accounted for only about 25 percent of global food imports and 30 percent of global food exports; by 2023, developing countries accounted for about 42 percent of global food trade. Productivity gains and technological innovations like double cropping in Brazil have helped developing countries increase export shares. Income and population growth have also spurred changes in diets, resulting in increased consumption of meat and dairy and processed food products. For some developing countries (for example, China), this has meant greater dependence on imports for feedstuffs and other agricultural products.

Another consequence of the growth of production in developing countries and in regions like the Black Sea following the breakup of the former Soviet Union is the growing diversification away from traditional suppliers like the United States, the European Union (EU), Canada, and Australia (Figure 3). Market concentration has declined for most cereals and oilseeds as global exporters including Brazil (soybeans, maize, animal products), Russia (wheat), Ukraine (wheat, maize, and sunflower oil), and Malaysia and Indonesia (palm oil) have grown in relative importance. With much of that growth occurring in the Southern Hemisphere, global production is more resilient to regional weather shocks. Moreover, diversified production means that producers in one hemisphere can often react within months of a production shortfall in another region, effectively reducing the global cycle to six months. Exceptions exist. Rice exports remain relatively concentrated in the exporting countries of South and Southeast Asia. Most palm oil production comes from Indonesia and Malaysia (though this is mitigated by its

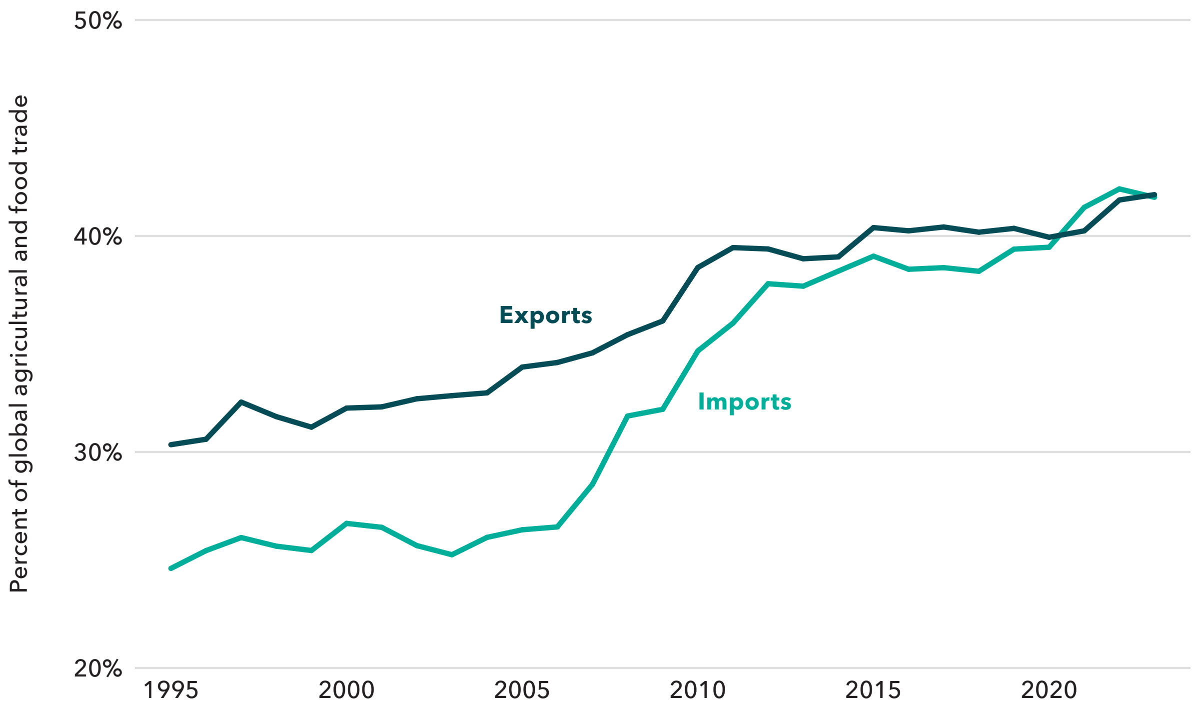
FIGURE 1 **Value of world food trade, 1980–2022**



Source: WTO Stats Portal.

Note: Trade value deflated by U.S. Consumer Price Index (1982–1984 = 100).

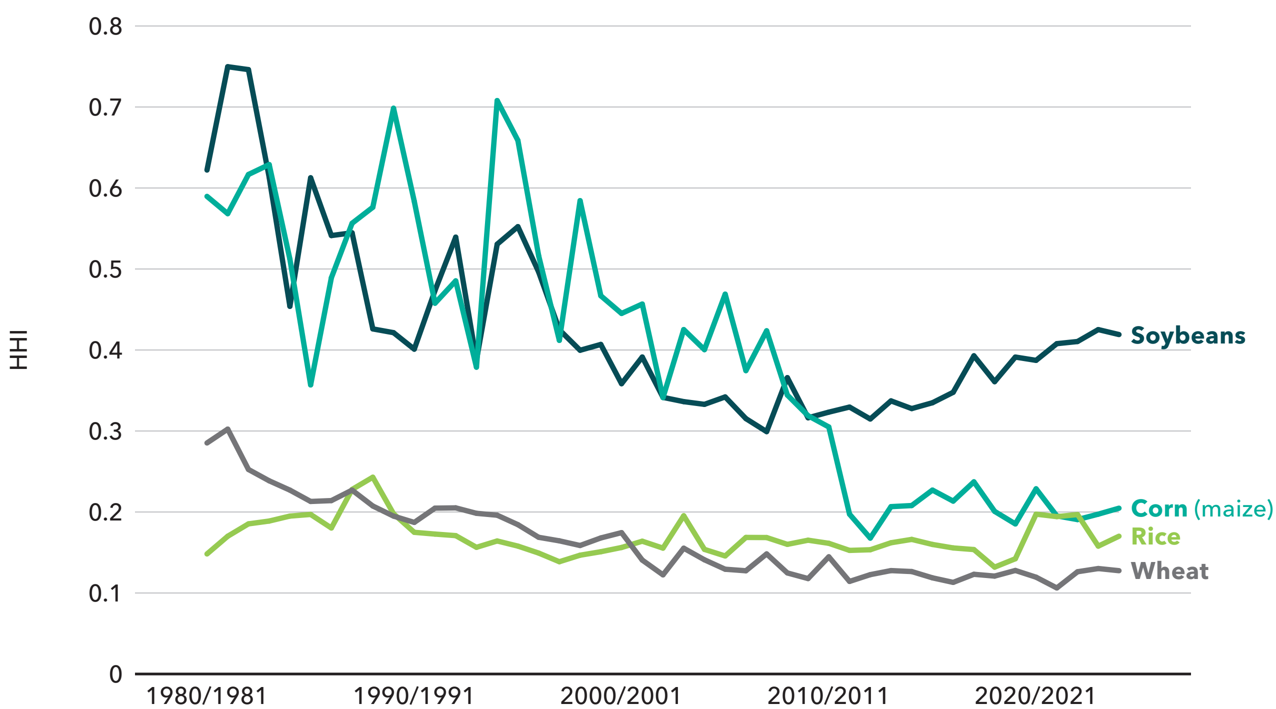
FIGURE 2 **Developing countries' share of agricultural trade, 1995–2023**



Source: UNCTAD Data Hub, https://unctadstat.unctad.org/

Note: All food items (SITC 0 + 1 + 22 +4).

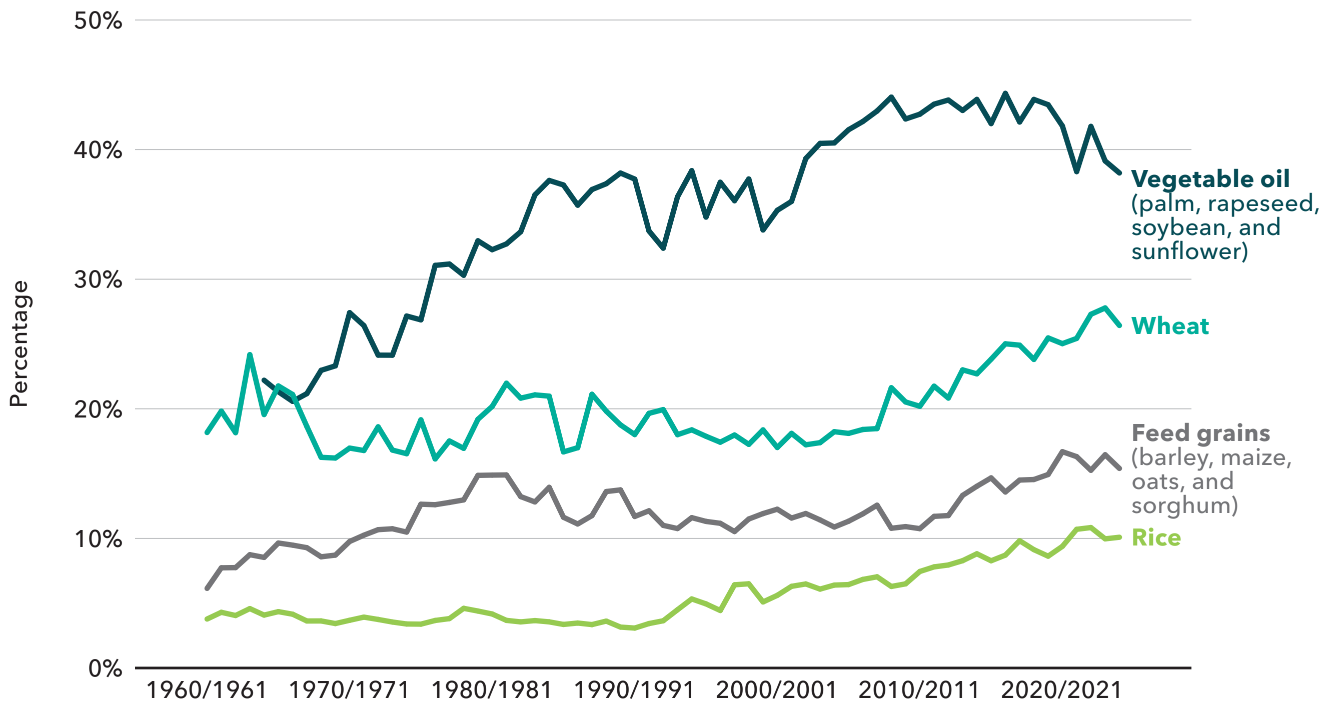
FIGURE 3 **Concentration of global grain and oilseed exports, 1980/1981–2024/2025**



Source: USDA/FAS/PSD Online, https://apps.fas.usda.gov/psdonline/app/index.html#/app/home

Note: HHI = Herfindahl-Hirschman Index. Herfindahl-Hirschman Index based on export quantities.

FIGURE 4 Imports as a share of total domestic use, 1960/1961–2024/2025



Source: USDA/FAS PSD database, October 11, 2024.

Note: Domestic use includes food, feed, and industrial use.

relative substitutability with other vegetable oils that are more regionally diversified).

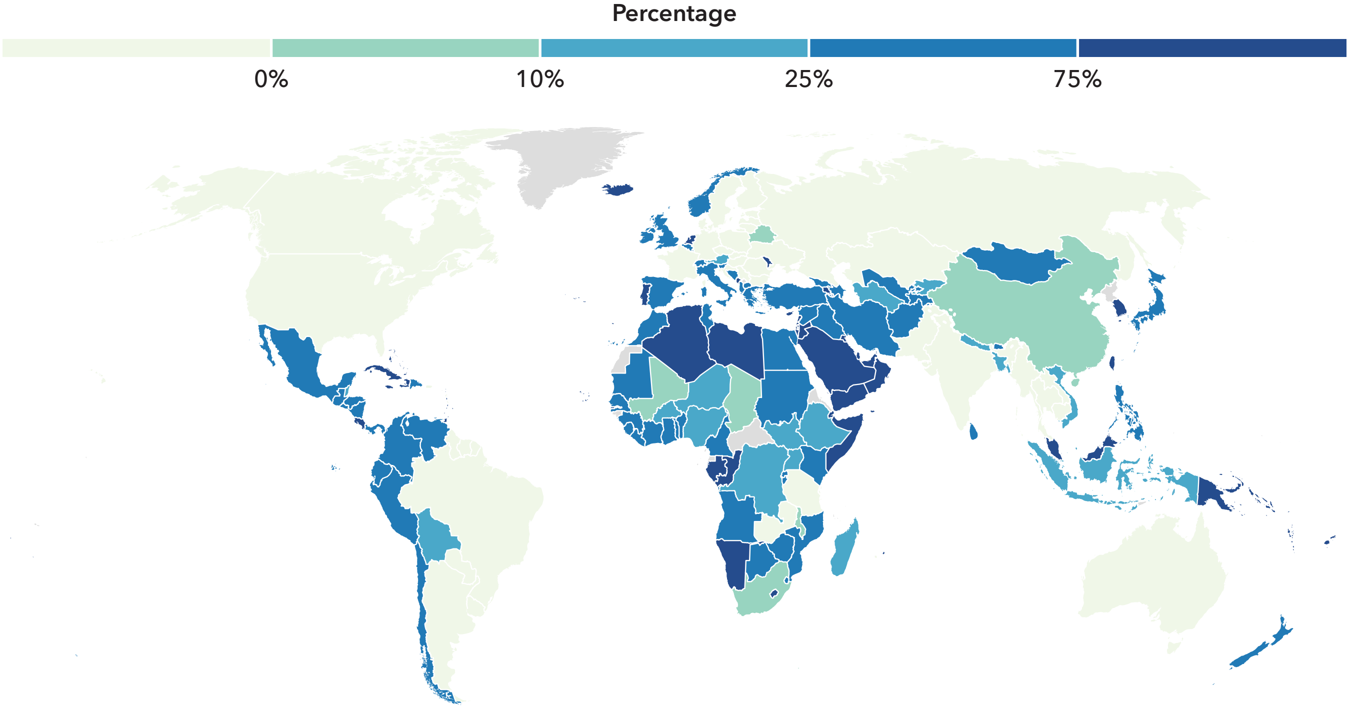
On the import side, increased demand means that many countries are increasingly dependent on foreign supplies. Import penetration rates at the global level have increased for wheat, rice, feed grains (barley, maize, oats, and sorghum), and vegetable oils (Figure 4). Not all of those imports go toward food consumption. Feed grains are primarily used as animal feed or in industrial uses such as biofuel production (though white maize is primarily consumed as food). Of the cereals, rice remains relatively thinly traded – imports account for only about 10 percent of global consumption. However, for many countries in sub-Saharan Africa such as Senegal or Benin, rice imports play a significant role in overall diets, particularly in urban areas.

Regionally, imports are important for much of Central America and non-MERCOSUR countries of South America, sub-Saharan Africa, and parts of Southeast Asia (Figure 5). The wheat-consuming countries of North Africa, the Middle East, and Central Asia are particularly dependent on imports, with import dependency rates in excess of 75 percent in countries such as Algeria, Libya, Saudi Arabia, and Yemen. The disruption in wheat trade following Russia's full-scale invasion of Ukraine in February 2022 demonstrated how vulnerable importing countries can be when supplies are adversely affected. Fortunately, the global trading system proved resilient, and countries were able to source food supplies (albeit at higher prices).

LATEST FORESIGHT RESEARCH

Near-term forecasts by the Organisation for Economic Co-operation and Development and the Food and Agriculture Organization of the United Nations (OECD/FAO 2024) and the U.S. Department of Agriculture (USDA/ERS 2024) estimate that imports as a share of global consumption will continue to grow for most cereals and oil crops over the next 10 years. The forecasts reflect continuing production growth in major exporting regions such as South America and the Black Sea region to meet growing demand in net food-importing regions like the Middle East and North Africa, China, and sub-Saharan Africa.

FIGURE 5 Cereal import dependency



Source: FAOSTAT

Note: Import dependency less than 0 indicate that the country is a net cereal exporter. Data reflect 3-year average (2020–2022).

In addition, projections from IFPRI's IMPACT[1] model suggest that global food trade will continue to expand over the longer term (Cenacchi et al. 2025 [Chapter 36 in this publication]; Robinson et al. 2024). Net exports of rice and wheat are projected to increase by more than 90 percent between 2020 and 2050, as rice production in India grows rapidly and as wheat production in Russia and Ukraine expands. Net exports of maize are projected to rise by 70 percent over the same period, driven by higher production in Brazil and Ukraine.

The United States is the world's largest net exporter of maize. Projections suggest, however, that growing domestic demand for bioethanol could significantly erode exportable supplies to the global market. This decrease is projected to be more than offset by rising maize exports from Latin America and Eastern Europe. By 2050, almost 90 percent of net maize exports are projected to come from seven countries.

Over the same period, climate change is expected to weigh on maize yields in several countries in which it is a key staple. For example, in Malawi, where maize accounts for one-half of daily per capita calories, rainfed yields are projected to be around 15 percent lower in 2050 than 2020. With little change in cultivated area expected, domestic maize production is also expected to fall by 15 percent over the period. This comes alongside an anticipated increase of 17 million in Malawi's population. As projected production and food demand for maize move in different directions, the country is likely to require significant imports to cover maize shortfalls. IMPACT projections suggest that net imports of maize could near 80 percent of Malawi's food demand by 2050, a significant increase over current levels. With few expected net exporters of maize in the region – South Africa's capacity to export maize is expected to decline significantly over the projection period – Malawi may be pushed to import from the major exporters noted above. The distance from these markets implies that trade costs will also exert pressure on the cost of staple foods.

1 International Model for Policy Analysis of Agricultural Commodities and Trade.

TABLE 1 Maize net imports as a share of maize food demand in selected countries in East and Southern Africa

Country	Maize contribution to average daily calorie availability (2020)	Maize net imports as a share of maize food demand	
		2020	2050
Malawi	50%	2.5%	78.8%
Zambia	40%	Net exporter	40.7%
Kenya	26%	25.9%	57.9%
Tanzania	25%	Net exporter	63.3%
Mozambique	22%	25.8%	80.1%

Source: IFPRI, IMPACT projections.

Several countries in East and Southern Africa are similarly vulnerable to this risk, which can materially affect food security and foreign exchange reserves. Table 1 identifies countries in the region where import dependency on maize is expected to rise sharply between 2020 and 2050.

This trend is not unique to maize in East and Southern Africa. Rice is an important staple in several countries in Asia, West Africa, and Latin America. Table 2 shows a selection of countries by region where rice import dependency is projected to increase significantly between 2020 and 2050. In the West and Central African countries identified, the import share of rice is already high, but these are expected to increase even more. Countries that have been close to self-sufficiency, such as Bangladesh, are expected to import as much as one-quarter of rice food demand by 2050.

Rice trade dependency is expected to be significant. Rice net exports are projected to be highly concentrated, with India's share of global net exports predicted to double to 70 percent between 2020 and 2050. This follows significant growth in rice production in India, while that of other

TABLE 2 Rice net imports as a share of rice food demand in selected countries

Country	Rice contribution to average daily calorie availability (2020)	Rice net imports as a share of rice food demand	
		2020	2050
West and Central Africa			
Guinea	37%	54%	>100%
Guinea-Bissau	51%	42%	57%
Côte d'Ivoire	24%	66%	84%
Sierra Leone	43%	40%	78%
Latin America and the Caribbean			
Costa Rica	15%	63%	78%
Ecuador	15%	26%	65%
Panama	24%	24%	61%
Peru	18%	13%	60%
South Asia and Southeast Asia			
Bangladesh	70%	2%	24%
Indonesia	43%	Net exporter	12%

Source: IFPRI, IMPACT projections.

TABLE 3 **Wheat net imports as a share of wheat food demand in selected countries in Central Asia, West Asia, and North Africa**

Country	Wheat contribution to average daily calorie availability (2020)	Wheat net imports as a share of wheat food demand	
		2020	2050
Afghanistan	60%	49%	83%
Turkmenistan	51%	12%	49%
Syria	49%	66%	>100%
Uzbekistan	42%	44%	85%
Pakistan	37%	Net exporter	53%

Source: IFPRI, IMPACT projections.

major exporters, such as Thailand and Viet Nam, slows over the projection period.

Wheat markets are less concentrated than rice and maize. IMPACT projections suggest that wheat net exports could grow by more than 90 percent between 2020 and 2050, with much of this growth driven by increased production in Russia and Ukraine. Wheat products are an important staple in most countries, and an especially important part of the food culture in Central and West Asia and North Africa. Table 3 shows countries in these regions where wheat import dependency is expected to increase significantly.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Food and agricultural trade grew substantially over the past 25 years, in part because of a more liberal trading regime under the World Trade Organization, but the global trading system faces challenges. Over the past 10 years, multiple trade disruptions occurred, including: conflicts such as Russia's invasion of Ukraine, which threatened global cereal and oilseed markets (Glauber and Laborde 2023); trade disputes, such as the recent trade war between the United States and China; export restrictions such as India's restrictions on rice exports, affecting almost 40 percent of global rice exports (Glauber and Mamun 2024); logistical disruptions affecting key chokepoints such as the Red Sea and the Panama Canal; and supply disruptions due to lockdowns and other responses to the COVID-19 pandemic.

Threats of increased protectionism under the new US administration and elevated trade tensions between China and other trading partners such as Canada and the EU could derail progress at a time when trade is becoming increasingly important.

Climate change will mean an increasing dependency on trade to meet global food needs. The disruptions to trade flows caused by weather extremes and subsequent reconstruction can undermine global supply chains (Verschuur, Koks, and Hall 2023).

Trade barriers and other distortions can thwart the movement of food and agricultural products, exacerbating food shortages when production shocks reduce global supplies. It is thus critical that the global trading system continue to facilitate trade by: reducing border measures and other trade-distorting measures; improving foresight and market analysis, such as through the G20 Agricultural Market Information System (AMIS), to better inform policy and investment choices; and promoting trade facilitation for lesser developed countries and developing countries highly dependent on imports to meet food needs.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Joseph Glauber**, a Research Fellow Emeritus at the International Food Policy Research Institute (IFPRI); and **Sherwin Gabriel**, a Scientist in the Foresight and Policy Modeling Unit at IFPRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Glauber, J., and S. Gabriel. 2025. "What Do We Know About the Future of Food Trade?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 13. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Tarcisio Schnaider/Shutterstock

References

Cenacchi, N., T.B. Sulser, and A. Mishra. 2025. "What Do We Know About the Future of Food Demand, Production, and Food Security Based on IMPACT Model Projections?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gator, Chapter 36. Washington, DC: IFPRI. https://hdl.handle.net/10568/175406

Glauber, J.W., and A. Mamun. 2024. "India Lifts Export Restrictions on Rice." *IFPRI blog*, November 8. https://www.ifpri.org/blog/india-lifts-export-restrictions-on-rice/

Glauber, J.W., and D. Laborde, eds. 2023. *The Russia-Ukraine Conflict and Global Food Security*. Washington, DC: IFPRI. https://doi.org/10.2499/9780896294394

OECD/FAO (Organisation for Economic Co-operation and Development/Food and Agriculture Organization of the United Nations). 2024. *OECD-FAO Agricultural Outlook 2024–2033*. Paris: OECD Publishing; Rome: FAO. https://doi.org/10.1787/4c5d2cfb-en

Robinson, S., S. Dunston, A. Mishra et al. 2024. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Documentation for Version 3.6*. Modeling Systems Technical Paper No. 1. Washington, DC: IFPRI. https://hdl.handle.net/10568/148953

Rosegrant, M.W., T.B. Sulser, S. Dunston, A. Mishra, N. Cenacchi, Y. Gebretsadik, R. Robertson, T. Thomas, and K. Wiebe. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41 (June): 100755. https://doi.org/10.1016/j.gfs.2024.100755

USDA/ERS (U.S. Department of Agriculture, Economic Research Service). 2024. International Baseline Database. https://www.ers.usda.gov/data-products/international-baseline-data/

USDA/FAS (Foreign Agricultural Service). 2024. PSD database. https://apps.fas.usda.gov/psdonline/app/index.html#/app/home

Verschuur, J., E.E. Koks, and J.W. Hall. 2023. "Systemic Risks from Climate-Related Disruptions at Ports." *Nature Climate Change* 13: 804–806. https://doi.org/10.1038/s41558-023-01754-w

WTO (World Trade Organization). 2024. Stats Portal. https://stats.wto.org/

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF URBANIZATION IN RELATION TO FOOD SYSTEMS?

Paul Dorosh (IFPRI) and James Thurlow (IFPRI)

Key messages

- The world is urbanizing rapidly. The global urban population increased from 2.87 billion in 2000 to 4.38 billion in 2020, a 53 percent rise, and is projected to reach 6.57 billion by 2050, representing 68 percent of the world's population (World Bank 2024a).
- Urbanization is often associated with structural economic transformation, marked by a growing share of nonagriculture sectors (that is, industry and services) in gross domestic product (GDP) and employment, as well as increased productivity and incomes – ideally driven by high-productivity industries.
- Rapid urbanization typically leads to significant growth in market volumes (Reardon and Timmer 2014; Minten et al. 2020). However, this growth can result in declining diet quality due to reduced availability of fruits and vegetables. Additionally, improving sanitation and food safety becomes a major challenge.
- Excessively rapid urbanization can lead to the development of urban slums and increased poverty, and it often coincides with underinvestment in agriculture and the rural economy, exacerbating rural poverty.
- More research is needed, using detailed spatial data to link biophysical and socioeconomic outcomes, to better understand the ongoing urbanization-driven transformation of food systems.

RECENT TRENDS AND CHALLENGES

Although annual global population growth slowed from 2.1 percent in 1970 to 1.2 percent in 2022, the total world population continues to rise, increasing by 27.3 percent between 2000 and 2020, from 6.14 to 7.82 billion. The world's rural population remained nearly constant, increasing by just 0.2 percent over the same timeframe. As a result, by 2020, 56.0 percent of the world's population lived in urban areas, up from 46.6 percent in 2000.

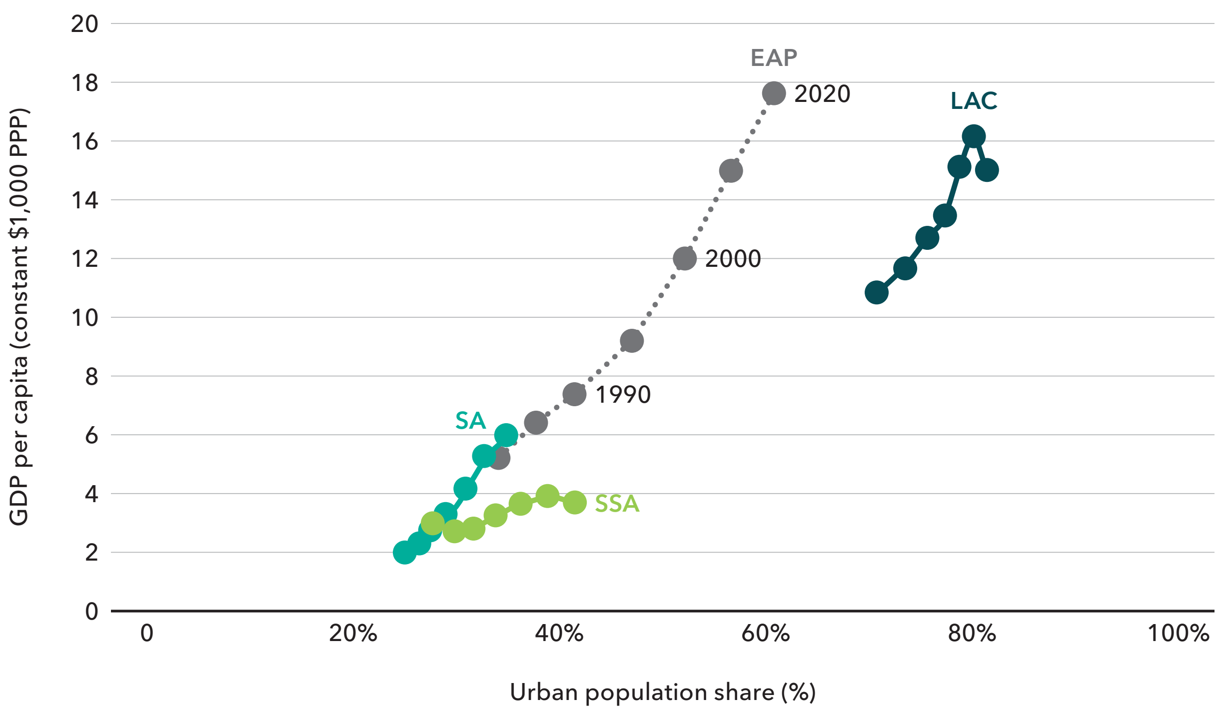
In many countries, increased urbanization has coincided with and contributed to rapid economic growth. This is partly due to structural transformation of the economy, where the share of nonagriculture sectors (that is, industry and services) in GDP and employment rises. Labor productivity in industry and services is typically higher than in agriculture, so shifting resources to these sectors boosts overall productivity and income levels. Moreover, the concentration of economic activity that accompanies urbanization can lead to further productivity gains through positive agglomeration effects due to economies of scale in infrastructure (for example, electricity and water supply), lower transport costs within cities, and improved information flows (Fujita, Krugman, and Venables 1999; Henderson and Wang 2005; World Bank 2009).

Both the urban population share and GDP per capita rose sharply in East Asia and the Pacific (EAP) between 1990 and 2020 (Figure 1). South Asia is on a similar trajectory, with its urban population share and real GDP per capita in 2015 and 2020 projected to be comparable to those of EAP. In Latin America, urban population shares have averaged nearly 30 percentage points higher than those in EAP. However, due to rapid economic growth, EAP now has a higher per capita income. Sub-Saharan Africa, which had urbanization and per capita income levels similar to those in South Asia in 1990, saw urbanization rise sharply from 27 percent to 38 percent, while its per capita GDP increased by only 25 percent.

LATEST FORESIGHT RESEARCH

Reardon and Timmer (2014) describe five interlinked aspects of the agrifood system that "are occurring rapidly

FIGURE 1 **Economic growth and urbanization by region, 2000–2010**



Source: Thurlow et al. (2019) and World Bank (2024b).

in Asia, and are well along in Latin America, and emerging in Africa": urbanization, diet change, agrifood system transformation, rural factor market transformation, and intensification of farm technology. Dietary changes — such as increasing diversity and rising consumption of non-grain foods, processed products, and prepared foods — typically accompany urbanization. As urban markets expand, food supply chains and markets are also transformed as, for example, in the case of teff in Ethiopia (Minten et al. 2016). In the later stages of this transformation, large-scale retail and secondary processing sectors emerge, frequently supported by substantial foreign direct investment. Rural factor markets, especially nonfarm labor markets, develop along with input markets to enable intensification of agricultural production and increases in productivity.

In most of Africa, where urbanization rates remain low, structural transformation has been limited. Investments in infrastructure, such as transport and Internet connectivity, are needed to help small towns expand downstream processing and marketing services. However, excessively rapid urbanization can lead to the growth of urban slums and increased poverty, particularly when underinvestment in agriculture and the rural economy drives rural-to-urban migration at a pace that exceeds investments in the urban infrastructure necessary to support rapid economic growth in the urban economy (Dorosh and Thurlow 2014, 2018).

Diet quality may decline with increased urbanization due to lower availability of fruits and vegetables in urban centers. Improving sanitation and food safety is another major challenge, requiring the development of effective governance mechanisms to implement and enforce regulations and standards to limit the spread of noncommunicable diseases (Resnick and Swinnen 2023).

Several recent studies have used detailed spatial data to analyze the biophysical and socioeconomic outcomes of food systems. Liu and colleagues (2023) examine variations in dietary water footprints (DWF) from household consumption patterns in China, finding that while plant-based foods dominate consumption, animal-based foods have higher DWF and contribute to regional inequalities. De Vos and colleagues (2024) combine spatial projections of urban expansion in Africa with a partial equilibrium economic model to estimate the future increases in rice production, consumption, and agricultural methane emissions. Model simulations by Dizon, Sherwani, and Su (2023) show that Africa will experience the greatest overlap between food-producing areas and urban expansion, particularly under a scenario of significant challenges to climate change adaptation. Using a very different approach, Rusca and colleagues (2022) construct a socioenvironmental scenario of the possible impacts of an unprecedented drought in Maputo, Mozambique, and argue that "future droughts in Southern Africa will probably polarize urban inequalities, generate localized public health crises and regress progress in water access."

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

More research is needed to explore the impacts of evolving market structures that accompany urbanization in most developing countries, particularly in promoting competition and preventing excessive concentration of market power for perishable commodities. Work on policies and investments aimed at improving urban diets and food safety — especially regarding fruits, vegetables, and meat products — could have major positive impacts on nutrition for urban households. Spatial analysis and policies to promote economic growth in small towns are essential for preventing excessive rural-to-urban migration. Finally, potential exists for new uses of artificial intelligence to deepen our understanding of changes in employment, food markets, and consumption patterns linked to ongoing urbanization.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Paul Dorosh**, a Senior Research Fellow in the Foresight and Policy Modeling (FPM) Unit at the International Food Policy Research Institute (IFPRI); and **James Thurlow**, Director of FPM at IFPRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Dorosh, P., and J. Thurlow. 2025. "What Do We Know About the Future of Urbanization in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 14. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Francisco Anzola/Flickr

References

De Vos, K., C. Janssens, L. Jacobs, et al. 2024. "African Food System and Biodiversity Mainly Affected by Urbanization via Dietary Shifts." *Nature Sustainability* 7 (7): 869–878. https://doi.org/10.1038/s41893-024-01362-2

Dizon, F., H. Sherwani, and R. Su. 2023. "Climate Change, Urban Expansion, and Food Production." World Bank Policy Research Working Paper 10411. World Bank, Washington, DC. https://openknowledge.worldbank.org/server/api/core/bitstreams/58752a68-d0c2-4bff-8a59-7fa74f2c02a8/content

Dorosh, P., and J. Thurlow. 2014. "Can Cities or Towns Drive African Development? Economywide Analysis for Ethiopia and Uganda." *World Development* 63: 113–123. http://dx.doi.org/10.1016/j.worlddev.2013.10.014

Dorosh, P., and J. Thurlow. 2018. "Beyond Agriculture Versus Non-Agriculture: Decomposing Sectoral Growth–Poverty Linkages in Five African Countries." *World Development* 109: 440–451. http://dx.doi.org/10.1016/j.worlddev.2016.08.014

Fujita, M., P. Krugman, and A.J. Venables. 1999. *The Spatial Economy Cities, Regions, and International Trade*. Cambridge, MA: MIT Press.

Henderson, J.V., and H.G. Wang. 2005. "Aspects of the Rural-Urban Transformation of Countries." *Journal of Economic Geography* 5: 23–42.

Liu, M., C. Fang, Y. Bai, B. Sun, X. Liao, and Z. Liu. 2023. "Regional Inequality and Urban-Rural Difference of Dietary Water Footprint in China." *Resources, Conservation and Recycling* 199: 107236. https://doi.org/10.1016/j.resconrec.2023.107236

Minten, B., S. Tamru, E. Engida, and T. Kuma. 2016. "Transforming Staple Food Value Chains in Africa: The Case of Teff in Ethiopia." *The Journal of Development Studies* 52 (5): 627–645. https://doi.org/10.1080/00220388.2015.1087509

Minten, B., M. Dereje, F. Bachewe, and S. Tamru. 2020. "Evolving Food Systems." In *The Future of Ethiopian Agriculture: Past Trends, Present Challenges, and Future Scenarios*, eds. P. Dorosh and B. Minten, 121–154. Washington, DC: IFPRI. https://doi.org/10.2499/9780896296916

Reardon, T., and C.P. Timmer. 2014. "Five Inter-Linked Transformations in the Asian Agrifood Economy: Food Security Implications." *Global Food Security* 3 (2): 108–117.

Resnick, D., and J. Swinnen. 2023. *The Political Economy of Food System Transformation: Pathways to Progress in a Polarized World*. Oxford University Press. https://doi.org/10.1093/oso/9780198882121.001.0001

Rusca, M.E.S., G. Di Baldassarre, A. Biza, and G. Messori. 2022. "Unprecedented Droughts are Expected to Exacerbate Urban Inequalities in Southern Africa." *Nature Climate Change* 13: 98–105. https://doi.org/10.1038/s41558-022-01546-8

Thurlow, J., P. Dorosh, and B. Davies. 2019. "Demographic Change, Agriculture and Rural Poverty." In *Sustainable Food and Agriculture: An Integrated Approach*, eds. C. Campanhola and S. Pandey, Chapter 3. London: Elsevier and FAO. https://doi.org/10.1016/B978-0-12-812134-4.00003-0

World Bank. 2009. *World Development Report 2009: Reshaping Economic Geography*. Washington, DC.

World Bank. 2024a. Population Estimates and Projections database. Accessed June 11, 2024. https://databank.worldbank.org/source/population-estimates-and-projections#

World Bank. 2024b. World Development Indicators database. Accessed May 13, 2024. http://databank.worldbank.org

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE IMPACTS OF THE NEXT EL NIÑO ON AGRIFOOD SYSTEMS?

Jawoo Koo (IFPRI) and Weston Anderson (University of Maryland)

This chapter was originally published as an online brief in June 2023; it has been lightly edited and a brief postscript has been added, but otherwise it appears in its original form.

Key messages

- As of June 2023, the U.S. National Oceanic and Atmospheric Administration (NOAA) declared that El Niño conditions were present and consensus existed among climate prediction centers that El Niño would likely persist from November 2023 to February 2024.
- El Niño is typically associated with seasonal climate anomalies and extreme weather events throughout the developing world, especially across sub-Saharan Africa, but the economic impacts caused by these events are difficult to disentangle from those of other climate shocks, natural disasters, and economic cycles. Additionally, the strength and consistency of El Niño's agroclimatic impacts vary by region.
- El Niño's unique slow onset, periodic pattern, and lead times of prediction (from a few months to a year) make it possible to design anticipatory policies and prepare emergency responses in advance.
- Policymakers should closely monitor the evolution of El Niño-Southern Oscillation (ENSO) phases and the potential impacts of El Niño and be prepared to coordinate policy responses quickly as the situation unfolds.
- As global warming continues and climate extremes occur more frequently, actions to foster climate-resilient agrifood systems should be broadly prioritized.

RECENT TRENDS AND CHALLENGES

As of June 2023, consensus existed among the climate science community and prediction centers that the El Niño-Southern Oscillation (ENSO) of the boreal winter season (November 2023–February 2024) would transition to an El Niño event, ending the recent three-year La Niña (FAO 2023). El Niño naturally reoccurs every 2 to 7 years, and its cycle typically lasts 9 to 12 months, starting with a slow onset during the boreal (Northern Hemisphere) spring season (March–June), peak intensity during the late fall or winter (November–February), followed by weakening during the spring or early summer (March–June). Its unique slow onset, periodic pattern, and lead times of prediction (from a few months to a year) make it possible to design anticipatory policies and prepare emergency responses a few months in advance.

Evidence shows El Niño is associated with seasonal climate anomalies and a higher occurrence of extreme weather events throughout the developing world, especially across sub-Saharan Africa, but the economic impacts caused by these events are difficult to disentangle from those of other climate shocks, natural disasters, and economic cycles.

Although an expanding literature examines how natural disasters are managed in the global South, quantitative evaluation of the policies and investments that could help avoid at least some of the damage caused by El Niño events is limited. Many technical and scientific challenges still arise to predicting ENSO with the desired level of confidence due to the complexity of the oceanic and atmospheric processes involved. For example, ENSO forecasts are notoriously difficult to make during the months of February, March, and April — a time often referred to as the "spring predictability barrier" — but become progressively more feasible over the course of May, June, and July for lead times up to the next boreal spring (Barnston et al. 2019). These factors complicate the design of policies and timely response mechanisms that could help mitigate economic damage and welfare losses. Thus, it is important for countries to closely monitor the development of El Niño/La Niña events and be prepared to make nimble adjustments to their risk management measures.

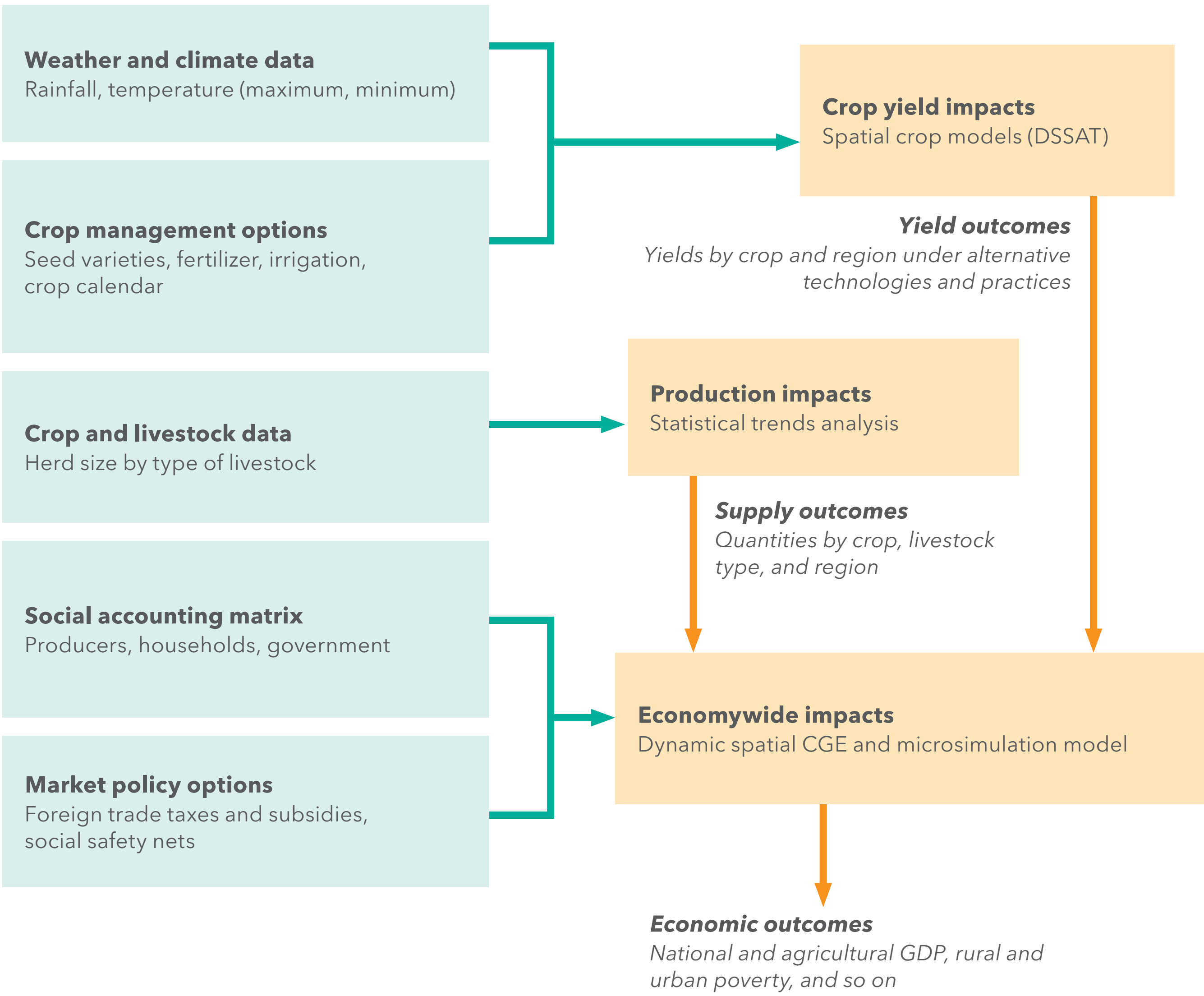
The strength and consistency of El Niño's agroclimatic impacts vary by region. Even when an El Niño develops, the expected impacts are robust and consistent in some regions but difficult to predict in others. This is partly due to the complexity of the El Niño phenomenon and its interaction with other modes of climate variability that influence the agroclimate in any given location, such as the Indian Ocean Dipole (IOD) and its impacts in Asia and Africa. While El Niño events are all associated with substantial warming of the central and eastern part of the tropical Pacific Ocean, which in turn affects climate extremes globally, no two El Niño events are quite the same. For example, the 2015/16 El Niño developed strength similar to the 1997/98 El Niño, but their localized climate impacts were very different (Xue and Kumar 2017). Nevertheless, some regions demonstrate a stronger link to El Niño than others. El Niño consistently brings drought and poor maize yields to South Africa, Zimbabwe, and southern Mozambique, while impacts farther north in Malawi, Zambia, and northern Mozambique are possible but less consistent. Therefore, maintaining high alerts on early warning systems is critical during El Niño events.

LATEST FORESIGHT RESEARCH

At the time of writing, all international climate science agencies — including the World Meteorological Organization (WMO), the International Research Institute for Climate and Society (IRI), and the U.S. National Oceanic and Atmospheric Administration (NOAA) — predicted a very high probability of a moderate-to-strong El Niño event in 2023/24 (WMO 2023; Johnson 2023; IRI 2023). The Agricultural Market Information System (AMIS) estimated that drier than average conditions would be likely in Central America, the Caribbean, northern South America, parts of western and northern East Africa, southern Africa, India, and northern China, while positive IOD conditions during June to October could ease the drying conditions in East Africa during the short rain season in November–December (FAO 2023).

The El Niño forecast did not warrant implementation of domestic market-protective policy measures. Even with the hypothetical worst-case scenario, where a historically strong El Niño affects maize and wheat yields in many regions simultaneously (Anderson et al. 2019, 2023), the total number of catastrophic and simultaneous breadbasket shocks globally in a given year is unlikely

FIGURE 1 **Integrated analytical framework used in the foresight analysis of economywide impacts of ENSO events**



Source: Koo et al. 2019.

to increase because an ENSO event increases the probability of yield shocks in some regions but decreases in others (Anderson et al. 2023). Additionally, preemptively implemented policies with uncertain forecasts can cause unintended economic impacts. For example, an integrated modeling analysis using subnational household data and crop models suggested that the Zambian government's maize export ban during the early-season drought in the 2015/16 El Niño event blocked producers' access to regional food markets, reduced income, and exacerbated rural households' poverty (Koo, Mamun, and Martin 2021).

A series of foresight analyses of economywide impacts of ENSO using an integrated analytical framework (Figure 1) identified a range of effective climate shock-mitigating interventions, including on-farm investments in technology and irrigation infrastructure, investments in roads and grain storage facilities to stabilize food markets, and social transfers to provide households with a cushion against immediate income and asset losses (Sutton et al. 2019a, 2019b, 2019c 2019d, 2019e; Koo et al. 2019). For Ethiopia specifically, IFPRI used the Rural Investment and Policy Analysis (RIAPA) model to analyze El Niño's impacts and the country's policy responses and estimated that the combined interventions of food import subsidies, distribution of stored grains, and cash transfers could effectively reduce El Niño's adverse impacts on the national poverty rate and the number of poor people (Koo et al. 2019).

It is worth noting that great uncertainty remains about how climate change will affect sea surface temperatures, ENSO, and teleconnections between regions. Analysis of historical ENSO events for the past 11,700 years indicates that any recorded changes in El Niño patterns are well within the range of natural variability. Similarly, climate model simulations without greenhouse gas emissions still produce large variations in ENSO due to the nature of the climate system (Di Liberto 2021).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Enhanced weather and climate forecasting skills will allow early detection and timely warning of floods and droughts. A well-maintained network of automated weather stations can improve the accuracy of El Niño impacts at the local level. Between 2000 and 2017, for example, advances in flood early-warning systems were estimated to have helped to reduce global flood-related human casualties by 45 percent and the number of people affected by floods by 24 percent (Perera et al. 2019). Conservative estimates based on a meta-analysis of global studies suggest that the benefit-cost ratio for reliable climate information services is about 10 to 1, with potential global benefits as high as US$30 billion per year in increased agricultural productivity and US$2 billion per year in reduced asset losses (WMO 2019). With timely and reliable early warning information, policymakers can prepare for disasters and reduce damage by declaring emergencies early and getting resources where they are likely to be needed in advance.

Recognizing both the strengths and the uncertainties in current ENSO forecasts, policymakers should closely monitor the development of El Niño impacts and be prepared to coordinate policy responses in an agile way as the situation unfolds. In the Philippines, for example, in preparation for the 2015/16 El Niño, the Roadmap to Address the Impact of El Niño (RAIN) initiative was launched as a pan-government strategic action plan. The RAIN initiative enabled multiple government agencies to coordinate and respond to the challenges associated with climate variability on food security, energy security, health, and safety. In 2016, the government of the Philippines found that RAIN was successful in mitigating the impact of El Niño, particularly in ensuring sufficiency in supply of food and keeping food prices stable, but that coordination with local government units should be strengthened to ensure that the distribution of food and other resources is timely (Philippines, NEDA 2016).

It is essential for governments, particularly in drought- and flood-prone regions, to proactively implement a range of risk-mitigating measures as the probability of future El Niño events increases. Promoting climate-resilient agrifood systems, strengthening climate forecast and early warning capacities, and implementing agile risk management policies are critical to mitigating the adverse effects of climate variability. By fostering collaboration among various institutions and actors, policymakers can plan to develop "no-regret" interventions — including climate information services, climate-smart agriculture practices, access to finance, and social safety nets — and implement country-specific comprehensive strategies that safeguard communities from the likely impacts of El Niño. Recognizing the inherent uncertainties in ENSO forecasts, governments should closely monitor the development of El Niño impacts and be prepared to adapt their policies and response mechanisms as the situation evolves. Investing in these anticipatory policies and emergency responses will not only help minimize the economic damage and welfare losses during El Niño events but also contribute to building more climate-resilient agrifood systems in the long run.

POSTSCRIPT

As a result of the strong El Niño event that did indeed develop, southern Africa experienced a record-breaking drought in January and February 2024 that caused widespread crop failures, including reductions in maize production exceeding 50 percent in Zimbabwe, 30 percent in Zambia and Malawi, and 10 percent in South Africa (FEWS NET 2024).

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Jawoo Koo**, a Senior Research Fellow in the Natural Resources and Resilience Unit at the International Food Policy Research Institute (IFPRI); and **Weston Anderson**, an Assistant Research Professor in the Department of Geographical Sciences at the University of Maryland, and formerly an Assistant Research Scientist in the Earth System Science Interdisciplinary Center at the University of Maryland and the Earth Sciences Division at NASA.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Koo, J., and W. Anderson. 2025. "What Do We Know About the Impacts of the Next El Niño on Agrifood Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 15. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: EU/ECHO/Anouk Delafortrie

References

Anderson, W., W. Baethgen, F. Capitanio, et al. 2023. "Climate Variability and Simultaneous Breadbasket Yield Shocks as Observed in Long-Term Yield Records." *Agricultural and Forest Meteorology* 331: 109321. https://doi.org/10.1016/j.agrformet.2023.109321

Anderson, W.B., R. Seager, W. Baethgen, M. Cane, and L. You. 2019. "Synchronous Crop Failures and Climate-Forced Production Variability." *Science Advances* 5: eaaw1976. https://doi.org/10.1126/sciadv.aaw1976

Barnston, A.G., M.K. Tippett, M. Ranganathan, and M.L. L'Heureux. 2019. "Deterministic Skill of ENSO Predictions from the North American Multimodel Ensemble." *Climate Dynamics* 53: 7215–7234. https://link.springer.com/article/10.1007/s00382-017-3603-3

Di Liberto, T. 2021. "ENSO and Climate Change: What Does the New IPCC Report Say?" *Climate.gov Blog*, September 27. http://www.climate.gov/news-features/blogs/enso/enso-and-climate-change-what-does-new-ipcc-report-say

FAO (Food and Agriculture Organization of the United Nations). 2023. *AMIS Market Monitor – June 2023.* Rome: AMIS Secretariat. www.amis-outlook.org/market-monitor

IRI (International Research Institute for Climate and Society). 2023. "May 2023 Quick Look." Columbia Climate School International Research Institute for Climate and Society. May 19. https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/

Johnson, N. 2023. "ENSO Update: El Niño Knocking on the Door." *Climate.gov Blog*, May 11. http://www.climate.gov/news-features/blogs/may-2023-enso-update-el-ni%C3%B1o-knocking-door

Koo, J., A. Mamun, and W. Martin. 2021. "From Bad to Worse: Poverty Impacts of Food Availability Responses to Weather Shocks." *Agricultural Economics* 52: 833–847. https://doi.org/10.1111/agec.12657

Koo, J., J. Thurlow, H. Eldidi, C. Ringler, and A. De Pinto. 2019. *Building Resilience to Climate Shocks in Ethiopia*. Washington, DC: IFPRI. https://doi.org/10.2499/9780896293595

Perera, D., O. Seldou, J. Agnihotri, et al. 2019. *Flood Early Warning Systems: A Review Of Benefits, Challenges And Prospects*. UNU-INWEH Report Series. Japan: United Nations University. https://inweh.unu.edu/flood-early-warning-systems-a-review-of-benefits-challenges-and-prospects/

Philippines, NEDA (National Economic and Development Authority). 2016. "Statement of Socioeconomic Planning Secretary Emmanuel F. Esguerra on the Status of the Roadmap to Address the Impact of El Niño (RAIN)." Republic of the Philippines Department of Economy, Planning, and Development. April 5. https://neda.gov.ph/statement-of-socioeconomic-planning-secretary-emmanuel-f-esguerra-on-the-status-of-the-roadmap-to-address-the-impact-of-el-nino-rain/

Sutton, W.R., J.P. Srivastava, J. Koo, I. Vasileiou, and A. Pradesha. 2019a. *Striking a Balance: Managing El Niño and La Niña in Cambodia's Agriculture*. Washington, DC: World Bank. https://hdl.handle.net/10986/31524

Sutton, W.R., J.P. Srivastava, M.W. Rosegrant, J. Koo, and R. Robertson. 2019b. *Striking a Balance: Managing El Niño and La Niña in Lao PDR's Agriculture*. Washington, DC: World Bank. https://hdl.handle.net/10986/31524

Sutton, W.R., J.P. Srivastava, M.W. Rosegrant, J. Thurlow, and I. Vasileiou. 2019c. *Striking a Balance: Managing El Niño and La Niña in Myanmar's Agriculture*. Washington, DC: World Bank. https://hdl.handle.net/10986/31523

Sutton, W.R., J.P. Srivastava, M.W. Rosegrant, R. Valmonte-Santos, and M.S. Ashwill. 2019d. *Striking a Balance: Managing El Niño and La Niña in Philippines' Agriculture*. Washington, DC: World Bank. https://hdl.handle.net/10986/31521

Sutton, W.R., J.P. Srivastava, M.W. Rosegrant, J. Thurlow, and L. Sebastian. 2019e. *Striking a Balance: Managing El Niño and La Niña in Vietnam's Agriculture*. Washington, DC: World Bank. http://hdl.handle.net/10986/31524

WMO (World Meteorological Organization). 2023. "WMO Update: Prepare for El Niño." https://public.wmo.int/en/media/press-release/wmo-update-prepare-el-ni%C3%B1o

WMO. 2019. *2019 State of Climate Services*. Geneva. https://library.wmo.int/idurl/4/56884

Xue, Y., and A. Kumar. 2017. "Evolution of the 2015/16 El Niño and Historical Perspective since 1979." *Science China Earth Sciences* 60: 1572–1588.

For more information, please see:

Abate, T., M. Fisher, T. Abdoulaye, et al. 2017. "Characteristics of Maize Cultivars in Africa: How Modern are They and How Many Do Smallholder Farmers Grow?" *Agriculture & Food Security* 6: 30. https://doi.org/10.1186/s40066-017-0108-6

Bist, D.R., P. Kumar, and V.C. Mathur. 2012. "Progress and Performance of Kisan Credit Card Scheme with a Case Study of Bihar." *Agricultural Economics Research Review* 25 (1): 125–135. http://doi.org/10.22004/AG.ECON.126050

Gebre, G.G., H. Mawia, D. Makumbi, and D.B. Rahut. 2021. "The Impact of Adopting Stress-Tolerant Maize on Maize Yield, Maize Income, and Food Security in Tanzania." *Food and Energy Security* 10: e313. https://doi.org/10.1002/fes3.313

Knippenberg, E., and J. Hoddinott. 2017. "Shocks, Social Protection, and Resilience: Evidence from Ethiopia." Strategy Support Program Working Paper 109. IFPRI, Washington, DC. https://hdl.handle.net/10568/148272

Kumar, A., V.K. Sonkar, and A.K. S. 2021. "Assessing the Impact of Lending through Kisan Credit Cards in Rural India: Evidence from Eastern India." IFPRI Discussion Paper 1997. IFPRI, Washington, DC. https://hdl.handle.net/10568/143408

Radeny, M., E.J.O. Rao, M.J. Ogada, J.W. Recha, and D. Solomon. 2022. "Impacts of Climate-Smart Crop Varieties and Livestock Breeds on the Food Security of Smallholder Farmers in Kenya." *Food Security.* 14: 1511–1535. https://doi.org/10.1007/s12571-022-01307-7

Setimela, P.S., C. Magorokosho, R. Lunduka, et al. 2017. "On-Farm Yield Gains with Stress-Tolerant Maize in Eastern and Southern Africa." *Agronomy Journal* 109: 406–417. https://doi.org/10.2134/agronj2015.0540

Shee, A., C.G. Turvey, and L. You. 2019. "Design and Rating of Risk-Contingent Credit for Balancing Business and Financial Risks for Kenyan Farmers." *Applied Economics* 51: 5447–5465. https://doi.org/10.1080/00036846.2019.1613502

Simtowe, F., E. Amondo, P. Marenya, D. Rahut, K. Sonder, and O. Erenstein. 2019. "Impacts of Drought-Tolerant Maize Varieties on Productivity, Risk, and Resource Use: Evidence from Uganda." *Land Use Policy* 88: 104091. https://doi.org/10.1016/j.landusepol.2019.104091

Tesfaye, K., L.T. Desta, T. Demissie, J. Seid, A. Haile, K. Mekonnen, and D. Solomon. 2021. *A Framework for Bundling Climate-Smart Agriculture (CSA) and Climate Information Services (CIS) in Ethiopia*. AICCRA Technical Report. Addis Ababa, Ethiopia: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://hdl.handle.net/10568/117472

World Bank. 2017. "Moving Away from Humanitarian Appeals to Managing Droughts in Ethiopia." *World Bank News*, May 2. https://www.worldbank.org/en/news/feature/2017/05/02/moving-away-from-humanitarian-appeals-to-managing-droughts-in-ethiopia

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FOOD ASSISTANCE?

Steven Were Omamo (IFPRI)

Key messages

- Food assistance has evolved to address both immediate needs and long-term resilience, reflecting the broader scope of interventions beyond traditional food aid.
- Localized and cash-based assistance is growing in importance, but externally sourced, in-kind assistance remains crucial in areas where markets and food systems are disrupted and thus unable to ensure timely and stable access to nutritious food.
- Future food assistance needs will increasingly reflect changing geographies, growing urban food insecurity, and heightened market volatility, requiring adaptive, anticipatory, and multilayered strategies.
- Significant gaps remain in understanding how to sustainably transition from international food assistance to locally driven, resilient food systems that address long-term nutritional adequacy and adapt to compounding crises.
- Foresight research can help highlight the intersection of climate change, conflict, and economic volatility as key drivers of future food assistance needs, and the nature of innovations to boost efficiency and impact.
- Expanded use of digital tools and integration of food assistance into social protection systems offer promising pathways toward enhanced efficiency and impact. Further research is needed to ensure that innovations reach the most vulnerable in low-resource settings and that integrated systems are sustainable.

RECENT TRENDS AND CHALLENGES

Food assistance plays a pivotal role in addressing hunger and food insecurity worldwide. In the past, this term primarily referred to emergency food aid, but today's food assistance encompasses a much broader array of interventions — from direct food provision to cash transfers, vouchers, nutrition programs, and livelihood support. This shift defines recent trends and challenges in food assistance and underpins progress and gaps in foresight research.

The demand for food assistance is surging globally, fueled by food insecurity generated by disruption and displacement linked to conflict, climate change, and economic instability. Today's food crises are increasingly multifaceted, with overlapping drivers of vulnerability. The Horn of Africa, the Sahel, Central Africa, Yemen, and Syria are notable examples of regions and countries facing intertwined challenges. The COVID-19 pandemic exposed and magnified vulnerabilities in many food systems, significantly expanding food assistance needs. Extreme weather events and longer-term shifts in weather patterns are disrupting agricultural production and food supply chains, leading to food price volatility, increased vulnerability among farming communities, and a heightened demand for external assistance. Food assistance programs must adapt to the reality of these environmental pressures while supporting the long-term resilience of affected communities (FAO et al. 2024; WFP 2017).

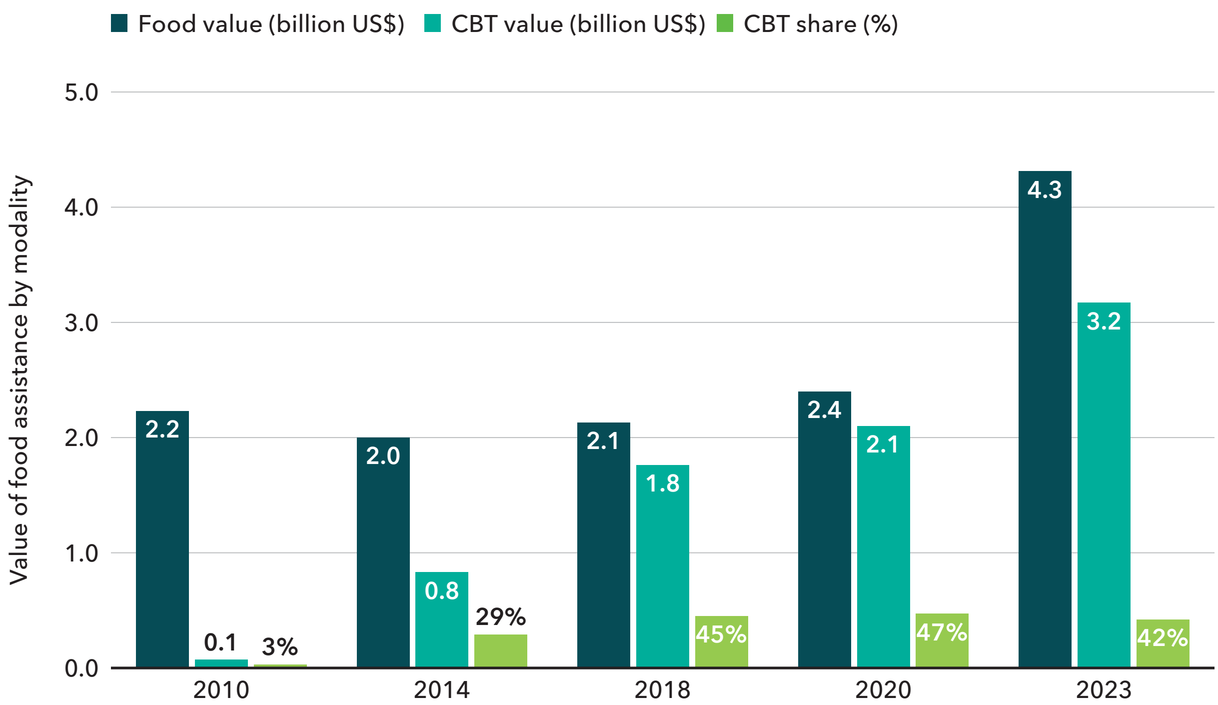
Market disruptions caused by conflict, inflation, and global supply chain instability are complicating food assistance delivery. These disruptions often reduce the availability of nutrient-dense foods and undermine the effectiveness of cash-based transfers. For example, global crises such as the Russia-Ukraine war and economic instability in fragile states have exacerbated food price inflation, limiting the purchasing power of cash assistance. In urban contexts, where climate-driven migration is intensifying, food insecurity is growing in informal settlements, requiring tailored approaches to address access and affordability challenges in densely populated areas (WFP and FAO 2024).

As demand for food assistance has grown, so too has the need to address both the quantity and the nutritional quality of food provided to vulnerable populations. Many regions affected by complex crises face high rates of malnutrition, particularly among children and pregnant women. Programs that integrate nutrition-sensitive approaches — such as food fortification or the inclusion of diverse, nutrient-rich foods like fruits, vegetables, and proteins — are widely acknowledged to be essential for reducing the long-term effects of malnutrition.

In-kind distribution of externally sourced food is still essential in many contexts, but a marked shift toward more flexible forms of assistance has taken place. Cash-based transfers, vouchers, and in-kind support based on local food procurement form a significant part of food assistance efforts (Figure 1). These approaches allow recipients to make their own food choices and often support local markets, fostering greater autonomy and dignity for beneficiaries. Food assistance operations are increasingly integrated with social protection systems, aiming to protect assets and boost resilience. But the greater diversity of tools comes with new challenges. Cash-based assistance can provide beneficiaries with more choices and potentially improve their nutritional intake, but it also depends heavily on the availability of nutrient-dense foods in local markets. If markets lack diversity or are disrupted by conflict or climate impacts, recipients may not be able to access a balanced diet, even with cash transfers. In many contexts, the value of cash-based transfers is being eroded by rampant food price inflation. In regions where markets are disrupted, or food is not readily available, in-kind support remains critical.

The increasing adoption of digital tools in food assistance operations has transformed how organizations monitor and respond to food insecurity. The UN World Food Programme (WFP) is a leading developer and implementer of digital solutions, aiming to improve efficiency, targeting, and transparency. Tools like the Mobile Vulnerability Analysis and Mapping (mVAM) and AI-based platforms such as HungerMap LIVE provide real-time insights on food consumption patterns, market prices, and food security risks, allowing for timelier, data-driven interventions. SCOPE, the cloud-based digital beneficiary and transfer management platform, integrates biometric data and is used to track and manage distributions, ensuring that food and cash reach intended beneficiaries securely. The Building Blocks platform allows for cash transfers to be delivered securely using blockchain, ensuring transparency, reducing fraud, and lowering transaction costs. The Vulnerability Analysis and Mapping Platform for the Impact of Regional Events (VAMPIRE)

FIGURE 1 Evolution of World Food Programme in-kind and cash-based transfers, 2010–2023



Source: World Food Programme Annual Performance Reports. https://www.wfp.org/publications/annual-performance-report

Note: CBT = cash-based transfers.

is used for real-time analysis of vulnerability and food security, primarily focusing on the impacts of regional or localized events such as droughts or political instability. In disaster-prone or conflict-affected regions, drones provide real-time data on infrastructure, flood damage, and affected populations. However, a major challenge remains in scaling these tools to low-resource settings where Internet and mobile connectivity may be unreliable, and digital literacy levels vary significantly (WFP 2024a, 2024b).

The funding landscape for food assistance has become increasingly strained. Donors face competing priorities, particularly in the context of post-COVID-19 domestic economic recovery and growing conflict-driven demands on humanitarian resources. This challenge raises questions about the sustainability of food assistance efforts and the need to diversify and expand funding sources. The rising cost of providing food assistance in increasingly numerous conflict zones is straining available resources. Nutrient-rich foods – such as fortified products, fresh produce, and animal-based proteins – are expensive but essential for addressing malnutrition. Ensuring sufficient funding to include these options in food assistance programs is increasingly challenging but critical, especially for vulnerable groups like children and pregnant women.

Given these trends and challenges, future food assistance will need to respond to three critical dynamics: (1) need for *long-term resilience* – as climate variability and natural disasters push more people into food insecurity, assistance programs will need to integrate resilience-building approaches, such as predisaster cash transfers, drought-resistant crops, and climate-adaptive livelihood support; (2) *market volatility*– as conflicts and global supply chain disruptions necessitate flexible food assistance models that combine cash-based and in-kind transfers, predictive tools and anticipatory planning will become critical for responding to fluctuating market conditions; and (3) *complex crises*– the convergence of climate change, conflict, and economic volatility will expand food insecurity more firmly into urban areas and require multilayered responses that integrate food assistance with social protection systems. In most contexts, greater reliance on anticipatory action and adaptive assistance models will be needed to address rapid changes in food prices, market access, and population displacement.

LATEST FORESIGHT RESEARCH

WFP has led several forward-looking initiatives to map future trends in hunger and food insecurity. These studies — many conducted in partnership with the Food and Agriculture Organization of the United Nations (FAO) — have emphasized the connections between climate risks, migration, and conflict as key drivers of food crises. WFP's research also advocates for a more comprehensive approach that combines immediate response with resilience building, recognizing that emergency assistance alone will not solve long-term hunger. WFP's foresight research increasingly focuses on nutrition-sensitive food assistance, advocating for fortified foods and diverse food baskets to improve nutritional outcomes.

The annual *Global Report on Food Crises* (GRFC) produced by a consortium of UN agencies and nongovernmental organizations provides a comprehensive global-, regional-, and country-level view of current and anticipated food crises linked to conflicts, economic shocks, and weather extremes. Aiming to guide operational and strategic planning, projections are both short-term (weeks to months) and medium-term (up to one year). Serving as the reference document for a comprehensive analysis of global-, regional-, and country-level acute food insecurity, the GRFC combines forward-looking analytics with field data to highlight emerging hunger hotspots and forecast future needs, making it a critical tool for policy and planning in food assistance (FSIN and GNAFC 2024).

Projections by the International Food Policy Research Institute (IFPRI) focus on how food systems will be impacted by global changes in climate, population, and economic conditions. Looking ahead from months to decades, IFPRI's analyses emphasize the integration of food assistance into broader development strategies, especially in fragile contexts where climate change and conflict intersect. Research indicates that climate change poses unprecedented challenges to food systems, threatening agricultural production and the biodiversity that underpins agriculture. IFPRI also highlights the complex relationship between conflict and food insecurity, noting that conflict disrupts food systems and exacerbates malnutrition. To address these challenges, IFPRI research stresses the importance of integrating food assistance into broader development strategies, particularly in fragile contexts where climate and conflict overlap. Studies highlight the nutritional risks posed by climate change, conflict, and economic instability. Future food assistance strategies must go beyond caloric intake to ensure that diets are nutritionally adequate. This involves not only immediate food aid but also investments in local food systems that can provide diverse, nutrient-rich foods in the long term (IFPRI 2023, 2024; Vos 2020).

Several research institutions within the global Cash Learning Partnership (CALP) Network are exploring how the potential of cash-based assistance can be maximized in humanitarian contexts and better aligned with local economies and resilience-building strategies. This research emphasizes the need for more localized approaches to food assistance, which could help reduce dependence on international aid and foster more sustainable, community-driven solutions (CALP Network 2024; WFP 2023).

A large body of foresight research both emphasizes and illustrates the growing role of digital innovations in transforming food assistance delivery and monitoring. Tools such as blockchain and machine learning are being integrated into food systems to improve traceability, transparency, and efficiency. For example, WFP's Building Blocks project highlights how blockchain technology can reduce transaction costs, prevent fraud, and provide real-time data for better decision-making. Machine learning has been used to forecast food security indicators such as the Food Consumption Score, the Household Dietary Diversity Score, and the reduced Coping Strategy Index, and to forecast the future behavior of the food security classifications in the Food Security Integrated Phase Classification (IPC) phases. Future research anticipates increased reliance on these tools, particularly in humanitarian contexts where the timeliness and transparency of food assistance are paramount (Herteux et al. 2024; Lentz et al. 2019).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Alongside the strong focus on resilience of much foresight research, deeper exploration is needed of how local food systems can be strengthened to operate independently of external food assistance. Understanding the role of national governments, the private sector, and civil society in creating robust safety nets and food systems will be key to reducing reliance on international assistance. A key gap in foresight research is how to strengthen local food systems to ensure the nutritional adequacy of food assistance. More research is needed on how local agricultural production, processing, and distribution can be enhanced to ensure a steady supply of nutrient-rich foods. Addressing this gap is critical for reducing long-term dependence on external aid and improving the overall health of communities. Also critical is increased understanding of how urban food insecurity can be addressed effectively, particularly in informal settlements, and how to adapt cash-based programs to contexts with high inflation or limited food availability.

Foresight research must deepen and expand examinations of the potential of emerging technologies such as blockchain, artificial intelligence, and digital financial tools in food assistance delivery systems. These rapidly evolving innovations have the potential to make food assistance more efficient, transparent, and responsive to the needs of recipients. They could also enhance the nutritional value of food assistance, helping to track the nutritional content of food baskets and making delivery systems more responsive to real-time needs.

While cash-based assistance gives beneficiaries the freedom to purchase food, it does not always guarantee access to nutritious options, particularly in areas where fresh and diverse foods are not readily available. Future research should focus on the long-term nutritional impacts of cash transfers and how they can be better designed to support balanced diets.

As food assistance becomes more integrated with broader social protection frameworks, more research on how these systems interact is essential. At issue is how food assistance programs can be designed to better align with national social protection systems, thereby strengthening the social safety nets of vulnerable populations. Integrating food assistance with social protection systems offers an opportunity to embed nutrition-sensitive programming within a broader development agenda. By aligning these two systems, governments and organizations can ensure that vulnerable populations have consistent access to nutritious food, not only during crises but as part of ongoing social safety nets.

While digital tools like mVAM and blockchain have shown promise, questions remain about the applicability of digital innovations in low-resource settings with poor infrastructure. How digital literacy and access to technology influence the effectiveness of these tools is poorly understood, particularly in rural areas where mobile connectivity is often lacking. More research is also needed on how digital tools can integrate with local food systems to strengthen resilience during crises.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The author of this chapter is **Steven Were Omamo**, Director of the Development Strategies and Governance Unit and Director for Africa at the International Food Policy Research Institute (IFPRI).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Omamo, S.W. 2025. "What Do We Know About the Future of Food Assistance?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 16. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

References

CALP Network. 2024. https://www.calpnetwork.org/

FAO (Food and Agriculture Organization), IFAD (International Fund for Agricultural Development), UNICEF, WFP (World Food Programme), and WHO (World Health Organization). 2024. *The State of Food Security and Nutrition in the World 2024: Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms*. Rome. https://doi.org/10.4060/cd1254en

FSIN (Food Security Information Network) and GNAFC (Global Network Against Food Crises). 2024. *Global Report on Food Crises 2024*. Rome. https://www.fsinplatform.org/report/global-report-food-crises-2024/

Herteux, J., C. Raeth, G. Martini, et al. 2024. "Forecasting Trends in Food Security with Real Time Data." *Communications Earth and Environment*5: 611. https://doi.org/10.1038/s43247-024-01698-9

IFPRI (International Food Policy Research Institute). 2023. *IFPRI Research and Engagement: Climate Change and Agrifood Systems*. Washington, DC. https://doi.org/10.2499/p15738coll2.136977

IFPRI. 2024. *2024 Global Food Policy Report: Food Systems for Healthy Diets and Nutrition*. Washington, DC. https://hdl.handle.net/10568/141760

Lentz, E.C., H. Michelson, K. Baylis, and Y. Zhou. 2019. "A Data-Driven Approach Improves Food Insecurity Crisis Prediction." *World Development* 122: 399–409. https://doi.org/10.1016/j.worlddev.2019.06.008

Vos, R. 2020. "Integrating Displaced Communities into Food Systems." *IFPRI Blog*, May 1. https://www.ifpri.org/blog/integrating-displaced-communities-food-systems/

WFP (World Food Programme). 2017. *At the Root of Exodus: Food Security, Conflict and International Migration*. Rome. https://www.wfp.org/publications/2017-root-exodus-food-security-conflict-and-international-migration

WFP. 2023. "Cash-Based Transfers Empower People while Building Resilience." Changing Lives series. Rome. https://www.wfp.org/publications/changing-lives-cash-based-transfers

WFP. 2024a. Hunger Map LIVE. https://hungermap.wfp.org/

WFP. 2024b. *Afghanistan mVAM Household Food Security Survey* 2nd quarter July 2024. Rome. https://www.wfp.org/publications/afghanistan-mvam-household-food-security-survey

WFP and FAO. 2024. *Hunger Hotspots. FAO–WFP Early Warnings on Acute Food Insecurity: June to October 2024 Outlook*. Rome. https://doi.org/10.4060/cd0979en

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about
THE FUTURE OF FOOD SYSTEMS IN SELECTED REGIONS?

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS IN WEST AND CENTRAL AFRICA?

Dolapo Enahoro (ILRI), Charles Mensah (University of Ghana), and Sika Gbegbelegbe (IITA)

Key messages

- Food systems in West and Central Africa (WCA) are challenged by slow growth in productivity and incomes and by climate change.
- Urbanization and related trends are creating new opportunities for the region's agricultural value chains to meet nutrition and employment needs, including those of women and young people.
- Climate change poses a significant threat to future agricultural production in the region, and dependence on food imports is mostly projected to increase.
- Foresight studies that account for the future can help guide the transformation of food, land, and water systems in WCA in response to climate change. However, new analyses are needed to address the multidimensional nature of the region's challenges.

RECENT TRENDS AND CHALLENGES

Countries in West and Central Africa (WCA) are facing immense pressure to meet the growing food, nutrition, employment, and other needs of their increasing urban populations (OECD, UNECA, and AfDB 2022). The region's vulnerability to climate change and low adaptive capacities due to socioeconomic and physical characteristics make it hard to respond effectively to these challenges (Fuller et al. 2018; Partey et al. 2018).

In the last 10 years, WCA's total population increased by 29 percent, compared to a 10 percent increase in the world's population, while WCA's urban population increased by 45 percent, versus 19 percent globally (FAO 2022a). The strong growth in urbanization (along with population growth) has been driving higher demand in the region for cereals, animal-source foods, and other food types associated with more urbanized diets (EUC 2019; Kruseman et al. 2020; Latino, Pica-Ciamarra, and Wisser 2020).

The demographic changes have occurred alongside poor economic performance across the region, characterized by slow economic growth, low incomes, and high rates of unemployment and underemployment, particularly in rural areas (AfDB 2019, 2020; Musibau, Shittu, and Yanotti 2022). An estimated 90 million of the region's 600-plus million people live in poverty (CGIAR 2022). Although progress has been made in the past two decades, hunger and malnutrition are still high in the region and have been exacerbated in the last few years by effects of the COVID-19 pandemic and the war in Ukraine (Chadare et al. 2022; FAO 2022b; Udmale et al. 2020).

Low agricultural productivity, weak local markets for agricultural and food products, and negative effects of global climate change on the natural resource base constitute major threats to the future of food security and livelihoods in WCA (CGIAR 2022). A combination of high temperatures that are above global averages, extreme climate events, civil conflicts, food insecurity, and economic hardship may have already contributed to the displacement of an estimated 17 million people in the region over the last two decades (Padgham, Jabbour, and Dietrich 2015; Filho, Olaniyan, and Alverio 2022; WFP 2017).

LATEST FORESIGHT RESEARCH

Given the myriad interacting demographic, sociocultural, political, infrastructural, technological, and environmental challenges that WCA faces, it will be important for decision-makers to better understand the transformation trends of the region's food, land, and water systems, and how these trends and their impacts are likely to evolve in the coming decades.

Climate change may be the most important long-term driver in the context of which other trends (such as migration and urbanization) and interventions (including policies and investments) will need to be addressed (OECD, UNECA, and AfDB 2022; CGIAR 2022). This chapter highlights some of the key studies relevant to the discourse. These studies analyzed the potential effects of climate change on agricultural land and production in WCA (Akpoti et al. 2022; Ugbaje, Odeh, and Bishop 2019; Manners et al. 2021; Zabel, Putzenlechner, and Mauser 2014); the impacts of income and population growth on food security (Jalloh et al. 2013); and linkages of future land use to food security in the region under alternative scenarios, including climate change (de Lattre-Gasquet, Moreau, and Okul 2018).

Akpoti et al. (2022) used a spatially explicit modeling approach and an ensemble of spatially downscaled and bias-corrected climate data to project changes in areas suitable for rice production in West Africa, compared to the baseline, for four time periods between 2030 and 2080. The projected changes, which result from variations in temperature and precipitation brought about by climate change, are on the order of 22–33 percent losses in rice area under the lowest reduction scenarios and more than 50 percent in the extreme case. The study suggested that strong adaptation measures along with technological advancement and adoption will be needed to address these adverse effects.

Ugbaje, Odeh, and Bishop (2019) similarly showed for maize that, relative to the current situation where more than 90 percent of West Africa is at least moderately suitable for production, agricultural suitability will decline in at least 43 percent of that region under future climate change, mostly due to changes in temperature. Under the worst-case scenario simulated in that study, only about 15 percent of the West African region remains suitable for maize production by 2080. A similar study analyzing crop suitability in Central Africa indicated that climate change will be somewhat favorable to root-, tuber-, and banana-based systems under specified agronomic practices, with widespread negative impacts seen only for potato production (Manners et al. 2021). This result supports projections from an earlier global study showing that the importance of root, tuber, and banana crops for food security will likely increase in the world's poorest regions (Petsakos et al. 2019). For West Africa, it is likely that land suitability for agriculture would worsen in the northern part and should improve somewhat in the southern part of the region by 2071–2100, with a similar trend also likely for Central Africa (Zabel, Putzenlechner, and Mauser 2014).

These studies generally agree that climate change will affect agricultural productivity and total food production, which have implications for poverty, food security, and nutrition. An earlier study showed that malnutrition could increase across the region under persisting conditions of low incomes and high population growth (Jalloh et al. 2013). Further, Rigaud et al. (2021) estimated that due to climate change, West Africa alone could ultimately see the internal displacement of as many as 32 million people by 2050. A different study linking changes in agricultural land and production to food importation and food self-sufficiency further buttresses projections of food security impacts of climate change in WCA. Using an analytical framework that combined quantitative and qualitative approaches, de Lattre-Gasquet, Moreau, and Okul (2018) showed that even where arable and permanent crop areas as well as pastures and meadows increase in WCA, overall food and animal feed production is likely to be insufficient, and food and animal feed import dependence is likely to increase. The exception in that study was a regionalization scenario in which West African states have joined to form regionally governed blocs. In this scenario, import demand was projected to decline, particularly for animal products. These results derived from the study's accounting for future scenarios of urbanization and rural transformation, dietary changes, and climate change and sustainability, among others.

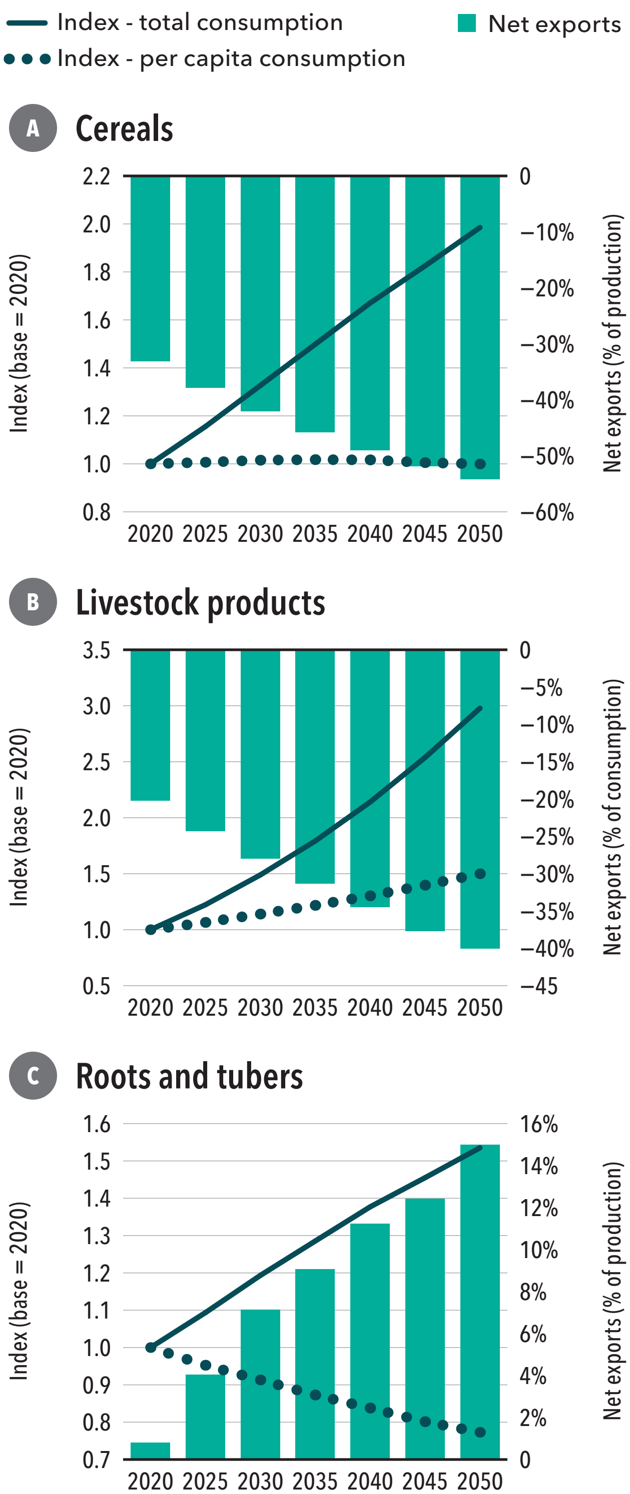
The studies raise questions about what governments, civil society, and other decision-makers in the region may need to do to position their countries to meet future food security challenges. They also highlight the relevance to national planning (including on land use) of accounting for multiple scenarios of future change.

Recent results from an updated version of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT, Version 3.4) show that the region could become more dependent on imports to meet its food consumption requirements by 2050 (Figure 1). The IMPACT results are based on a business-as-usual (BAU) scenario that involves (1) middle-of-the-road changes in socioeconomic trends; and (2) climate change, represented through the Representative Concentration Pathway 7 (RCP 7) and the IPSL-CM5A-LR Earth System Model (IFPRI 2024). For cereals, net imports could increase to reach about 50 percent of cereal consumption requirements by 2045 under the BAU scenario (Figure 1a). However, per capita consumption would remain relatively constant over the years. It is likely that climate change could reduce yields, possibly reducing per capita consumption and food security. These projections also imply rising net imports of livestock products, which could reach about 40 percent of consumption by 2050 (Figure 1b). Per capita consumption is also projected to increase over time, due in part to rising incomes and changing diets. The region is projected to become a net exporter of roots and tubers over the projection period (Figure 1c). These rising net exports for roots and tubers would be associated with a reduction in per capita consumption within the region. Such a trend implies that the region will need to increase domestic production to meet the demand for both domestic and export markets. Multiple scenarios indicate that it is likely that per capita consumption of key staple foods in WCA could decrease significantly under climate change, with negative implications for food and nutrition security in the region.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Foresight studies for WCA generally agree that climate change will have significant impacts on agricultural and food systems in the region, from crop suitability and agricultural productivity to food and animal feed production, food import dependence, and migration. These impacts can be small or large and negative or positive for the different crop, livestock, and food systems and/or geographies. Indications are that emerging demographic and socioeconomic trends will interact with biophysical changes to generate increased challenges to the future

FIGURE 1 Projected trends for consumption and net exports for (a) cereals, (b) livestock products, and (c) roots and tubers: West and Central Africa



Source: Authors, using data from IFPRI (2024).

food security of WCA. However, these interactions have often not been explicitly or fully analyzed. It is not obvious what the impacts (for example, on nutrition, food security, and employment) will be under climate change of ongoing trends related to urbanization or dietary change, or how the important trade-offs that emerge between these impacts should be managed. While indications of increased food dependence exist in the region, there are very few quantitative regionwide simulations to show whether these will have negative or positive impacts for WCA overall; that is, beyond meeting the foremost or initial objectives of food security. In addition, most foresight studies targeting WCA have not considered weather extremes or the biotic impacts linked to climate change.

Additional quantitative analyses are thus needed to link alternative scenarios of future climate change — characterized by changes as well as extremes in temperature, precipitation, and other abiotic indices — not just to agricultural production, but also to biotic impacts and to agricultural value chains and food systems in their entirety. That way, the interactions of climate change with demographic (including urbanization and migration), socioeconomic (including gender and youth), technological, and environmental factors and impacts in WCA can be more adequately captured. Finally, there may be incentives to explore synergies between quantitative and qualitative foresight approaches to support the governance and implementation of sustainable food systems transformation in WCA.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Dolapo Enahoro**, a Senior Agricultural Economist at the International Livestock Research Institute (ILRI); **Charles Mensah**, a PhD student in the Department of Agricultural Economics and Agribusiness, University of Ghana, and formerly a Research Officer at ILRI; and **Sika Gbegbelegbe**, an Agricultural Economist at the International Institute of Tropical Agriculture (IITA).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Enahoro, D., C. Mensah, and S. Gbegbelegbe. 2025. "What Do We Know About the Future of Agrifood Systems in West and Central Africa?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 17. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Jasmine Halki/Flickr

References

AfDB (African Development Bank). 2019. *Central Africa Regional Integration Strategy Paper, 2019–2025*. https://www.Afdb.Org/En/Documents/Central-Africa-Regional-Integration-Strategy-Paper-2019-2025

AfDB. 2020. *West Africa Regional Integration Strategy Paper, 2020–2025*. https://www.Afdb.Org/En/Documents/West-Africa-Regional-Integration-Strategy-Paper-2020-2025-0

Akpoti, K., T. Groen, E. Dossou-Yovo, A.T. Kabo-bah, and S.J. Zwart. 2022. "Climate Change-Induced Reduction in Agricultural Land Suitability of West-Africa's Inland Valley Landscapes." *Agricultural Systems* 200: 103429. https://doi.org/10.1016/j.agsy.2022.103429

CGIAR. 2022. *CGIAR Research Initiative: West and Central African Food Systems Transformation*. CGIAR Research Initiatives. https://www.cgiar.org/initiative/wca-food-systems-transformation/

Chadare, F.J., M. Affonfere, E.S. Aidé, et al. 2022. "Current State of Nutrition in West Africa and Projections to 2030." *Global Food Security* 32: 100602. https://doi.org/10.1016/j.gfs.2021.100602

de Lattre-Gasquet, M., C. Moreau, and J. Okul. 2018. "Regional Dimension of the Agrimonde-Terra Scenarios: The Example of Sub-Saharan Africa." In *Land Use and Food Security in 2050: A Narrow Road*, eds. C. le Mouël and M.O. de Lattre-Gasquet. Nairobi: UNEP. https://esa.un.org/unpd/wpp/

EUC (European Union Commission). 2019. *Global Food Supply and Demand: Consumer Trends and Trade Challenges*. EU Agricultural Markets Briefs No. 16 (September). https://agriculture.ec.europa.eu/system/files/2019-09/market-brief-food-challenges-sep2019_en_0.pdf

FAO (Food and Agriculture Organization of the United Nations). 2022a. FAOSTAT Statistical Database. https://www.fao.org/faostat/en/#data

FAO. 2022b. *Impact of the Ukraine-Russia Conflict on Global Food Security and Related Matters Under the Mandate of the Food and Agriculture Organization of the United Nations*. Hundred and Seventieth Session. https://www.fao.org/3/nj164en/nj164en.pdf

Filho, W. L., O.F. Olaniyan, and G.N. Alverio. 2022. "Where to Go? Migration and Climate Change Response in West Africa." *Geoforum* 137: 83–87. https://doi.org/10.1016/j.geoforum.2022.10.011

Fuller, T.L., P.R. Sesink Clee, K.Y. Njabo, et al. 2018. "Climate Warming Causes Declines in Crop Yields and Lowers School Attendance Rates in Central Africa." *Science of the Total Environment* 610–611: 503–510. https://doi.org/10.1016/j.scitotenv.2017.08.041

IFPRI (International Food Policy Research Institute). 2024. *IMPACT Projections of Food Production, Area and Demand to 2050 With Climate Change*. IMPACT Model, Version 3.4. Washington, DC: IFPRI.

Jalloh, A., G.C. Nelson, T.S. Thomas, R. Zougmoré, and H. Roy-Macauley. 2013. *West African Agriculture and Climate Change: A Comprehensive Analysis*. IFPRI Research Monograph. Washington, DC: IFPRI. http://dx.doi.org/10.2499/9780896292048

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-Food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Latino, L.R., U. Pica-Ciamarra, and D. Wisser. 2020. "Africa: The Livestock Revolution Urbanizes." *Global Food Security* 26: 100399. https://doi.org/10.1016/j.gfs.2020.100399

Manners, R., E. Vandamme, J. Adewopo, et al. 2021. "Suitability of Root, Tuber, and Banana Crops in Central Africa Can Be Favoured Under Future Climates." *Agricultural Systems* 193: 103246. https://doi.org/10.1016/j.agsy.2021.103246

Musibau, H.O., W.O. Shittu, and M. Yanotti. 2022. "Natural Resources Endowment: What More Does West Africa Need in Order to Grow?" *Resources Policy* 77: 102669. https://doi.org/10.1016/j.resourpol.2022.102669

OECD (Organisation for Economic Co-operation and Development), UNECA (United Nations Economic Commission for Africa), and AfDB. 2022. *Africa's Urbanisation Dynamics 2022: The Economic Power of Africa's Cities*. West African Studies. Paris: OECD Publishing. https://doi.org/10.1787/3834ed5b-en

Padgham, J., J. Jabbour, and K. Dietrich. 2015. "Managing Change and Building Resilience: A Multi-Stressor Analysis of Urban and Peri-Urban Agriculture in Africa and Asia." *Urban Climate* 12: 183–204. https://doi.org/10.1016/j.uclim.2015.04.003

Partey, S.T., R.B. Zougmoré, M. Ouédraogo, and B.M. Campbell. 2018. "Developing Climate-Smart Agriculture to Face Climate Variability in West Africa: Challenges and Lessons Learnt." *Journal of Cleaner Production* 187: 285–295. https://doi.org/10.1016/j.jclepro.2018.03.199

Petsakos, A., S.D. Prager, C.E. Gonzalez, et al. 2019. "Understanding the Consequences of Changes in the Production Frontiers for Roots, Tubers and Bananas." *Global Food Security* 20: 180–188. https://doi.org/10.1016/j.gfs.2018.12.005

Rigaud, K.K., A. de Sherbinin, B. Jones, et al. 2021. *Groundswell Africa: Internal Climate Migration in West African Countries*. Washington, DC: World Bank. https://documents1.worldbank.org/curated/en/453241634531082194/pdf/Groundswell-Africa-Internal-Climate-Migration-in-West-African-Countries.pdf

Udmale, P., I. Pal, S. Szabo, M. Pramanik, and A. Large. 2020. "Global Food Security in the Context of COVID-19: A Scenario-Based Exploratory Analysis." *Progress in Disaster Science* 7: 100120. https://doi.org/10.1016/j.pdisas.2020.100120

Ugbaje, S.U., I.O.A. Odeh, and T.F. A. Bishop. 2019. "Fuzzy Measure-Based Multicriteria Land Assessment for Rainfed Maize in West Africa for the Current and a Range of Plausible Future Climates." *Computers and Electronics in Agriculture* 158: 51–67. https://doi.org/10.1016/j.compag.2019.01.011

WFP (World Food Programme). 2017. *At the Root of Exodus: Food Security, Conflict and International Migration*. Rome. https://climate-diplomacy.org/sites/default/files/2020-10/WFP_At%20the%20root%20of%20Exodus.pdf

Zabel, F., B. Putzenlechner, and W. Mauser. 2014. "Global Agricultural Land Resources—A High Resolution Suitability Evaluation and Its Perspectives Until 2100 Under Climate Change Conditions." *PloS One* 9 (9): e107522. https://doi.org/10.1371/journal.pone.0107522

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR | INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS IN EAST AND SOUTHERN AFRICA?

Kindie Tesfaye Fantaye (AGRA), Faaiqa Hartley (IFPRI), Timothy Thomas (IFPRI), Sika Gbegbelegbe (IITA), and Sherwin Gabriel (IFPRI)

Key messages

- Food demand in East and Southern Africa (ESA) is expected to be three to nine times higher by 2050 (relative to 2010), depending on the emerging economic and demographic trends.
- To meet demand, agrifood systems (AFS) in the region must expand and diversify. Consumption demand for meats and fruits and vegetables will more than triple by 2050, creating economic opportunities but also inclusivity challenges.
- Transformations in AFS must increase the sector's resilience to supply-side shocks that threaten food security and nutrition.
- Favorable policies and investments that are country-specific, inclusive, and sustainable will be powerful tools to shape and influence AFS transitions in the region.

RECENT TRENDS AND CHALLENGES

The East and Southern Africa region (ESA) is home to over 656 million people and has one of the most vulnerable food systems in the world. Elevated levels of poverty and socioeconomic disparities prevent most of the population from accessing adequate, safe, and nutritious food every day. ESA's agrifood systems (AFS) are shaped by several megatrends (AGRA 2022).

Climate change. Analysis shows rising temperatures, highly variable rainfall, and more frequent extreme weather events across the region, with negative impacts on agricultural production, food insecurity, and malnutrition (AGRA 2022; FSIN 2022; Doi, Behera, and Yamagata 2022; IPCC 2022). The region has been identified as a global hotspot for human vulnerability, malnutrition, and micronutrient deficiencies (IPCC 2022).

Population growth and land scarcity. ESA's population is projected to more than double by 2050 (from 2010), with faster growth in urban areas (Messina et al. 2014). Coupled with land scarcity, higher food demand has led to declines in smallholder farm size, more continuous field cultivation, and changes in land allocations, increasing existing challenges to broad-based, inclusive AFS development (AGRA 2022).

Urbanization, economic growth, and inequality. Rapid urbanization, concentrated in smaller cities and towns, and economic growth have led to rising per capita incomes and a growing middle class (Ogwu 2019; Tschirley, Haggblade, and Reardon 2014; Tschirley, Reardon et al. 2015). Food preferences are thus shifting toward purchased, processed, perishable, and high-value products (AGRA 2022). While this presents an opportunity for growth, current AFS have failed to meet demand. Dietary changes together with disparities in healthy food access driven by income inequality will have implications for the incidence of diet-related noncommunicable disease if not managed.

Supply-side disruptions. Food system shocks due to global pandemics, extreme weather, pest and disease outbreaks, political and market instability, and conflict are increasing in frequency and severity, raising the risk of chronic and acute food insecurity (AGRA 2022). Climate, pest outbreaks, and armed conflicts have negatively affected food supply, while global value chain disruptions have increased food prices. Since 2019, nearly 50 million additional people in Africa, most in ESA, have become food insecure. Food insecurity for women has been exacerbated.

Rapid innovation in digital agriculture. More than 390 distinct digital agriculture solutions have been developed in Africa (Tsan, Totapally, and Hailu 2019), including in ESA. These digital solutions are used in five major areas: advisory services, market linkages, financial access, supply chain management, and macro agricultural intelligence (Tshirley, Reardon et al. 2015). The rapid adoption of mobile phones and internet connectivity has accelerated the deployment of agricultural services (Mabaya and Porciello 2022). Continued technology use can raise AFS resilience through better coordination and increased use of big data to predict and mitigate against shocks (AGRA 2022).

LATEST FORESIGHT RESEARCH

We identify four key research papers on AFS transformation foresight in the ESA region. The first focuses on two key trends: global food prices and urban income growth (Jayne, Meyer, and Traub 2014). The authors consider four plausible futures for sub-Saharan Africa (SSA) that include a mixture of high/low global food price environments and broad/narrow increases in income growth. The second paper also identifies household income growth as a key determinant of ESA's AFS transformation (Tschirley, Haggblade, and Reardon 2014). In this study, changes in rural and urban diets (by tercile) are projected to 2040 under differing household income growth assumptions across terciles and settlement types (urban/rural). Changes are projected for 23 food groups and allocated to broader food consumption groups such as own production versus market, unprocessed versus processed, informal versus formal processed, and low versus high value-added processed foods. The third paper uses estimates of consumer expenditure growth to project changes in food and nonfood expenditures to 2040 in Ethiopia, Malawi, Mozambique, Tanzania, Uganda, and Zambia (Tschirley, Snyder et al. 2015). These demands are then used to estimate AFS and non-AFS employment. The fourth and most recent paper uses IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to project food demand and supply globally, including in ESA (Rosegrant et al. 2024), and considers the potential impact of climate change. Findings from Thomas et al. (2022) and Thomas and Robertson (2024) are also included as the most recent work on climate change and crop production in the ESA region. These papers consider changes in temperature, precipitation, and weather variability under different global climates and potential futures.

Studies by Tschirley, Haggblade, and Reardon (2014) and Jayne, Meyer, and Traub (2014) show that while an increase in demand for market and processed foods is expected, the rate of change is very much determined by the pace and breadth of household income growth. By 2040, food demand is estimated to increase between three times (pessimistic economic development) and nine times (optimistic) the 2010 level (Tschirley, Haggblade, and Reardon 2014). For ESA, Rosegrant et al. (2024) estimate a near doubling of food consumption between 2020 and 2050. More equitable income growth (optimistic) results in larger increases in food demand but also faster shifts toward processed foods (Jayne, Meyer, and Traub 2014; Tschirley, Haggblade, and Reardon 2014). For food groups, the largest share declines are in maize and own production toward "food away from home," beef, fruit, and high-value processed items (Tschirley, Haggblade, and Reardon 2014). Demand shares of root crops and plantain decrease, while wheat and wheat products, beverages, and eggs increase. Rosegrant et al. (2024) find similar trends in ESA with a shift to meats and fruits and vegetables.

Changes in dietary patterns are important for the development of agro-processing systems and market development. By 20240, the modern food sector's estimated market share rises to nearly 50 percent (Tschirley, Haggblade, and Reardon 2014). The expansion of this sector is likely to lead to increased food safety, and lower and more stable prices, but it will also squeeze out smallholder farmers and small stores. Women will be disproportionately affected by market changes, as they are the main retailers in the traditional food market sector, although some women will gain from the rise in food demand as the smallholder sector will remain a key provider of food. Unequal increases in incomes, however, are likely to result in higher food import shares as the scale of demand may be insufficient to attract the necessary investment for local industry development (Jayne, Meyer, and Trabu 2014). Despite robust growth in production, net food trade (that is, net exports) is projected to become sharply negative in ESA (Rosegrant et al. 2024) (Figure 1).

Changing dietary patterns also hold opportunities for employment and increased equality. Dietary changes could increase the employment share of nonfarm AFS sectors in ESA to between 9.7 percent (low growth) and 11.3 percent (high) in 2025 (7.9 percent in 2010) (Tschirley, Snyder et al. 2015), with employment levels in food manufacturing, food preparation, and marketing and transport more than doubling. Employment effects, however, depend significantly on the capital intensity of non-AFS sectors. More capital-intensive sectors create fewer jobs, thereby limiting employment opportunities outside of agriculture and increasing income inequality. Higher levels of income inequality, as indicated above, negatively affect the expansion of nonfarm AFS sectors.

While the share of maize in total consumption is likely to decline, the crop will remain a crucial source of calories and nutrients (Jayne, Meyer, and Traub 2014: Thomas et al. 2022). Although climate change will slow maize yield growth from what it would be without climate change, maize yields in ESA as a whole will be less adversely impacted in average years than in the rest of the world (Thomas and Robertson 2024). This is because many maize-producing areas in ESA are in cooler highlands. Nonetheless, the impact of climate change on maize yields is much higher in Uganda, Zambia, and Zimbabwe than it is in the rest of ESA.

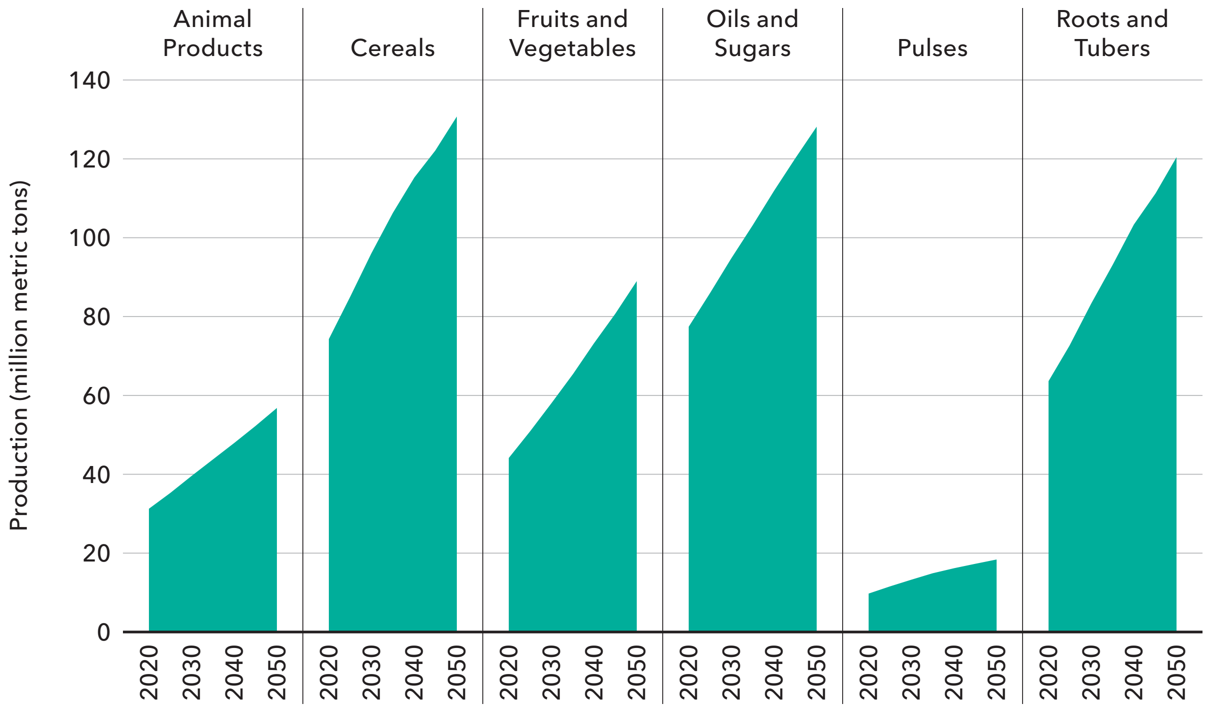
In addition to the impact of climate change on yields in average years, it is important to understand the impact of extreme events. In low-yield years caused by drought or unusually high temperatures, the impact on yields will be greater. Maize yields in Southern Africa could decrease by as much as 16 percent by 2060, relative to 2020, in a bad year (1-in-20-year event; high global emissions scenario, ignoring technological change). The frequency of bad years is likely to increase: a 1-in-20-year event is expected every 3.5 years with climate change (Thomas et al. 2022). Subregional impacts could be more severe (Gbegbelegbe et al. 2024).

Although the proportion of the population at risk of hunger in ESA is projected to fall between 2020 and 2050 in the baseline scenario, the number of people at risk is projected to increase. Furthermore, the number of people at risk of hunger in ESA in 2050 is projected to be 10 million more than it would be under a more optimistic climate change scenario (see Chapter 36 in this publication).

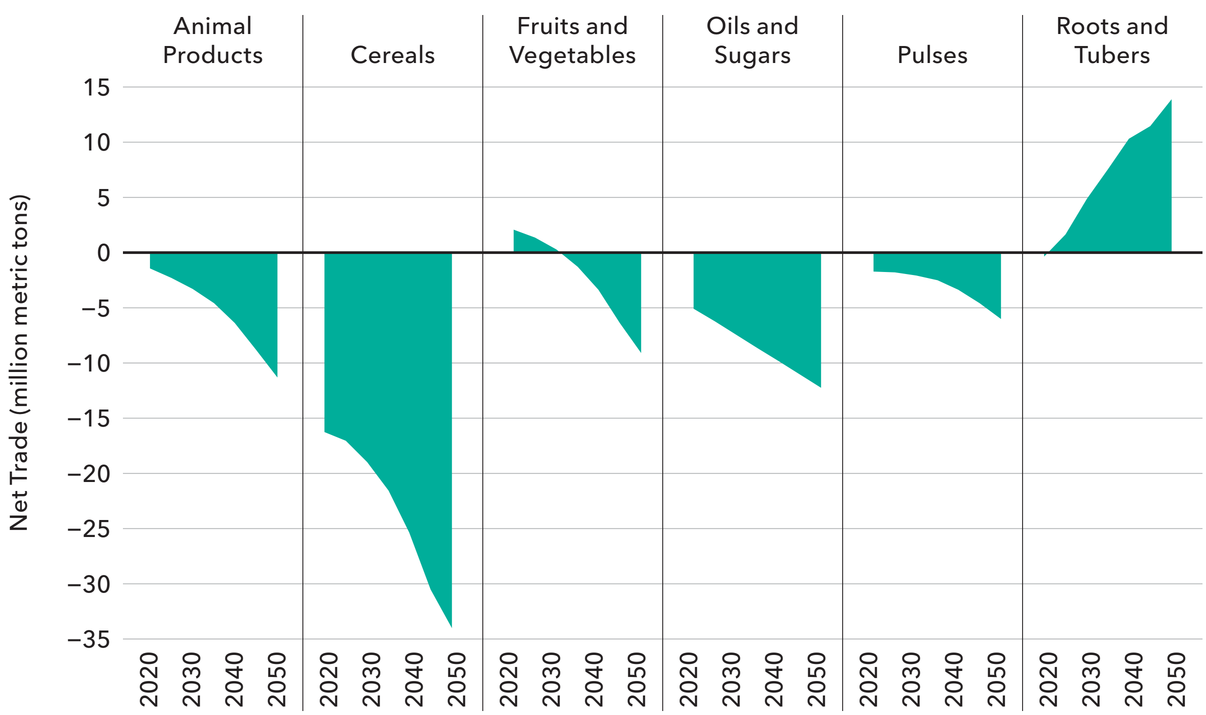
Many of the trends experienced in ESA are influenced and/or determined by policies and investments. AFS-related

FIGURE 1 Change in production and net trade in ESA, 2020–2050

A Change in production in ESA by commodity group, 2020–2050



B Change in net trade in ESA by commodity group, 2020–2050



Source: Rosegrant et al. (2024).

Note: Based on data from the reference scenario: SSP2-RCP7.0-IPSL, from IMPACT version 3.4. ESA = East and Southern Africa. Net trade refers to net exports.

policies need to be country- and context-specific, as transformations across the region and within countries will be heterogenous. Policy decisions that hinder investment and fail to create needed infrastructure for transport, marketing, energy, and communications will negatively affect AFS transformation. Investing in education and developing technical skills are crucial to the success of food systems transformation in the region.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

We are not aware of any recent AFS foresight studies specifically focused on the ESA region, although several studies do look at subregions or specific countries. Foresight research opportunities related to AFS transformation in ESA include (1) urbanization patterns, changing market structures, and the role of the traditional food sector; (2) the impacts of changing diets on nutrition, health, and inclusivity; (3) the interaction of population growth, urbanization, and smallholder farming under changing climate and global socioeconomic conditions; (4) income disparities, food prices, and intraregional and intra-Africa trade; and (5) the impact of food systems transformation on land use, carbon emissions, and resilience.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Kindie Tesfaye Fantaye**, Head of Climate Adaptation and Resilience at AGRA, and formerly a Principal Scientist at the International Maize and Wheat Improvement Center (CIMMYT); **Faaiqa Hartley**, a Scientist in the Foresight and Policy Modeling (FPM) Unit at the International Food Policy Research Institute (IFPRI); **Timothy Thomas**, a Senior Research Fellow in FPM at IFPRI; **Sika Gbegbelegbe**, an Agricultural Economist at the International Institute of Tropical Agriculture (IITA); and **Sherwin Gabriel**, a Scientist in FPM at IFPRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Tesfaye Fantaye, K., F. Hartley, T. Thomas, S. Gbegbelegbe, and S. Gabriel. 2025. "What Do We Know About the Future of Agrifood Systems in East and Southern Africa?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 18. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Georgina Smith/CIAT

References

AGRA (Alliance for a Green Revolution in Africa). 2022. *Africa Agriculture Status Report. Accelerating African Food Systems Transformation* (Issue 10). Nairobi.

Doi, T., S.K. Behera, and T. Yamagata. 2022. "On the Predictability of the Extreme Drought in East Africa during the Short Rains Season." *Geophysical Research Letters* 49: e2022GL100905. https://doi.org/10.1029/2022GL100905

FSIN (Food Security Information Network). 2022. *2022 Global Report on Food Crises: Joint Analysis for Better Decisions*. Rome: Food and Agricultural Organization of the United Nations, and World Food Programme; Washington, DC. https://hdl.handle.net/10568/141235

Gbegbelegbe, S., D. Chikoye, A. Alene, S. Kyei-Boahen, and G. Chigeza. 2024. "Strategic Foresight Analysis of Droughts in Southern Africa and Implications for Food Security." *Frontiers in Sustainable Food Systems* 7: 1159901. https://doi.org/10.3389/fsufs.2023.1159901

IPCC (Intergovernmental Panel on Climate Change). 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, eds. H.O. Pörtner, D.C. Roberts, M. Tignor, et al. Cambridge, UK, and New York: Cambridge University Press. https://doi.org/10.1017/9781009325844

Jayne, T.S., F. Meyer, and L.N. Traub. 2014. "Africa's Evolving Food Systems: Drivers of Change and the Scope for Influencing Them." IIED Working Paper. IIED, London. http://pubs.iied.org/14637IIED

Mabaya, E., and J. Porciello. 2022. "Can Digital Solutions Transform Agrifood Systems in Africa?" *Agrekon* 61 (1): 67–79. https://doi.org/10.22004/ag.econ.348124

Messina, J., U. Adhikari, J. Carroll, et al.. 2014. *Population Growth, Climate Change and Pressure on the Land – Eastern and Southern Africa*. East Lansing: Global Center for Food Systems Innovation, Michigan State University.

Ogwu, M.C. 2019. "Towards Sustainable Development in Africa: The Challenge of Urbanization and Climate Change Adaptation Chapter." In *The Geography of Climate Change Adaptation in Urban Africa*, eds. P.B. Cobbinah and M. Addaney, 29–55. Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-030-04873-0

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Thomas, T., R.D. Robertson, K. Strzepek, and C. Arndt. 2022. "Extreme Events and Production Shocks for Key Crops in Southern Africa Under Climate Change." *Frontiers in Climate* 4 (May 23). https://doi.org/10.3389/fclim.2022.787582

Thomas, T.S., and R.D. Robertson. 2024. "Climate Change and Agriculture in Eastern and Southern Africa: An Updated Assessment Based on the Latest Global Climate Models." IFPRI Discussion Paper 2239. International Food Policy Research Institute, Washington, DC. https://hdl.handle.net/10568/139503

Tsan, M., D.S. Totapally, D.M.C. Hailu, and B.K.C. Addom. 2019. *The Digitalization of African Agriculture Report 2018-2019*. Wageningen: Technical Centre for Agricultural and Rural Cooperation. https://hdl.handle.net/10568/101498

Tschirley, D., S. Haggblade, and T. Reardon, eds. 2014. *Africa's Emerging Food System Transformation: Eastern and Southern Africa*. East Lansing: Global Center for Food Systems Innovation, Michigan State University.

Tschirley, D., T. Reardon, M.D. Ager, and J. Snyder. 2015. "The Rise of a Middle Class in East and Southern Africa: Implications for Food System Transformation." *Journal of International Development* 27: 628–646. https://doi.org/10.1002/jid.3107

Tschirley, D., J. Snyder, M. Dolislager, et al. 2015. "Africa's Unfolding Diet Transformation: Implications for Agrifood System Employment." *Journal of Agribusiness in Developing and Emerging Economies* 5: 102–136. https://doi.org/10.1108/JADEE-01-2015-0003

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS IN CENTRAL AND WEST ASIA AND NORTH AFRICA?

Aymen Frija (ICARDA)

Key messages

- The subregions of Central and West Asia and North Africa (CWANA) will continue to import around 50 percent of domestic food requirements by 2050.
- Natural resources will continue to degrade in the CWANA region until 2050 and beyond.
- Agrifood systems transformation in CWANA can be facilitated by fast-tracking technology transfer approaches, leading to sustainable productivity growth.
- Foresight analyses are needed to generate scenarios of agrifood system transformation in CWANA, with a focus on reducing trade and importation risks related to international market volatility.

RECENT TRENDS AND CHALLENGES

Food systems in Central and West Asia and North Africa (CWANA)[1] are characterized by a subset of well-known and documented dynamics and transformations. The region is recognized for its critical challenges in numerous areas: environmental (dry areas; a high level of degradation of soil, water, and rangelands; a hotspot for climate change); socioeconomic (population growth; gender and other inequities; conflicts; a preponderance of small farms; lack of technology transfer and of investment capacity; and heavy dependence on food imports); and political (political economy and related market biases; low efficiency and effectiveness of programs; and lack of economic incentives for investments) (Shideed, Shomo, and Aw-Hassan 2010). Current and future foresight studies of agrifood systems indicate that marginality and vulnerability in food production and access are already high, mainly due to the following factors:

- Climate change is leading to reduced availability of blue and green water. One-half of the population in the Middle East and North Africa (MENA), a subregion of CWANA, already lives under water stress (Belhaj and Soliman 2021).

- Population growth in CWANA is among the highest in the world, with a total fertility rate of 2.8 in 2021, but is expected to decrease to 2.2 in 2050 (second highest after sub-Saharan Africa), while the region's population is expected to reach 770 million by 2050 (UN 2022). This is expected to intensify social pressure, increase job and food demand, and encourage migration (Belhaj and Soliman 2021; Läderach et al. 2022). However, agricultural productivity rates are not growing at the same pace as population growth (Rosegrant et al. 2017; Fuglie et al. 2019).

- Diets and nutrition are challenging issues in CWANA. Local production — dominated by cereals (wheat in wetter areas and barley in drier areas), legumes (chickpeas, lentils, and fodder) (Frija 2021) — forms the core of the population's diet. But domestic supplies of all these commodities are becoming increasingly unreliable and inadequate.

- Around one-third of calories consumed in MENA originate from subsidized wheat (Belhaj and Soliman 2021; Kruseman et al. 2020, 2021; Frija 2021) with negative impacts of diets on human health (such as obesity) (Agnivesh 2023).

- Malnutrition is another key challenge (Agnivesh 2023). Around 55 million people in MENA are estimated to be undernourished, and around 20 percent of the population is food insecure (Belhaj and Soliman 2021). The numbers of food insecure are particularly high in conflict areas (about 24 million in Yemen, 12 million in Syria, and 4 million in Iraq), while malnutrition is driven by inflation and other economic and financial factors in countries such Lebanon, Tunisia, and Egypt. Malnutrition imposes long-term economic costs that can reach 3 percent of gross domestic product (GDP) in some poor countries (World Bank 2006).

- Continuous heavy depletion of natural resources — including water (Agnivesh 2023; de Waal et al. 2023; Droogers et al. 2012; Lentz 2021), rangelands (Frija et al. 2023; Sghaier et al. 2024), soils (Bahri et al. 2019), and biodiversity (Sarant 2019) — are also of concern, with implications for long-term sustainability.

LATEST FORESIGHT RESEARCH

Recent foresight studies suggest that CWANA's agrifood challenges can be partly mitigated through more sustainable use of land, soil, and water (Agnivesh 2023; de Waal et al. 2023; Droogers et al. 2012; Lentz 2021). However, water scarcity is expected to continue to adversely impact job opportunities, farm incomes, reliability of agricultural exports, and the ability of vulnerable communities in the region to access domestic water and food at affordable prices (El Kharraz et al. 2012). A World Bank report indicates that by the end of this decade, the amount of water available annually per capita will be below the absolute water scarcity threshold of 500 cubic meters (de Waal et al. 2023). An additional 25 billion cubic meters of water per year will be needed by 2050 to meet the region's needs (de Waal et al. 2023; Droogers et al. 2012). Projections from IFPRI's International Model for

1 Central and West Asia and North Africa (CWANA) is the term used by CGIAR to refer to the drylands extending from Morocco in North Africa to Central Asia.

Policy Analysis of Agricultural Commodities and Trade (IMPACT) show that blue water consumption will grow by 30 billion cubic meters by 2050, an increase of over 10 percent over 2020 (Rosegrant et al. 2017).

Despite the expected increase in input use in rainfed production systems, water and soil fertility will remain binding constraints for productivity growth in MENA until 2050 (Le Mouël et al. 2016). Deeper transformations of food systems in CWANA will be needed to overcome environmental degradation, institutional inefficiencies, and growing demand (Agnivesh 2023; de Waal et al. 2023; Droogers et al. 2012; Lentz 2021).

Foresight studies suggest the following trends in consumption, diets, and nutrition in most countries of the region (Dupouy and Gurinovic 2020; Frija 2021; Kruseman et al. 2021):

- Per capita wheat consumption is not expected to increase by 2050 (based on an analysis of future trends using historical data). However, expected growth in overall wheat demand in the region will be driven by population growth (Frija 2021). Part of the grain cereals consumption is expected to be replaced by energy-dense foods and livestock and fish proteins (Frija 2021).
- Legume consumption per capita is expected to increase in some countries (such as Tunisia and Turkey) by 2050, but will remain low in terms of relative importance in the overall diet.
- Central Asia is expected to face rising overweight and obesity, micronutrient deficiencies, and diet-related non-communicable diseases (Dupouy and Gurinovic 2020).

Domestic food supplies in CWANA are insufficient to cover domestic consumption, and supply gaps are filled through substantial imports. Foresight studies show that this situation will persist in the coming few decades (by 2030 and 2050) (Frija 2021; Kruseman et al. 2020, 2021). CWANA's dependence on food imports is expected to grow from 40 percent of domestic food consumption to around 50 percent by 2050 (Le Mouël et al. 2016). Although diet composition is projected to see a decrease in the share of cereals in 2050, the share of oils and sugar is expected to grow, and the region is projected to remain highly dependent on imports for both food groups, according to IMPACT model projections (Figure 1).

Better decision-making to reduce **risks related to importation** from international markets is critical. This can help reduce risks related to dependence on food imports and world market price volatility. Risk reduction can be achieved by reducing yield volatility in major crops, but also by enhancing countries' capacities for world food price prediction and anticipated purchase and storage decision systems and related infrastructure. By doing so, governments can reduce commodity price volatility and stabilize their budgets through better predictability of food imports (Belhaj and Soliman 2021).

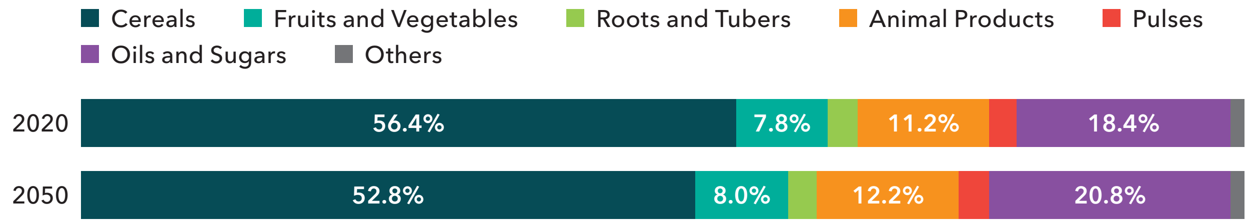
Technology transfer for long-term growth of agricultural productivity is also important. Technical progress and increased efficiency are the best option to reduce CWANA's dependence on food imports by 2050. Enhanced technology transfer scenarios (leading to enhanced productivity) remain among the best identified alternatives to mitigate the shortage of domestic food supply (Le Mouël et al. 2016). Most extension systems in the region remain low-performing, lacking holistic innovation systems consistent with agrifood system levels and frameworks. Ryan et al. (2012) suggest that despite achievements in applied research, poorly developed technology transfer systems and weak analytical facilities remain stumbling blocks to the widespread dissemination of accumulated knowledge to farmers. The scope of agricultural innovations not only covers agricultural productivity growth but can lead to economic opportunities and growth, in turn increasing labor market demand, social welfare, and investments. Technology transfer can also support enhanced governance settings for natural resource management, which is a must for the next decades.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

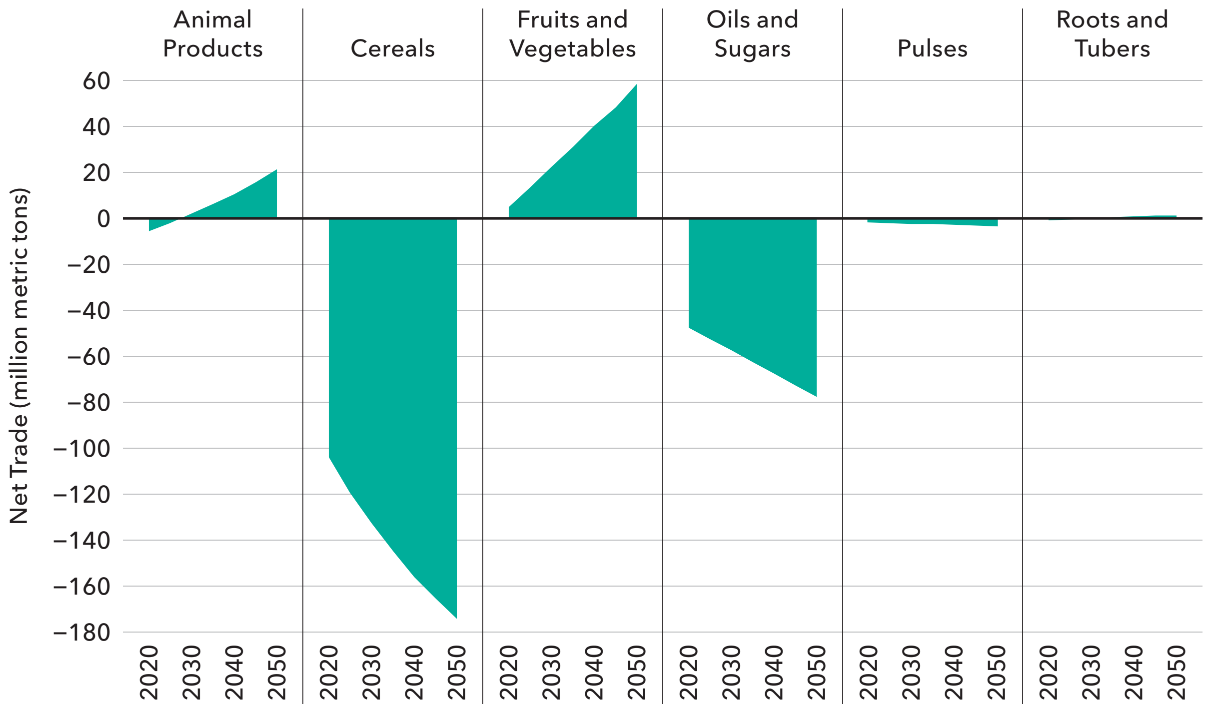
Food system resilience is conceptualized from a holistic perspective, encompassing the complexity of the whole food system, including social, economic, and biophysical processes operating at many scales (Tendall et al. 2015). Consistent and holistic R&D approaches to inform future decisions on investments in innovation system functions are lacking, as they should be nested within the broader food system components and aggregates.

FIGURE 1 CWANA diet composition and net trade

A Diet composition in 2020 and 2050



B Net trade between 2020 and 2050 (million metric tons)



Source: Rosegrant et al. 2024.

Note: Results for business-as-usual (BAU) scenario, IMPACT model version 3.4. This scenario assumes population and income trends from SSP2, a middle-of-the-road socio-economic scenario. Climate change shocks are derived from Representative Concentration Pathway (RCP) 7.0 as projected under IPSL's general circulation model.

A significant trend toward exploring more environmentally friendly and socially inclusive **agroecological approaches for sustainable transformation of agrifood systems** is currently evident in the literature and in some key policy arenas. However, data and foresight studies about the prospective costs and benefits of different transformation pathways in CWANA are still scarce. Improved estimates of future costs and benefits of alternative future transformation scenarios generated by foresight studies would be of great value to policymakers in support of the sustainable transition of agrifood systems.

Development of **novel viable financial models and schemes** for supporting the governance and sustainability of agrifood systems at all levels – while supporting productivity enhancement, agroecological transformation, and decentralized natural resources governance – is a key driver of transformation. Alternative sustainable and responsible funding mechanisms and approaches for agricultural modernization and sustainability in the region are needed. Foresight studies can explore the impact of different organizational settings and their impact on financial sustainability for food system transitions.

Social protection measures (safety nets and food aid programs) are being questioned and revised by governments in most CWANA countries. The lack of evidence and accurate assessments to support decision-making in this regard remains a key gap that can be addressed through strategic foresight studies. Social considerations such as the "feminization of agricultural labor" and youth engagement are other important gaps in our understanding of the future of food systems that need to be investigated.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The author of this chapter is **Aymen Frija**, a Senior Scientist and Agricultural Economist in the Social, Economic, and Policy Research Team at the International Center for Agricultural Research in the Dry Areas (ICARDA).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Frija, A. 2025. "What Do We Know About the Future of Agrifood Systems in Central West Asia and North Africa?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 19. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Vincent Simonneaux/IRD

References

Agnivesh, H. 2023. "MENA Watch: Region Faces Dire Water Scarcity by 2050." *Global Business Outlook*, August 23. https://globalbusinessoutlook.com/energy/mena-watch-region-faces-dire-water-scarcity/

Bahri, H., M. Annabi, H. Cheikh M'Hamed, and A. Frija. 2019. "Assessing the Long-Term Impact of Conservation Agriculture on Wheat-Based Systems in Tunisia Using APSIM Simulations Under a Climate Change Context." *Science of the Total Environment* 692: 1223–1233. https://doi.org/10.1016/j.scitotenv.2019.07.307

Belhaj, F., and A. Soliman. 2021. "MENA Has a Food Security Problem, But There Are Ways to Address It." *Opinion*, September 25. https://www.worldbank.org/en/news/opinion/2021/09/24/mena-has-a-food-security-problem-but-there-are-ways-to-address-it

de Waal, D., S. Khemani, A. Barone, and E. Borgomeo. 2023. *The Economics of Water Scarcity in the Middle East and North Africa: Institutional Solutions*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1739-7

Droogers, P., W.W. Immerzeel, W. Terink, J. Hoogeveen, M.F.P. Bierkens, L.P.H. Van Beek, and B. Debele. 2012. "Water Resources Trends in Middle East and North Africa Towards 2050." *Hydrology and Earth System Sciences* 16 (9): 3101–3114. https://doi.org/10.5194/HESS-16-3101-2012

Dupouy, E., and M. Gurinovic. 2020. "Sustainable Food Systems for Healthy Diets in Europe and Central Asia: Introduction to the Special Issue." *Food Policy* 96: 101952. https://doi.org/10.1016/J.FOODPOL.2020.101952

El Kharraz, J., A. El-Sadek, N. Ghaffour, and E. Mino. 2012. "Water Scarcity and Drought in WANA Countries." *Procedia Engineering* 33: 14–29. https://doi.org/10.1016/J.PROENG.2012.01.1172

Frija, A., H. Ouerghemmi, and K.A. Mottaleb. 2021. *Dietary Change in Asia, Sub-Saharan Africa, and North Africa: Historical Changes and Future Food Consumption Perspectives*. ICARDA Policy Brief. ICARDA. https://hdl.handle.net/20.500.11766/66832

Frija, A., M. Sghaier, M. Fetoui, B. Dhehibi, and M. Sghaier. 2023. "Pathways for Improving Rangeland Governance Under Constraining Land Tenure Systems: Application of a Participatory Bayesian Belief Approach." *Land Use Policy* 126: 106519. https://doi.org/10.1016/J.LANDUSEPOL.2022.106519

Fuglie, K., M. Gautam, A. Goyal, and W.F. Maloney. 2019. *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1393-1

Kruseman, G., K.A. Mottaleb, A. Frija, S.D. Gbegbelegbe, S. Bairagi, and M. Springmann. 2021. *Effects of Dietary Change—Synthesis Across the Case Studies*. Texcoco, Mexico: CIMMYT. https://hdl.handle.net/10883/21821

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-Food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Läderach, P., F. Schapendonk, S. Ruckstuhl et al. 2022. *Climate Security in the MENA Region*. Position Paper No. 2022/3. CGIAR FOCUS Climate Security. https://hdl.handle.net/10568/117616

Le Mouël, C., A. Forslund, P. Marty, S. Manceron, and B. Schmitt. 2016. "Sub-Chapter 3.2.7. Climate Change and Dependence on Agricultural Imports in the MENA Region." In *The Mediterranean Region Under Climate Change*, eds. Jean-Paul Moatti and Stéphane Thiébault, IRD Éditions, 511–517. Marseilles, France: IRD. https://doi.org/10.4000/books.irdeditions.23862

Lentz, E.C. 2021. "Food and Agriculture Systems Foresight Study: Implications for Gender, Poverty, and Nutrition." *Q Open* 1 (1): 1–53. https://doi.org/10.1093/QOPEN/QOAA003

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security Under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Rosegrant, M.W., T.B. Sulser, D. Mason-D'Croz, et al. 2017. *Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio*. Project Report for USAID. Washington, DC: IFPRI. https://hdl.handle.net/10568/148186

Ryan, J., H. Ibrikci, A. Delgado, J. Torrent, R. Sommer, and A. Rashid. 2012. "Significance of Phosphorus for Agriculture and the Environment in the West Asia and North Africa Region." *Advances in Agronomy* 114: 91–153. https://doi.org/10.1016/B978-0-12-394275-3.00004-3

Sarant, L. 2019. "Predicting Climate Change Impact on Afro-Arabian Biodiversity." *Nature Middle East News*, February 7. https://doi.org/10.1038/NMIDDLEEAST.2019.18

Sghaier, M., A. Frija, J. Postigo, S. Speelman, V. Alary, and M. Sghaier. 2024. "Assessing Pastoral Reforms Through the Performance of Agro-Pastoral Community-Based Organizations in South Tunisia." *Rangeland Ecology & Management* 98: 49–62. https://doi.org/10.1016/J.RAMA.2024.07.008

Shideed, K.H., F. Shomo, and A. Aw-Hassan. 2010. "Chapter 69 Population Growth and Trends in Food Production and Consumption in the CWANA Region." *Handbook of Agricultural Economics* 4: 3531–3570. https://doi.org/10.1016/S1574-0072(09)04069-9

Tendall, D.M., J. Joerin, B. Kopainsky, et al. 2015. "Food System Resilience: Defining the Concept." *Global Food Security* 6: 17–23. https://doi.org/10.1016/j.gfs.2015.08.001

World Bank. 2006. *Repositioning Nutrition as Central to Development: A Strategy for Large-Scale Action*. Washington, DC: World Bank. https://hdl.handle.net/10986/7409

UN (United Nations). 2022. *World Population Prospects 2022: Summary of Results*. UN DESA/POP/2021/TR/NO.3. Department of Economic and Social Affairs Population Division, United Nations. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FOOD SYSTEMS IN SOUTH ASIA?

Swamikannu Nedumaran (ICRISAT), Judy Thomas (ICRISAT), Ravi Nandi (CIMMYT), Jyosthnaa Padmanabhan (ICRISAT), and Victor Afari-Sefa (ICRISAT)

Key messages

- Micronutrient availability in South Asia is projected to increase by 46 percent by 2050, reflecting a significant transition from traditional cereal-based diets to diverse, nutrient-rich foods, though affordability limits access for low-income groups.
- The shift from traditional diets to processed foods has led to an increase in obesity and diet-related noncommunicable diseases. Rising demand for animal-source foods also puts pressure on local resources and increases reliance on imports.
- Agriculture in South Asia relies heavily on freshwater, primarily groundwater, which is critically overused. Additionally, soil degradation and the burning of crop residues contribute to air pollution and pose risks to the sustainability and productivity of the region's agricultural land.
- Climate change is expected to significantly affect crop yields, particularly for staples such as rice, wheat, and maize, with projected reductions by 2050. This climate impact will exacerbate food insecurity in the region, especially as food demand continues to grow.
- Current foresight studies often overlook the impacts of unexpected external shocks, such as pandemics and the Russia-Ukraine war, on agriculture and food systems. Addressing these research gaps and focusing on context-specific technological solutions, climate-smart practices, and self-sufficiency could enhance resilience and sustainability across South Asia's agrifood sector.

RECENT TRENDS AND CHALLENGES

South Asia is the most densely populated region in the world, with a current population of 1.8 billion (one-fourth of the global population), which is projected to increase to more than 2 billion by 2050. This rapid population growth will put significant pressure on agriculture and food systems. Despite being an agricultural powerhouse, South Asia has high levels of food insecurity, with many people suffering from malnutrition and hunger. It is also among the regions most vulnerable to climate change and relies heavily on intensive farming practices, leading to several inadequacies in agriculture and food systems that bear directly on food production and security. Further, the highest concentration of agrifood system workers are in South Asia, with 793 million people. South Asia is also home to more than 600 million young people (ages 15–35), who make up around one-half of all agrifood system workers.

Socioeconomic and demographic context

High poverty and malnutrition rates. Despite contributing significantly to global food production, South Asia faces intense food insecurity and poverty challenges. Widespread malnutrition, particularly among youth and marginalized groups, restricts access to affordable, nutritious food and exacerbates the struggle against hunger and poverty (FAO 2019; World Bank 2021).

Systemic socioeconomic inequalities. Social, economic, and geographic disparities hinder access to nutritious foods and agricultural resources. These inequalities disproportionately affect marginalized communities, contributing to persistent poverty and malnutrition, and creating lasting barriers from production to consumption in the region (Gillespie, Van Den Bold, and Hodge 2019; Rehman et al. 2024).

Labor shortages and youth migration. Rural out-migration, particularly among youth seeking better opportunities in urban areas, has resulted in farm labor shortages (Nandi et al. 2022). This trend increases production costs, complicates efforts to maintain agricultural output levels, and threatens the continuity of agricultural knowledge and practices across generations (Ronto, Wu, and Singh 2018; Singh et al. 2023).

Policy and market limitations. Many farmers face weak market access, inadequate extension services, limited irrigation facilities, and nonoptimal enabling policy support. These factors contribute to a significant portion of arable land being left fallow after harvests (Tran et al. 2023; Rehman et al. 2024).

Environmental pressures and resource depletion

Water scarcity and overuse. Agriculture accounts for more than 90 percent of freshwater withdrawal in South Asia, creating severe water stress. The dependence on groundwater for irrigation — especially for water-intensive crops such as rice, wheat, and sugarcane — poses a significant risk to the long-term viability of farming systems in South Asia, which is aggravated by the region's low groundwater recharge rates (FAO 2021; OECD 2017).

Increasing land degradation and fallowing: A substantial portion of agricultural land in the region faces human-induced degradation driven by dwindling freshwater resources and declining soil health, leading to nearly 22 million hectares lying fallow after the main monsoon season.

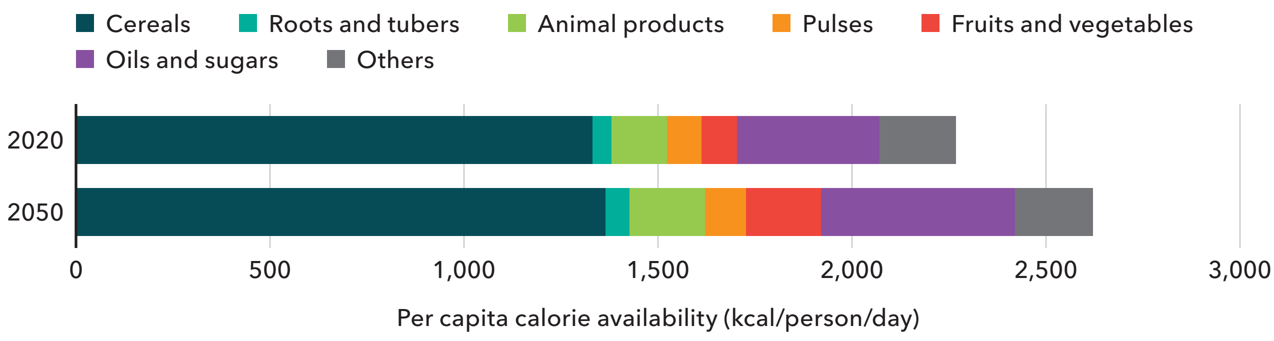
Agriculture-related air pollution. The prevalence of crop residue burning and excessive use of nitrogenous fertilizers in South Asia contributes to increased air pollution, which negatively impacts agrifood systems by diminishing crop yields and nutritional quality, degrading soil health, and jeopardizing food security and the economic viability of farming (Lin and Begho 2022).

Policy challenges. Inadequate water governance in South Asia fails to balance agricultural demands, leading to drying shallow wells and unsustainable water use (Chakraborty and Bhaduri 2023).

Changing dietary patterns and health implications

Nutrition transition. South Asia is experiencing a shift from traditional cereal-based diets to highly processed foods rich in sugars, fats, and salts. This transition has led to a rise in obesity and lifestyle- and diet-related noncommunicable diseases, presenting new and enormous public health challenges (Bishwajit 2015; Baker et al. 2020; Pingali 2007).

FIGURE 1 South Asia's projected per capita calorie demand (kcal/person/day)



Source: IMPACT V3.6 model simulations.

Rising consumption of animal-source foods. The growth in consumption of animal-source foods is likely to increase demand for animal feed and reliance on food imports for humans despite the region's considerable pastureland resources (FAO 2024; Sarker, Rahman, and Khan 2021).

Economic barriers to nutritious diets. Nutrient-dense foods remain unaffordable for many households in the region. Significant seasonal fluctuations and spatial variations in the costs of perishable foods affect rural and low-income populations in particular (Dizon, Mulmi, and Wang 2021).

LATEST FORESIGHT RESEARCH

Nutrition and dietary shifts are increasingly recognized in foresight studies of the South Asia region as critical factors for shaping sustainable food systems, with direct implications for both human health and environmental resilience. Nutrient availability is expected to increase across South Asia by an average of 46 percent from 2020 to 2050, according to Rosegrant and colleagues (2024), with per capita kilocalorie demand shifting significantly (Figure 1). The International Food Policy Research Institute's (IFPRI) IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model simulations indicate notable changes in production, yields, and harvested area for major commodity groups in the region over this period. Specifically, production is expected to rise substantially for animal products (81.3 percent), cereals (48.8 percent), and fruits and vegetables (114.8 percent). Crop yields are projected to experience the highest growth in fruits and vegetables (65.4 percent), followed by pulses (46.7 percent) and cereals (38.3 percent). However, harvested area projections show a decline in pulses (–16.9 percent), while cereals are anticipated to increase (+7.6 percent). Additionally, the area for oils and sugars is projected to rise by 13.8 percent, and the harvested area for fruits and vegetables is projected to grow by 29.9 percent. The model projects a diversification away from cereals, reducing their contribution to total kilocalories from 58.7 percent in 2020 to 52.1 percent by 2050.

Meanwhile, projections from MAGNET[1] and GLOBIOM[2] show a gradual decrease between 2010 and 2050 in the share of energy from cereals as rising incomes facilitate dietary diversification, with a slight increase in calories from fruits and vegetables as other nutritious food products are consumed (van Meijl et al. 2020).

Climate-induced food insecurity will have far-reaching consequences for South Asian countries' social, economic, and political stability. The region is expected to experience the highest increase in food demand by 2050. The negative impact of climate change by 2050 could be as high as US$1.01 trillion for the next 40 years, with consumers bearing most of the costs due to increased food prices. However, farmers stand to gain US$52 billion due to higher prices for their produce, which would more than

1 Modular Applied General Equilibrium Tool (MAGNET) (Woltjer et al. 2014).

2 The Global Biosphere Management Model (GLOBIOM) (Havlík et al. 2014).

compensate for the general decline in production. Food will become less accessible with increasing prices, especially for people experiencing acute poverty, reducing the average per capita consumption of all food crops by 1.7 percent in 2030 and by 3.2 percent in 2050 (Deb Pal and Tyagi 2022).

South Asia's food production faces climate-driven shifts in crop suitability, with particular impacts on key staples such as rice, wheat, and maize. Climate modeling anticipates increased wheat production in high-latitude regions, while warmer areas in South Asia may experience reduced suitability for certain crops. Rice and maize are projected to experience reductions in unsuitable areas by 2050, allowing for improved yields if adaptive strategies are implemented (Ali et al. 2024). However, IFPRI projects substantial yield reductions for key crops in South Asia due to climate stress – wheat (−50 percent), rice (−17 percent), and maize (−6 percent) – by 2050 relative to 2000 levels, because of which South Asia will have the most significant number of food-insecure people by 2050 (World Bank 2021).

Integrated assessments estimate significant cereal production declines by 2050 across South Asia: Bangladesh (−31.5 percent), Pakistan (−24.2 percent), Sri Lanka (−25.7 percent), and India (−6.4 percent) (Alvi et al. 2021). Spatially aggregated yields of all crops show a lower growth rate from 2010 to 2030 for the climate change scenario (+41 percent) compared to the no climate change scenario (+48 percent) based on the IMPACT model analysis. Cereal yields are expected to grow more slowly due to climate impacts, with cash crops including vegetables, cotton, and wheat projected to perform better (Hinz et al. 2020).

Food demand dynamics reshaped by urbanization trends are likely to drive demand for livestock products and diversify dietary intake away from cereals, shifting toward protein-rich foods, dairy, and fish (Zhang et al. 2022). Demand for livestock products will increase by nearly 100 percent between 2010 and 2050, offering nutritional gains and posing environmental challenges (Enahoro et al. 2019; Prager and Wiebe 2021). The global per capita food consumption average is projected at 3,000 kcal/day by 2050, with South Asia's average significantly increasing from 2005 (Le Mouël and Forslund 2017).

By 2050, an estimated 72 percent of maize in South Asia will be explicitly allocated for livestock feed, a considerable increase from 34 percent in 2010, reflecting the growing importance of livestock in regional diets (Kruseman et al. 2020), as well as the fact that efficient feed is the optimal solution to the reduction of greenhouse gas emissions in livestock production systems, especially for cattle.

Rapid urbanization alters food consumption habits, with a growing urban population demanding higher-quality and safer food options. By 2050, a significant portion of South Asia's population is projected to reside in urban areas, leading to increased reliance on modern retail and processed foods (Vorley and Lançon 2016).

An alternative pathway developed to sustainably meet the food grain demand of 310 metric tons (MT) in India through specific interventions using a regional model (SAFARI[3]) projects that by 2050, strategies such as shifting to precision irrigation, reducing groundwater dependence, limiting sugarcane acreage, and replacing one-half of rice cultivation with high-yield coarse cereals would help achieve food production sufficiency within the limitations imposed by the availability of natural resources (Ashok et al. 2021).

Despite South Asia being a global hotspot for nitrogen pollution, a concerning projection by Chang and colleagues (2021) suggests that limiting regional nitrogen surplus below a critical boundary without any management strategies could result in a 13 percent reduction in crop and livestock production by 2050. This scenario raises serious concerns regarding dietary energy and protein availability, with up to 495 million people in South Asia potentially at risk of hunger by 2050 due to insufficient nutrient availability.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Foresight studies in South Asia's agrifood systems frequently focus on broad global challenges such as climate change, food security, and economic trends.

3 Sustainable Alternative Futures for India (SAFARI) (Ashok et al. 2021).

However, they often neglect the implications of external shocks such as the Russia-Ukraine war and health-related shocks, including those experienced during the COVID-19 pandemic. These health crises expose significant vulnerabilities within agriculture, labor dynamics, and supply chains, emphasizing the necessity for foresight research that anticipates these impacts more effectively.

Additionally, while sustainable transitions in agriculture are vital, comprehensive multidimensional synergies and trade-off analyses regarding proposed changes are notably lacking. Such analyses are essential for understanding the broader implications of these transitions for farmers' economic viability and the social fabric of farming communities. Furthermore, documented evidence on effective climate-smart options that can be scaled across the region is scarce, limiting the potential for leveraging best practices in the agriculture sector.

Given South Asia's diverse agricultural and economic contexts, a country-specific focus within foresight research on emerging technologies and innovations is imperative. Conducting detailed assessments of technology feasibility and implementation timelines, along with context-specific solutions, would allow individual countries to adopt the advancements most suitable for their unique conditions. The region's significant dependence on imports further exposes it to risks associated with global supply chain disruptions, as demonstrated during the recent COVID-19 pandemic. To mitigate this vulnerability, foresight research should prioritize evaluating strategies aimed at reducing import reliance and enhancing self-sufficiency, especially in pulses and oilseeds, thereby increasing resilience against external shocks.

Limited high-quality data on consumption, productivity, and climate impacts hinder evidence-based policy decisions. The informal economy is vital for food security and employment but is often neglected in foresight studies. Insights into consumer behavior, especially preferences around health and sustainability, remain insufficient, impacting production and supply chains. Finally, investing in alternative agricultural value chains should be a key focus of foresight research to maximize developmental outcomes across South Asia. By addressing these critical gaps, future research can contribute to a more resilient and sustainable agrifood system in the region.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Swamikannu Nedumaran**, a Principal Agricultural Economist in the Global Research Program on Enabling Systems Transformation at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); **Judy Thomas**, a Research Fellow at ICRISAT; **Ravi Nandi**, an Innovation Systems Scientist at the International Maize and Wheat Improvement Center (CIMMYT), Bangladesh; **Jyosthnaa Padmanabhan**, an Associate Scientist at ICRISAT; and **Victor Afari-Sefa**, Director of the Global Research Program on Enabling Systems Transformation at ICRISAT.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Nedumaran, S., J. Thomas, R. Nandi, J. Padmanabhan, and V. Afari-Sefa. 2025. "What Do We Know About the Future of Agrifood Systems in South Asia?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 20. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Prashanth Vishwanathan/CCAFS

References

Ali, S., M. Umair, T.A. Makanda, S. Shi, S.A. Hussain, and J. Ni. 2024. "Modeling Current and Future Potential Land Distribution Dynamics of Wheat, Rice, and Maize under Climate Change Scenarios Using MaxEnt." *Land* 13 (8): 1156. https://doi.org/10.3390/land13081156

Alvi, S., R. Roson, M. Sartori, and F. Jamil. 2021. "An Integrated Assessment Model for Food Security under Climate Change for South Asia." *Heliyon* 7 (4): e06707. https://doi.org/10.1016/j.heliyon.2021.e06707

Ashok, K., R. Natarajan, P. Kumar, K. Sharma, and M. Mathur. 2021. "Sustainable Alternative Futures for Agriculture in India: The Energy, Emissions, and Resource Implications." *Environmental Research Letters* 16 (6): 064001. https://doi.org/10.1088/1748-9326/abf0cd

Baker, P., P. Machado, T. Santos, et al. 2020. "Ultra-Processed Foods and the Nutrition Transition: Global, Regional and National Trends, Food Systems Transformations and Political Economy Drivers." *Obesity Reviews* 21 (12): e13126. https://doi.org/10.1111/obr.13126

Bishwajit, G. 2015. "Nutrition Transition in South Asia: The Emergence of Non-communicable Chronic Diseases." *F1000Research* 4: 8. https://doi.org/10.12688/f1000research.5732.2

Chakraborty, S., and T. Bhaduri. 2023. "Opinion: Nepal Needs a Comprehensive Groundwater Policy." *Dialogue Earth*, July 18. https://dialogue.earth/en/water/opinion-nepal-needs-a-comprehensive-groundwater-policy/

Chang, J., P. Havlík, D. Leclère, et al. 2021. "Reconciling Regional Nitrogen Boundaries with Global Food Security." *Nature Food* 2 (9): 700–711. https://doi.org/10.1038/s43016-021-00366-x

Deb Pal, B., and N.K. Tyagi. 2022. *Synthesis Report: Scaling-Up Climate Smart Agriculture in South Asia*. New Delhi: IFPRI. https://doi.org/10.2499/p15738coll2.135902

Dizon, F., P. Mulmi, and Z. Wang. 2021. "The Cost of a Nutritious Diet in Bangladesh, Bhutan, India, and Nepal." Policy Research Working Paper WPS 9578. World Bank, Washington, DC. https://hdl.handle.net/10986/35285

Enahoro, D., D. Mason-D'Croz, M. Mul, et al. 2019. "Supporting Sustainable Expansion of Livestock Production in South Asia and Sub-Saharan Africa: Scenario Analysis of Investment Options." *Global Food Security* 20: 114–121. https://doi.org/10.1016/j.gfs.2019.01.001

FAO (Food and Agriculture Organization of the United Nations). 2019. *Crop Prospects and Food Situation*, Quarterly Global Report 4. Rome. https://openknowledge.fao.org/handle/20.500.14283/ca7236en

FAO. 2021. *The State of the World's Land and Water Resources for Food and Agriculture: Systems at Breaking Point*. Synthesis Report 2021. Rome. https://doi.org/10.4060/cb7654en

FAO. 2024. *Food Outlook: Biannual Report on Global Food Markets*. Rome. https://doi.org/10.4060/cd1158en

Gillespie, S., M. Van Den Bold, and J. Hodge. 2019. "Nutrition and the Governance of Agri-food Systems in South Asia: A Systematic Review." *Food Policy* 82: 13–27. https://doi.org/10.1016/j.foodpol.2018.10.013

Havlík, P., H. Valin, M. Herrero, et al., 2014. "Climate Change Mitigation Through Livestock System Transitions." *PNAS* 111 (10): 3709–3714. https://doi.org/10.1073/pnas.1308044111

Hinz, R., T.B. Sulser, R. Hüfner, et al. 2020. "Agricultural Development and Land Use Change in India: A Scenario Analysis of Trade-Offs between UN Sustainable Development Goals (SDGs)." *Earth's Future* 8 (2): e2019EF001287. https://doi.org/10.1029/2019EF001287

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Le Mouël, C., and A. Forslund. 2017. "How Can We Feed the World in 2050? A Review of the Responses from Global Scenario Studies." *European Review of Agricultural Economics* 44 (4): 541–591. https://doi.org/10.1093/erae/jbx006

Lin, M.Y., and T. Begho. 2022. "Crop Residue Burning in South Asia: A Review of the Scale, Effect, and Solutions with a Focus on Reducing Reactive Nitrogen Losses." *Journal of Environmental Management* 314: 115104. https://doi.org/10.1016/j.jenvman.2022.115104

Nandi, R., C.M. Pratheepa, S. Nedumaran, N. Rao, and R. Rengalakshmi. 2022. "Farm Parent and Youth Aspirations on the Generational Succession of Farming: Evidence from South India." *Frontiers in Sustainable Food Systems* 5: 804581. https://doi.org/10.3389/fsufs.2021.804581

OECD (Organisation for Economic Co-operation and Development). 2017. *Water Risk Hotspots for Agriculture*. OECD Studies on Water. Paris: OECD Publishing. https://doi.org/10.1787/9789264279551-en

Pingali, P. 2007. "Westernization of Asian Diets and the Transformation of Food Systems: Implications for Research and Policy." *Food Policy* 32 (3): 281–298. https://doi.org/10.1016/j.foodpol.2006.08.001

Prager, S.D., and K. Wiebe. 2021. "Strategic Foresight for Agriculture: Past Ghosts, Present Challenges, and Future Opportunities." *Global Food Security* 28: 100489. https://doi.org/10.1016/j.gfs.2020.100489

Rehman, A., Z. Batool, H. Ma, R. Alvarado, and J. Oláh. 2024. "Climate Change and Food Security in South Asia: The Importance of Renewable Energy and Agricultural Credit." *Humanities and Social Sciences Communications* 11 (1): 1–11. https://doi.org/10.1057/s41599-024-02847-3

Ronto, R., J.H. Wu, and G.M. Singh. 2018. "The Global Nutrition Transition: Trends, Disease Burdens and Policy Interventions." *Public Health Nutrition* 21 (12): 2267–2270. https://doi.org/10.1017/s1368980018000423

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Sarker, N.R., S.M.R. Rahman, and M.Y.A. Khan. 2021. "Feeds & Fodder Production in Bangladesh: Present Trend, Availability, Future Requirements and Challenges for Dairying in 2030." *Growth* 15 (16): 201.

Singh, V., M. Stevanović, C.K. Jha, et al. 2023. "Assessing Policy Options for Sustainable Water Use in India's Cereal Production System." *Environmental Research Letters* 18 (9): 094073. https://doi.org/10.1088/1748-9326/acf9b6

Tran, N., U.P. Rodriguez, C.Y. Chan, et al. 2023. "Future Scenarios of Fish Supply and Demand for Food and Nutrition Security in Bangladesh: An Analysis with the Asia Fish Model." *Aquaculture* 568: 739288.

van Meijl, H., L. Shutes, H. Valin, et al. 2020. "Modelling Alternative Futures of Global Food Security: Insights from FOODSECURE." *Global Food Security* 25: 100358. https://doi.org/10.1016/j.gfs.2020.100358

Vorley, B., and F. Lançon. 2016. "Food Consumption, Urbanisation and Rural Transformation." IIED Working Paper, IIED, London. www.iied.org/10767iied

World Bank. 2021. *Climate Change Action Plan 2021–2025: South Asia Roadmap*. Washington, DC. http://documents.worldbank.org/curated/en/262891632949399367

Woltjer, G.B., M. Kuiper, A. Kavallari, et al.. 2014. *The MAGNET Model: Module Description.* Report 14-57. LEI Wageningen UR: The Hague. https://edepot.wur.nl/310764

Zhang, Y., S. Li, L. Jin, and F. Wu. 2022. "How Will the Global Food Landscape Accommodate Developing Countries' Dietary Change under Urbanization?" *Foods* 11 (22): 3598. https://doi.org/10.3390/foods11223598

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS IN SOUTHEAST ASIA?

Nhuong Tran (HSB-VNU and ANU), Harold Glenn Valera (BSP), Chin Yee Chan (WorldFish), Valerien Olivier Pede (IRRI), Yee Mon Aung (Yezin Agricultural University), and Ronald Jeremy Antonio (BSP)

Key messages

- The food systems of Southeast Asia (SEA) are projected to be under increasing pressure due to multiple drivers, including population growth, urbanization, biodiversity loss, and the uncertainties stemming from climate change.
- Rice and fish will remain staple foods and the backbone of diets in the region's rural and urban areas. In 2019, SEA produced 72 percent of the world's aquatic food products and 25 percent of the world's rice. Rice accounts for 50 percent of calorie intake for its population, while fish contributes more than 50 percent of per capita average animal protein intake. These shares are expected to rise over the next several decades due to population growth.
- Production and consumption of staple foods are expected to fall due to the impacts of climate change, potentially jeopardizing food and nutrition security in the region and beyond. The projected magnitude of climate change impacts on rice production varies greatly, depending on the models used.
- Previous regional foresight studies have explored the implications of climate change on food production in SEA, but other driving forces and outcomes of food systems transformation have received less attention.

RECENT TRENDS AND CHALLENGES

Rice and fish systems are key to food and nutrition security in Southeast Asia (SEA). These systems are subject to increasing pressure due to multiple drivers. Rapid urbanization with high population growth and economic development are projected to increase demand for nutrient-enriched cereals and animal-source foods (livestock and fish). Global climate change, land and environmental change, technological innovations, changes in dietary patterns, and accelerated urbanization will trigger food systems transformation in SEA. The region will remain important in global rice and aquatic food markets. As global annual per capita consumption of aquatic foods increased from 1961 to 2019, the SEA region's per capita consumption also grew, accounting for 72 percent of the total aquatic foods available for human consumption (FAO 2022). Within SEA, per capita consumption of rice decreased in Thailand from the late 1980s through 2020, while it increased in Bangladesh, the Philippines, and Viet Nam (Bin Rahman and Zhang 2023), and is projected to decrease further by 2030 (OECD-FAO 2021). Future growth in rice demand in the region will be mainly due to population growth (Pede et al. 2024).

Yield stagnation and limited land and farming expansion pose key challenges to the region's remaining a major global rice and fish supplier in the context of increasing global and regional demand in the future. One issue for major cereals in the region meeting the increased demand brought by urbanization and change in dietary patterns. Moreover, these crops are also drivers of greenhouse gas (GHG) emissions and natural resource degradation. Aquaculture growth in the region continues to increase to meet the demand for animal protein, but is accompanied by land competition with agriculture, feed competition with livestock, and the problem of using edible fish to feed farmed fish (Zurek, Hebinck, and Selomane 2020).

LATEST FORESIGHT RESEARCH

As food and nutrition security is a major problem in the region, several foresight studies draw pathways to increase the supply of affordable and healthy foods and to ensure consumers' access to them. Current trends suggest that while diets will improve in terms of calories and some micronutrients, the intake of foods that contribute to high-quality diets only in small quantities will tip over into excessive consumption (Haddad et al. 2016). Woodhill et al. (2022) project that by 2025 11 percent of the population will live in moderate poverty in East and Southeast Asia, with agriculture in the latter region employing 56 percent of the impoverished population.

Haddad et al. (2016) projected that SEA would be the third-fastest-growing region in Asia in terms of real per capita gross domestic product by 2030. Sales of ultra-processed foods in East and Southeast Asia are expected to approach those of high-income countries by 2035. A key difficulty for the Philippines will be to bring red meat consumption more in line with recommended levels by 2050. Nearly two-thirds of the South and Southeast Asian population will be overweight or obese by 2030. Findings from Yuan et al. (2022) showed the sizable exploitable yield gaps in the SEA region, particularly in Cambodia, Myanmar, the Philippines, and Thailand. Their study provides insights for increasing regional production on existing cropland by narrowing existing yield gaps. In the SEA region's deltas, sea level rise is becoming more pronounced and is likely to worsen over time, leading to saltwater intrusion and flooding (Schneider and Asch 2020). This will continue to be the major climate hazard affecting the land used for rice cultivation in the region.

Based on a reference scenario with international agricultural research and development continuing along current trajectories, Kruseman et al. (2020) projected that both production and consumption of the major staples in Asia — such as rice, maize, and wheat — will increase between 2010 and 2050. The major cereals retain a dominant role in both the supply and demand sides of the agrifood system. Therefore, investing in agricultural productivity in Asia is imperative to increase cereal production, with rural transformation important to tackling the increasing demand brought by urbanization and dietary change. In terms of projected calorie consumption growth in the region, the share of cereals in calorie intake will decline as diets become richer in animal products and high-value products between 2020 and 2050.

Regarding the linkage between food systems, the environment, and climate change, Zurek, Hebinck, and Selomane (2020) projected that agricultural GHG emissions (particularly from rice production, livestock production, and fertilizer use) would increase by at least 28 percent between 2010 and 2050, suggesting that GHG emissions could be reduced through the development of improved technologies or strategies. Cenacchi et al. (2021) also projected that climate impacts will affect most of the cereal crops in SEA, decreasing income and total calorie availability and increasing the population at risk of hunger (relative to a no-climate-change scenario). They indicated that enhanced investments in public international agricultural research and development could offset the region's climate impacts on food security. Mason-D'Croz et al. (2016) analyzed agricultural investment, enforcement capacity and regional collaboration, land degradation, and market scenarios in Cambodia, Laos, and Viet Nam. The authors projected an increase in rice yield of 10-20 percent by 2030 using the International Model for the Policy Analysis of Agricultural Commodities and Trade (IMPACT) and GLOBIOM models. Using calorie availability as a metric, the authors showed modest future food security improvements.

In the ASEAN (Association of Southeast Asian Nations) region, fish production and consumption are projected to continue growing until 2050. A scenario that is favorable to aquaculture sector development will contribute to increasing fish supply and demand and fish exports and reducing consumer prices compared to business-as-usual (BAU) (Chan et al. 2017; Tran et al. 2017). However, alternative scenarios such as disease outbreaks in aquaculture and climate change result in declining fish supply, demand, exports, and nutrient supply from fish in Bangladesh (Tran et al. 2022b). Climate change represents a potentially significant threat to sustainable fishery production in Viet Nam (Tran et al. 2022a). Using the IRRI Global Rice Model (IRGM), Pede et al. (2024) projected that Asia will remain the world's major source of rice production until 2050, with SEA contributing 27 percent of the region's rice output. The increase in fertilizer prices due to the Russia-Ukraine war also posed a challenge to rice production, given the projected decrease of 0.4-1.4 metric tons per hectare in Asian rice yields due fertilizer price increases (Mishra et al. 2024). Balié and Valera (2020), also using the IGRM, simulated the potential impacts of the removal of quantitative restrictions on rice imports in 2019 and the imposition of a 35 percent import tariff in the Philippines. They projected that the reform would lead to a sharp increase in imports, while domestic production would decline. Perez and Pradesha (2019) conducted a similar simulation using IMPACT and estimated that removing quantitative restrictions would substantially lower farm and retail rice prices. Policymakers would need to consider using the revenue from the tariff to support rice growers either to increase their competitiveness and modernize their rice production or to shift to other crops.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Although a few studies have looked at the future of specific commodities under various scenarios in the SEA region, particularly rice and fish, we are not aware of analyses that examine the implications for other outcome areas, such as gender equity, employment, aquaculture investment cost, GHG emissions, nutrition and poverty, and environmental sustainability, associated with different future projected trends. Future research is needed to explore the impact of major drivers, such as policy change, food system regulations, urbanization, technology innovations, and dietary change issues on food systems activities and outcomes in the region. Change in dietary patterns toward more sustainable, healthy, and balanced diets could be a major driver of change toward more climate-friendly food systems, but more work is needed to understand how diets will evolve and how policies can encourage desired outcomes. Also needed is future foresight work to highlight interactions, trade-offs, and synergies among multiple development outcomes, such as economic development, green growth and GHG emissions reduction, poverty alleviation, and environmental protection. Resolving some of the uncertainties around food system transformation outcomes through future foresight work can help inform how and when to bundle various interventions. Foresight studies can highlight the need for more holistic national policies and investments in agrifood systems to mitigate the effects of climate change with the achievement of climate-smart food systems and the Sustainable Development Goals.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Nhuong Tran**, a Senior Researcher and Lecturer at Hanoi School of Business and Management, Vietnam National University (HSB-VNU), and Honorary Associate Professor in the Crawford School of Public Policy at The Australian National University (ANU), and formerly an Applied Economic Senior Scientist at WorldFish; **Harold Glenn Valera**, a Principal Researcher in the

BSP Research Academy at the Bangko Sentral ng Pilipinas (BSP) in Manila, The Philippines, and formerly a Scientist at the International Rice Research Institute (IRRI); **Chin Yee Chan**, a Scientist at WorldFish; **Valerien Olivier Pede**, a Senior Agricultural Economist at IRRI; **Yee Mon Aung**, a Lecturer at Yezin Agricultural University, Myanmar; and **Ronald Jeremy Antonio**, a Bank Economist IV in the BSP Department of Economic Research at BSP, and formerly an Assistant Scientist at IRRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Tran, N., H.G. Valera, C.Y. Chan, V.O. Pede, Y.M. Aung, and R.J. Antonio. 2025. "What Do We Know About the Future of Food Systems in Southeast Asia?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 21. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Majken Schmidt Søgaard/WorldFish

References

Balié, J., and H.G. Valera. 2020. "Domestic and International Impacts of the Rice Trade Policy Reform in the Philippines." *Food Policy* 92: 101876. https://doi.org/10.1016/j.foodpol.2020.101876

Bin Rahman, A.R., and J. Zhang. 2023. "Trends in Rice Research: 2030 and Beyond." *Food and Energy Security* 12 (2): e390. https://doi.org/10.1002/fes3.390

Cenacchi, N., S. Dunston, T.B. Sulser, et al. 2021. *The Future of Diets and Hunger in Southeast Asia under Climate Change and Alternative Investment Scenarios: Technical Report Based on IMPACT Model Results.* CCAFS Report. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://hdl.handle.net/10568/117912

Chan C.Y., N. Tran, C.D. Dao, et al. 2017. "Fish to 2050 in the ASEAN Region." Working Paper: 2017-01. Worldfish, Penang, Malaysia; IFPRI, Washington, DC. https://hdl.handle.net/20.500.12348/111

FAO (Food and Agriculture Organization of the United Nations). 2022. *The Future of Food and Agriculture: Drivers and Triggers for Transformation*. The Future Agriculture, No.3. Rome. https://doi.org/10.4060/cc0959en

Haddad, L., C. Hawkes, J. Waage, et al. 2016. *Food Systems and Diets: Facing the Challenges of the 21st Century*. https://openaccess.city.ac.uk/id/eprint/19323/

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Mason-D'Croz, D., J. Vervoort, A. Palazzo et al. 2016. "Multi-factor, Multi-state, Multi-model Scenarios: Exploring Food and Climate Futures for Southeast Asia." *Environmental Modelling & Softwares* 83: 255–270. http://dx.doi.org/10.1016/j.envsoft.2016.05.008

Mishra, A., H.G. Valera, T. Yamano, and V. Pede. 2024. "The Russian Invasion of Ukraine, Fertilizer Prices, and Food Security: Evidence from Rice-Producing Economies in Asia." ADB Economics Working Paper Series No. 724. Asian Development Bank, Manila, Philippines. http://dx.doi.org/10.22617/WPS240233-2.

Pede, V.O., H.G. Valera, A.K. Mishra, and J. Balié. 2024. "Future of Rice in Asia: Perspectives and Opportunities, 2050." In *Food Security Issues in Asia*, ed. P. Teng, 108–138. Singapore, Singapore: World Scientific Publishing Co. https://doi.org/10.1142/13469.

Perez, N.D., and A. Pradesha. 2019. *Philippine Rice Trade Liberalization: Impacts on Agriculture and the Economy, and Alternative Policy Options*. NEDA-IFPRI Policy Studies Brief. Washington, DC: IFPRI. https://doi.org/10.2499/p15738coll2.133371

Schneider, P., and F. Asch. 2020. "Rice Production and Food Security in Asian Mega Deltas—A Review on Characteristics, Vulnerabilities and Agricultural Adaptation Options to Cope with Climate Change." *Journal of Agronomy and Crop Science* 206 (4): 491–503. https://doi.org/10.1111/jac.12415

Tran, N., C.Y. Chan, Y.M. Aung, et al. 2022a. "Foresighting Future Climate Change Impacts on Fisheries and Aquaculture in Vietnam." *Frontiers in Sustainable Food Systems* 6: 829157. https://doi.org/10.3389/fsufs.2022.829157

Tran, N., U.-P. Rodriguez, C.Y. Chan, et al. 2022b. "Future Scenarios of Fish Supply and Demand for Food and Nutrition Security in Bangladesh: An Analysis with the AsiaFish Model." *Aquaculture* 568: 739288 https://doi.org/10.1016/j.aquaculture.2023.739288

Tran, N., U.-P. Rodriguez, C.Y. Chan, et al. 2017. "Indonesian Aquaculture Futures: An Analysis of Fish Supply and Demand in Indonesia to 2030 and Role of Aquaculture Using the AsiaFish Model, Mar." *Policy* 79 (2017): 25–32. https://doi.org/10.1016/j.marpol. 2017.02.002

Woodhill, J., A. Kishore, J. Njuki, et al. 2022. "Food Systems and Rural Wellbeing: Challenges and Opportunities." *Food Security* 14: 1099–1121. https://doi.org/10.1007%2Fs12571-021-01217-0

Yuan, S., A.M. Stuart, A.G. Laborte, et al. 2022. "Southeast Asia Must Narrow Down the Yield Gap to Continue to Be a Major Rice Bowl." *Nature* Food 3 (3): 217–226. https://doi.org/10.1038/s43016-022-00477-z

Zurek, M., A. Hebinck, and O. Selomane. 2020. *Food and Agriculture Systems Foresight Study – Implications for Climate Change and the Environment*. Independent Science for Development Council (ISDC).

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
CGIAR IFPRI

What do we know about THE FUTURE OF AGRIFOOD SYSTEMS IN LATIN AMERICA AND THE CARIBBEAN?

Valeria Piñeiro (IFPRI), Guy Hareau (CIP), and Robert Andrade (CIAT)

Key messages

- **Heterogeneity and inequality:** Latin America and the Caribbean's (LAC) agrifood systems are marked by significant disparities across the region and within countries in production, trade, and access to food, with inequality a central challenge. These disparities not only undermine food security but also hinder the region's ability to develop sustainable and resilient food systems.

- **Sustainability and climate resilience:** The future of LAC's agrifood systems will be shaped by the region's ability to balance agricultural growth with environmental sustainability and the conservation of the stock of natural resources in the long run.

- **Role of policies:** Closing the gap between the rich and poor, between large and small producers, and between urban and rural populations requires targeted action, including investing in rural infrastructure, facilitating access to appropriate technologies, and encouraging regional cooperation.

- **Specialization and governance:** The region's continued specialization in agricultural exports presents both opportunities and challenges. Strengthening food security governance frameworks and promoting inclusive policies will be essential to ensure that the benefits of agricultural growth are shared more equitably and that agrifood systems are resilient in the face of climate change and other global challenges.

- **Foresight research** can help address these challenges, focusing on the consequences of structural transformation, the trade-offs between agricultural productivity and sustainable management of LAC natural resources, the long-term effects of climate change, and how disruptors and drivers of agrifood systems transformation can affect the different LAC regions and countries.

RECENT TRENDS AND CHALLENGES

The Latin America and the Caribbean region (LAC) is highly heterogeneous, marked by stark contrasts in agricultural production, food security, trade, and natural resource distribution. This diversity, both in terms of geography and socioeconomic contexts, presents a range of challenges and opportunities for the region's agrifood systems. To effectively address these, it is crucial to understand the regional trends shaping agriculture and food security and consider the ways in which they affect efforts to promote equitable and sustainable agrifood systems transformation.

The LAC region is a major global player in agricultural production and trade. Several countries, including Brazil and Argentina, are among the world's largest producers and exporters of commodities such as soybeans, coffee, sugar, and beef (Figure 1) (see also Chapter 23). LAC accounts for a larger share of global agricultural production than the European Union or the United States plus Canada. Large amounts of cropland, relatively low domestic consumption, and favorable policies have made LAC the world's largest net food exporter, so the region plays a critical role during global food crises.

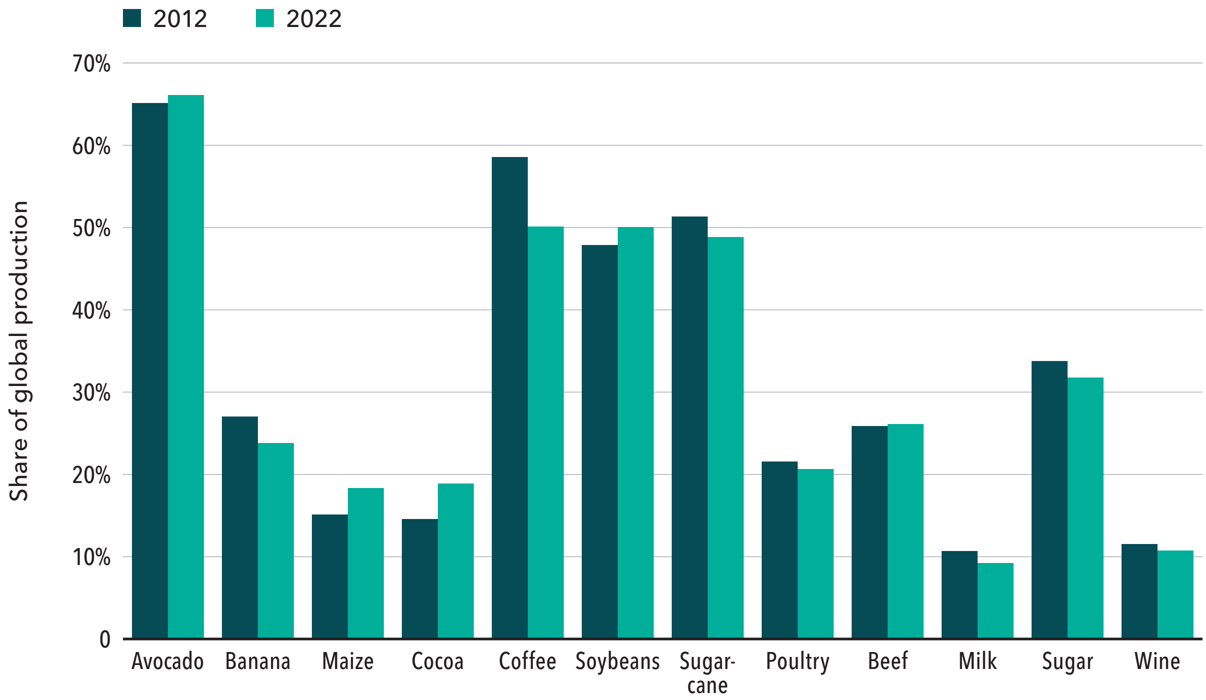
The region boasts a wealth of natural resources, including vast arable lands, forests, and savannahs; freshwater reserves; and biodiversity hotspots, which collectively position it as a key contributor to shaping global weather patterns, mitigating climate change, and improving global food security.

However, this apparent abundance coexists with significant food insecurity, particularly in poorer and more vulnerable populations. For instance, countries such as Haiti and Venezuela experience some of the highest levels of food insecurity in the region, with widespread malnutrition and limited access to sufficient, safe, and nutritious food. In the Andean highlands, highly productive valleys coexist with poverty pockets where people barely meet their daily needs. At the same time, LAC countries face rising rates of obesity and diet-related noncommunicable diseases, particularly in urban populations, creating a paradox of undernutrition and overnutrition within the same populations. This dual burden reflects the deep-rooted inequalities that characterize the region, where access to resources, technology, and markets is unevenly distributed.

Trade is another critical factor shaping LAC's food systems. The region is highly integrated into global markets, with significant portions of its agricultural output destined for export. To enhance resilience, it is essential for LAC to diversify both its sources of production and the destinations for its products. Relying too heavily on a few key markets or commodities leaves the region vulnerable to external shocks, such as fluctuating global commodity prices, trade policy shifts, and global disruptions including political instability, conflicts, and the COVID-19 pandemic. The pandemic, in particular, exposed inefficiencies in food supply chains and underscored the need for diversified, resilient, and equitable agrifood systems capable of weathering future disruptions. By broadening its trade relationships and promoting regional markets, LAC can reduce risks and foster more sustainable food systems.

LAC's rich biodiversity, ecological diversity, and water reserves are vital to its agricultural systems. The Amazon rainforest, for example, is not only a crucial carbon sink but also supports a wide variety of ecosystem services that are essential for sustainable agriculture. Yet environmental degradation, deforestation, and unsustainable farming practices are increasingly threatening these natural resources, leading to concerns about the long-term sustainability of the region's food production systems.

FIGURE 1 **LAC's share of global production, selected commodities, 2012 and 2022**



Source: Authors' elaboration based on FAOSTAT. https://www.fao.org/statistics/en

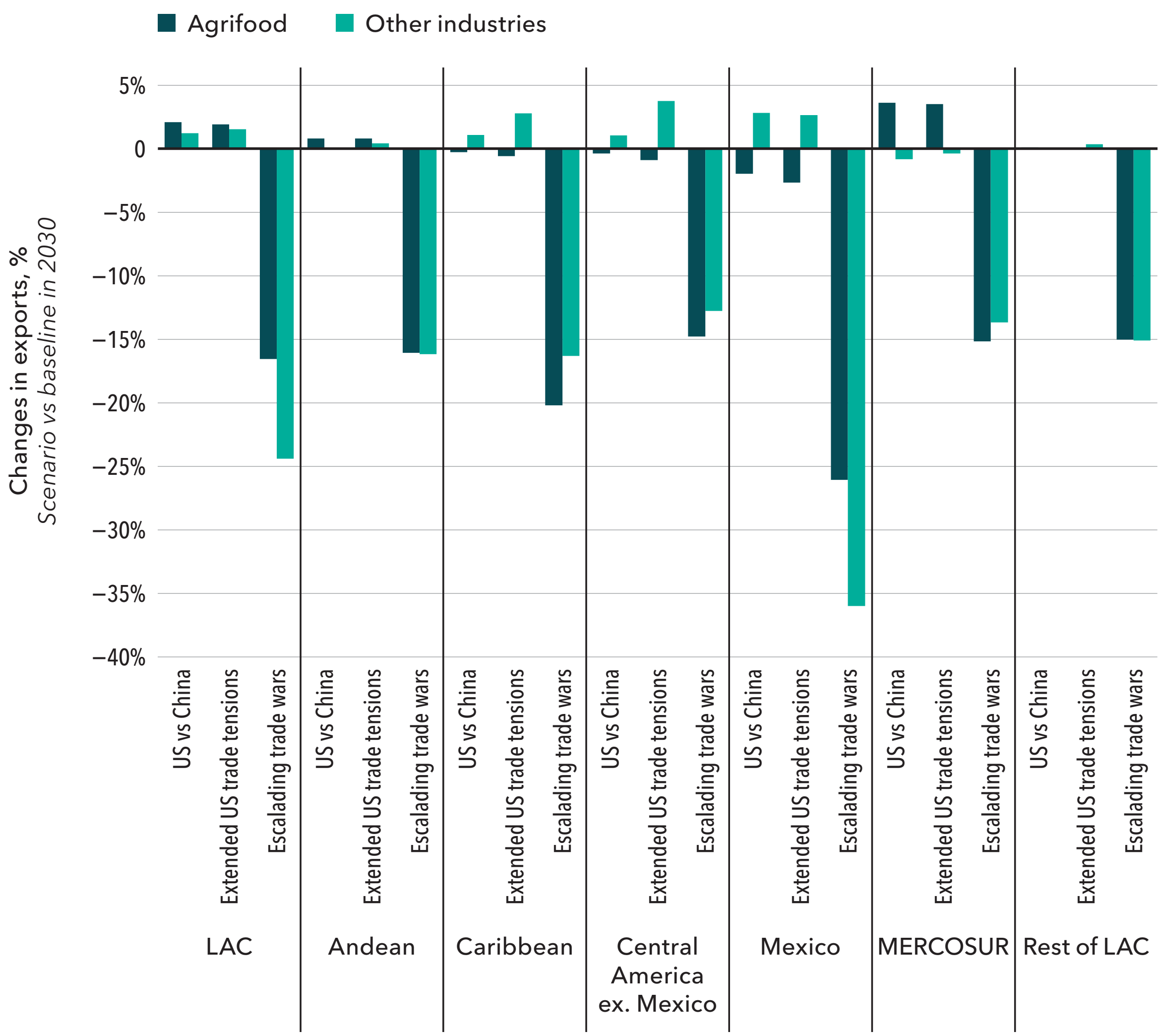
LATEST FORESIGHT RESEARCH

One of the most recent comprehensive studies on the future of food systems in LAC (Morris et al. 2020) examines the complex trade-offs between growing the economy, reducing poverty, feeding the population, and preserving vital ecosystems. Managing these trade-offs will be essential to avoid extremely high costs to the region and the world. While LAC's population is projected to grow modestly – from around 660 million in 2024 to around 730 million by 2050 – demand for food, particularly animal-source food, is expected to rise significantly due to changing diet patterns and demand from international markets. The authors recognize four distinct groups of countries based on size, location, ecological and climatic characteristics, and agricultural economies: (1) Mexico and Central America, (2) the Caribbean States, (3) the Andean Zone, and (4) the Southern Cone (including Brazil). This heterogeneity is also evident in the different types of food systems (traditional, transitional, and integrated) that are present in all countries with varying relative importance. They identify nine drivers of agriculture and food systems transformation (population growth, urbanization, migration, income growth, changing tastes and dietary preferences, productivity growth, emerging technologies, climate change, and policies) and create five scenarios, with different drivers influencing each of them: The Age of Exodus; Healthy Diets Rule; Fragmented World; LAC Agro-Export Powerhouse; and Agri-food 4.0. In light of recent developments, one of the drivers missing from this report is the political instability in several LAC countries, which indirectly influences agricultural policies (Figure 2).

Four insights are drawn from these scenarios: (1) the importance of both supply and demand-side factors; (2) the degree of openness of the global trading system; (3) technology as a double-edged sword that could leave millions behind if some population groups are unable to gain access to it; and (4) the unpredictable effects of climate change. The study proposed a set of 20 actions, some imperative and others more strategic, to address the challenges posed by these scenarios.

Modeling projections from Rosegrant et al. (2024) show that by 2050 total production of selected groups of commodities are expected to grow in LAC between 40 percent (roots and tubers, animal products, and fruits and vegetables)

FIGURE 2 Changes in exports under three trade war scenarios, LAC countries



Source: Morris et al. (2020), based on IFPRI MIRAGRODEP CGE simulations (for background information, see Piñeiro et al. 2020).

and 83 percent (cereals), the world's highest increase. Yields grow between 19.9 percent (fruits and vegetables) and 39.7 percent (pulses), while area grows between 14.4 percent (roots and tubers) and 38.3 percent (cereals). The combination of area and yield growth increases LAC's share in global cereal production by 2050, although this includes production of maize as animal feed and for industrial purposes (Kruseman et al. 2020). A major outcome projected by this modeling scenario is that LAC also reduces the number of hungry people by 2050, although it does not reach the 5 percent target of Sustainable Development Goal (SDG) 2.1 until 2040. Challenges to achieving SDG goals in LAC relate to food affordability rather than availability, reflecting a combination of issues such as income distribution, inflation, widespread rural poverty, and macroeconomic instability in many countries (OECD 2024).

Patrouilleau, Taraborrelli, and Alonso (2022) focus on policies governing future food systems for different LAC countries, highlighting that different models of agricultural development and inequality in natural resources distribution have led to the deterioration of the food security situation for some rural groups, and note that the future of trade agreements in the region is diverse and uncertain. To provide a more adequate analytic framework given the region's heterogeneity, the authors propose that future food systems studies move from the regional to a subregional or country scale. Similar conclusions are drawn by Schneider et al. (2025), who propose a system to track governance of food systems at a regional or subregional scale. Rivera (2023), analyzing policies that affect the transformation of food systems in LAC, proposes that country studies integrate joint analysis with other policies such as social protection. The Inter-American Development Bank also found divergence between LAC countries in terms of trends in agricultural policies such as producer and consumer price support and carbon-neutral emissions, although it does not provide foresight analysis for these policies (Conroy et al. 2023).

While domestic policies to increase export-oriented food production continue in the short and even medium term, helping governments address for example, food security and poverty, trade-offs between food production and the environment (including keeping the biodiversity stock) are among the most pressing challenges the region faces to realize its comparative advantage in world food markets and to sustain its dominant position in global food markets in the long term.

One of the most pressing challenges facing LAC's agrifood systems is the persistent inequality that defines the region. Inequality in access to resources, opportunities, and outcomes continues to widen the gap between the rich and the poor, between smallholder farmers and large-scale agribusinesses, and between rural and urban populations. This inequality is mirrored in the region's agrifood systems, where the benefits of agricultural growth are not evenly distributed, leaving many vulnerable populations behind.

Closing this gap will require targeted and comprehensive action on multiple fronts. First, there is a need to address structural inequalities that limit access to land, credit, technology, and markets for smallholder farmers and marginalized communities. These groups are often excluded from the benefits of modern agricultural advancements and remain trapped in low-productivity, subsistence farming. Empowering these farmers through inclusive policies, investments in rural infrastructure, and access to financial services can help unlock their potential and drive more equitable growth.

Second, enhancing regional integration and cooperation is critical to overcoming the fragmentation that characterizes LAC's food systems. Although countries in the region share similar challenges — such as climate change, market volatility, and social inequality — their responses to these issues are often disconnected. Greater coordination among governments, regional organizations, and international partners is needed to harmonize policies, share best practices, and foster collaboration on shared priorities, such as climate resilience and sustainable development.

Third, innovation and technological advancement hold the key to transforming the region's agrifood systems. Precision agriculture, digital platforms, and climate-smart technologies have the potential to boost productivity, reduce environmental footprints, and improve farmers' livelihoods. However, these innovations must be accessible to all, not just to the wealthiest and most technologically advanced players. Public and private sector investments in R&D, along with capacity-building programs for smallholder farmers, are essential to ensuring that these technologies benefit the entire region.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Looking ahead, the future of agriculture and food systems in LAC is shaped by several key trends, including the increasing specialization of agricultural production, evolving governance structures, structural transformation due to domestic migration, and the growing importance of sustainability in food systems.

While specialization, driven by comparative advantage and global market demands, will continue to dominate the region's agricultural landscape, there is growing need for diversification. Countries such as Argentina, Brazil, and Mexico will likely continue to be major exporters of food commodities, while smaller countries may develop niche markets for high-value crops (such as Peru for fruits and vegetables). However, all countries may seek to broaden their production base to enhance resilience, reduce dependency on specific markets, and create more inclusive opportunities for smallholder farmers within global value chains.

Governance will play a critical role in shaping the future of LAC's agrifood systems. As the region faces growing pressures from climate change, population growth, and environmental degradation, governments will need to strengthen their regulatory frameworks and policies to promote sustainable agriculture and food security. This will require a shift from short-term, market-driven solutions to long-term, inclusive strategies that prioritize social equity, environmental protection, and economic resilience.

Structural transformation is rapidly reshaping the rural landscapes in LAC. Rural–urban migration and the reduction in the average size of rural families are leaving communities in certain areas as ghost towns, where farmers only show up to help with their crops during the peak demand for labor. At the same time, this demographic change drives technological change that is not yet fully understood.

Four relevant research questions are proposed for future foresight research in LAC food systems transformation:

1. What consequences will the ongoing structural transformation in LAC (including rural–urban migration) have for food systems (both export and domestic market-oriented)? And how do other policies, such as social protection and agricultural programs, influence these trajectories?

2. What strategies can be implemented to enhance agricultural productivity in LAC while ensuring the sustainable management of natural resources such as land, water, biodiversity, and carbon stocks? And what are the potential benefits to other regions of the rich genetic diversity in the LAC region?

3. How will climate change affect long-term agricultural production in LAC?

4. How will current and future trends and disruptors of major drivers of the agrifood system affect the different LAC regions (Mexico and Central America, the Caribbean States, the Andean Region, and the Southern Cone)?

The future of LAC's food systems hinges on the region's capacity to address its deep-seated inequalities and navigate the growing challenges of climate change and the vulnerability of the region to shocks. Without targeted interventions, persistent disparities in access to resources, technology, and markets will continue to fuel cycles of poverty, food insecurity, and environmental degradation. However, with coordinated efforts from governments, the private sector, and civil society, LAC can transform its agrifood systems into more inclusive, resilient, and sustainable models. By embracing innovation, climate-smart agriculture, and sustainable resource management, the region can both enhance its contribution to global food security and also position itself as a leader in building climate-resilient food systems capable of thriving in the face of future challenges.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Valeria Piñeiro**, Regional Representative for Latin America and the Caribbean and Senior Research Coordinator in the Markets, Trade and Institutions Unit at the International Food Policy Research Institute (IFPRI); **Guy Hareau**, a Principal Scientist in Social and Nutritional Sciences at the International Potato Center (CIP); and **Robert Andrade**, a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at the International Center for Tropical Agriculture (CIAT).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Piñeiro, V., G. Hareau, and R. Andrade. "What Do We Know About the Future of Agrifood Systems in Latin America and the Caribbean?" In *What Do We Know About the Future of Food Systems?*, edited by K. Wiebe and E. Gotor, Chapter 22. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Curioso.Photography/Shutterstock

References

Conroy, H.V., G. Rondinone, C.P. De Salvo, and G. Muñoz. 2023. *Agricultural Policies in Latin America and the Caribbean.* IDB Monograph No. 1226. Washington, DC: Inter-American Development Bank. http://dx.doi.org/10.18235/0013100

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-Food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Morris, M., A.R. Sebastian, V.M.E. Perego, et al. 2020. *Future Foodscapes: Re-imagining Agriculture in Latin America and the Caribbean.* Washington, DC: World Bank Group. https://hdl.handle.net/10986/34812

OECD and FAO (Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations). 2024. *OECD–FAO Agricultural Outlook 2024–2033*. Paris: OECD. https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2024-2033_4c5d2cfb-en

Patrouilleau, M.M., D.S. Taraborrelli, and I. Alonso. 2022. "Futures Studies and the Food Question in Latin America: A Literature Review." In *Public Policies and Food Systems in Latin America*, eds. J.-F. Le Coq, C. Grisa, S. Guéneau, and P. Niederle, Chapter 2. Versailles: éditions Quae https://library.oapen.org/handle/20.500.12657/57572

Piñeiro, V., T.S. Thomas, D. Laborde, and E. Diaz-Bonilla. 2020. "Drivers and Disruptors Shaping the Future of Agriculture and the Food System in LAC: Climate Change and Trade Tensions." IFPRI Discussion Paper 1967. IFPRI, Washington, DC. https://doi.org/10.2499/p15738coll2.134084

Rivera, R. 2023. *Leveraging Social Protection and Economic Inclusion Interventions for Agrifood System Transformation: A Case Study of Peru*. Rome: Food and Agriculture Organization. https://doi.org/10.4060/cc5740en

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security Under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Schneider, K.R., R. Remans, T.H. Bekele, et al. 2025. "Governance and Resilience as Entry Points for Transforming Food Systems in the Countdown to 2030." *Nature Food* 6: 105–116. https://doi.org/10.1038/s43016-024-01109-4

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FOOD SYSTEMS IN SELECTED COUNTRIES?

CGIAR | INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE IFPRI

What do we know about THE FUTURE OF AGRICULTURE IN ARGENTINA, BRAZIL, PARAGUAY, AND URUGUAY?

Nicolas Jorge (Bolsa de Cereales), Silvia Kanadani Campos (Embrapa), Juan Pablo Gianatiempo (IFPRI), Vanessa da Fonseca Pereira (MAPA and Embrapa), and Valeria Piñeiro (IFPRI)

Key messages

- Argentina, Brazil, Paraguay, and Uruguay (ABPU) have significant weight in the global agricultural market. In 2020–2022, the bloc accounted for 53.1 percent of Latin America and the Caribbean's total agricultural exports, and 9.3 percent of the world total. This contribution is key in many products at the global level too, such as soybean products (for which the group accounts for 56 percent of world trade), corn (32 percent), bovine meat (26 percent), poultry meat (20 percent), pork meat (6 percent), and wheat (6 percent) (2020–2022 Comtrade data).

- These commodities are essential for global food security, particularly in regions with growing populations and increasing food demand, notably Asia and Africa. Ensuring the sustainability of ABPU production is paramount not only for food security but also for environmental concerns.

- ABPU projections show robust growth in cereal and oilseed production, which is expected to increase by 26 percent (118 million tons) by 2033/34 relative to 2023/24. Total exports of cereals and oilseeds are projected to rise by 74 million tons, reaching 355 million tons, driven largely by corn, soybeans, and wheat.

- Despite slowing growth in global demand and trade of food products, opportunities exist for ABPU countries to increase their food production and exports. Making the most of these opportunities will require increasing yields to maintain production growth while ensuring sustainability. To this end, technological advancements such as minimal soil disturbance, permanent cover cropping, crop diversification, intensive fattening, biotechnology, biological inputs, and precision agriculture can help increase productivity while minimizing environmental impact.

- The investments required to increase the use of enhanced technology could benefit greatly from a more stable political and macroeconomic context, as well as clear and consistent policies. For example, multilateral trade negotiations in agriculture should not be undermined.
- Collaboration among ABPU countries could greatly enhance the strategies needed to achieve these sustainability and food security objectives. The analysis described here is intended to kick-start this collaboration, which has shown significant potential for future work.

RECENT TRENDS AND CHALLENGES

The Argentina, Brazil, Paraguay, and Uruguay (ABPU) bloc plays an important role in global food systems and food security, as the world's leading net food-exporting region. It is a substantial economic force, with total agricultural exports valued at US$186 billion and net agricultural trade at US$164 billion.

In particular, in 2020–2022, the bloc accounted for 53.1 percent of Latin America and the Caribbean's total agricultural exports, and 9.3 percent of the world total. This contribution is key in many products at the global level too, such as soybean products (for which the group accounts for 56 percent of world trade), corn (32 percent), bovine meat (26 percent), poultry meat (20 percent), pork meat (6 percent), and wheat (6 percent) (2020–2022 Comtrade data).

The huge contribution of the agriculture sector to ABPU exports makes the sector crucial for these countries. Among their top 20 exported products, 10 are from the agrifood sector. In terms of trade trends, ABPU countries' share of grain and oilseed exports has risen. Notably, participation of Asian countries among export destinations is increasing, while shares to North America and the European Union (EU) have declined.

Two disruptive factors influencing global agrifood systems are emerging: climate change and increasing geopolitical fragmentation. Both disruptors would generate a heterogeneous impact on different regions and countries and thus alter their relative advantages in production and trade. Disruptions generated by climate change would have a greater impact. In particular, product groups mainly destined for domestic markets would be more vulnerable and the adverse effects are expected to be greater in the countries that produce them. This phenomenon alters the structure of international trade, with certain products and regions gaining advantages due to climate change and geopolitical fragmentation, while others experience adverse effects. ABPU countries would improve their comparative advantages in vegetable oils, dairy and eggs, and fruits and vegetables. These emerging trends raise critical questions about the future of global trade, necessitating further analysis to understand the implications of these disruptions. The modeling section below will present quantitative results that further illustrate these dynamics.

The region is facing several specific challenges already, including an increasing number of certifications, the EU 2023/1115 regulation,[1] and slow growth or stagnation in total factor productivity (TFP). While the Latin America and Caribbean region experienced relatively high total factor productivity (TFP) growth during the 1990s and 2000s, this growth slowed considerably in the past decade. The notable exception is Brazil, which has maintained exceptionally high TFP growth over the last 20 years (Laborde and Piñeiro 2022). Additionally, countries are grappling with the growing number of unilateral measures imposed by some nations, exemplified by the EU's Deforestation Regulation (EUDR), which require exporters to ensure product traceability and compliance with stringent regulations.

Addressing these challenges in ABPU amid the disruptive scenarios posed by climate change and geopolitical fragmentation is vital for ensuring global food security. Moreover, coordinated political action within this bloc is essential. By working together, member countries can leverage their collective strengths to develop innovative

1 EU Deforestation Regulation (Regulation (EU) 2023/1115), published in mid-2023, aims to minimize deforestation and forest degradation associated with agricultural raw materials imported into the European Union. It is part of the EU's biodiversity strategy running to 2030.

strategies that adapt to environmental changes and shifting global markets. This collaborative approach could not only bolster food security in the region but also promote sustainable production practices, ensuring that food systems are both environmentally friendly and economically viable. Coordinated action also has the potential to attract green investment, strengthening the capacity of ABPU countries to contribute to global food security in a sustainable way.

LATEST FORESIGHT RESEARCH

Developing an agricultural outlook for the MERCOSUR founding countries — Argentina, Brazil, Paraguay, and Uruguay — is essential for understanding the region's specific agricultural dynamics. While international organizations such as the Food and Agriculture Organization of the United Nations (FAO) and the Organisation for Economic Co-operation and Development (OECD) provide valuable global projections, ABPU-focused forecasts offer localized insights that better reflect these countries' unique characteristics and perspectives. Given that various projections are based on differing assumptions about future trends, a tailored ABPU outlook adds significant value by addressing the region's distinct needs.

The process to develop these projections involved three steps. First, we established the assumptions for the key drivers, including population, macroeconomic growth, and productivity trends. Then we used partial equilibrium modeling to simulate the projected periods. In the third step, the results were reviewed with experts from ABPU countries, who analyzed and validated the model's assumptions and outputs and suggested corrections, moving the process back to the first step.

Although our focus is on ABPU countries, it is also critical to account for key global trends during the projected period (2023/24 to 2033/34), informed by sources such as OECD-FAO (2024) and the U.S. Department of Agriculture (USDA) (Dohlman, Hansen, and Chambers 2024). First, growth in global food demand is expected to slow compared to previous decades due to decelerating population and economic growth, though consumption growth will still exceed population growth. Additionally, current net exporters will likely expand their export capacity, while net importers are expected to increase their imports. Finally, price projections face high uncertainty, with potential volatility arising from economic fluctuations and extreme weather events that could significantly disrupt markets.

In the context of these global trends, ABPU projections show robust growth in cereal and oilseed production, which is expected to increase by 26 percent (118 million tons) by 2033/34 relative to 2023/24 (Figure 1). This growth will result from a combination of productivity improvements and a 12 percent increase (15 million hectares) in harvested area. Total exports of cereals and oilseeds are projected to rise by 74 million tons, reaching 355 million tons, driven largely by corn, soybeans, and wheat.

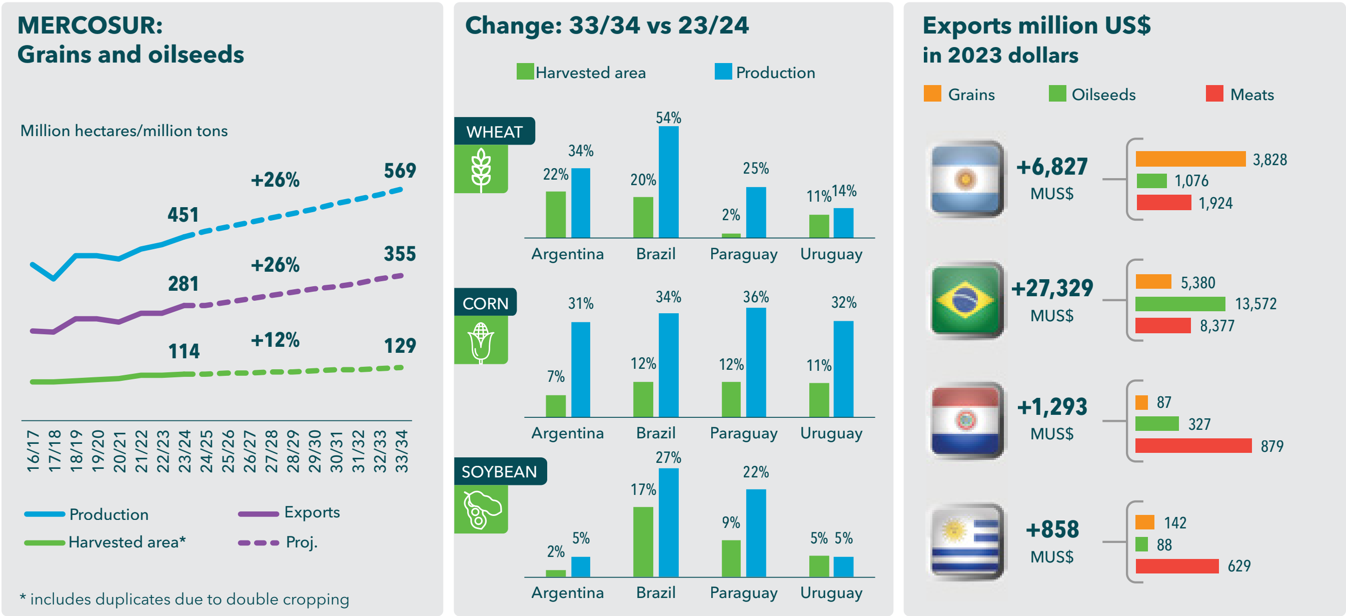
Specifically, ABPU wheat yields are projected to increase from 2.7 to 3.1 tons per hectare (+15 percent), corn from 5.9 to 7.1 tons per hectare (+20 percent), and soybeans from 3.2 to 3.5 tons per hectare (+8 percent). However, these projected 2033/34 yields remain below the potential yields estimated by the Global Yield Gap and Water Productivity Atlas. Corn production, in particular, is expected to increase by 58 million tons (+33 percent) over 2023/24 levels, with yield improvements contributing 68 percent of this growth. Corn exports are anticipated to grow by 31 million tons to reach 113 million tons. Part of Brazil's additional production serves domestic needs, especially animal feed and ethanol, but it also explains more than one-half of ABPU's increase in exports (+20 million tons). Argentina's exports will rise by 11 million tons, partly due to recovery from the 2023 corn stunt disease, while Paraguay and Uruguay are expected to see production growth largely absorbed by domestic use, resulting in minimal net trade changes.

ABPU countries' soybean production is projected to grow by 46 million tons (+21 percent), with exports increasing by 34 million tons to reach 141 million tons by the end of the period. Brazil will lead in soybean exports with an increase of 31 million tons, followed by Argentina with 4 million, Paraguay with 2 million, and Uruguay with 220,000 tons. Overall, soybean processing will increase by 13 million tons, with a rise in local soybean oil consumption, primarily for biodiesel.

Wheat production in ABPU countries is expected to increase by 9.9 million tons (+39 percent), with exports up by 3.7 million tons, led mainly by Argentina. Brazil's wheat consumption will grow by 2.6 million tons, but net imports will decline as local production rises.

In the meat sector, total production is projected to grow by 5.8 million tons, with poultry reaching 20 million tons,

FIGURE 1 Agricultural outlook for MERCOSUR



Source: Author's calculations based on PEATSim-AR model.

followed by beef at 17 million tons, and pork at 6.7 million tons. By the end of the projection period, poultry exports are expected to surpass beef exports in volume, with all ABPU countries showing substantial growth.

Overall, these projected exports are estimated to generate US$36.3 billion for ABPU countries, including $6.8 billion for Argentina, $27.3 billion for Brazil, $1.3 billion for Paraguay, and $0.85 billion for Uruguay.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

This analysis could be improved or extended in many areas, each of them opening new research paths. For example:

- ***Multicropping and integrated systems.*** Current results do not track the differences between first or second crops. They also do not consider integrated productive systems, such as crop-livestock-forestry systems. Projections for these would allow for better understanding of total land use and yield growth.
- ***Regionalization.*** Given that ABPU countries contain many heterogeneous productive regions, insights on the future evolution in smaller areas would be useful.
- ***Land use change.*** How will production growth affect land use change and deforestation? What is the expected impact of the increase of deforestation-free requirements affecting ABPU production and exports?
- ***Climate change.*** How would different climate change scenarios affect production and food availability in these countries?
- ***Climate change adaptation.*** What specific adaptation measures are needed in different regions of ABPU to mitigate the impacts of climate change on agricultural production?
- ***Policy coordination.*** How can ABPU countries better coordinate their agricultural policies to enhance regional competitiveness and address shared challenges?
- ***Sustainable intensification.*** How can technological innovations and sustainable agricultural practices be promoted to increase yields while minimizing environmental impacts?

- ***Logistics.*** How are agrifood products transported in these countries, and what investments are required? What would be the impact of major logistics and infrastructure projects?

- ***Stochastic analysis.*** Given that projections are heavily affected by alternative assumptions regarding gross domestic product growth and weather events, it would be interesting to estimate confidence intervals for the main variables.

- ***Nutritional analysis.*** How can we enhance our understanding of the nutritional content of food produced in different agriculture systems? Investigating nutrient availability alongside food production can inform policies aimed at improving food security and public health outcomes.

- ***Emissions measurement.*** Quantifying greenhouse gas emissions from agricultural practices in different regions could provide information on the most effective strategies to reduce emissions while maintaining productivity. The greenhouse gas emissions could also be used to environmentally adjust productivity measures.

- ***Sustainability.*** Understanding the interaction between water availability and agricultural production is crucial to ensure sustainable food production.

- ***Competing markets.*** What would be the impact on ABPU of increased agricultural production in Africa?

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Silvia Kanadani Campos**, a Researcher at the Brazilian Agricultural Research Corporation (Embrapa); **Juan Pablo Gianatiempo**, a Research Analyst in the Markets, Trade, and Institutions (MTI) Unit at the International Food Policy Research Institute (IFPRI); **Nicolas Jorge**, an Economist at Bolsa de Cereales, Argentina; **Vanessa da Fonseca Pereira**, an Advisor at the Ministry of Agriculture and Livestock (MAPA) and an Analyst at Embrapa, Brazil; and **Valeria Piñeiro**, Regional Representative for Latin America and the Caribbean and Senior Research Coordinator in MTI at IFPRI.

The authors acknowledge the collaboration provided by Jimena Masaro (CEO Group); Miguel Carriquiry (UDELAR); Manuel Brusquetti (UGP); Nelson Illescas and Washington Duran (GPS); Cecilia Conde, Sebastián Gariboldi, and Estefanny Vasquez (Buenos Aires Grain Exchange); Adalberto Araujo, Alcido Wander, Álvaro Dossa, André Moraes, Aryeverton Fortes, Glauco Carvalho, Hilton Ferraz, Jason Duarte, Marcelo Miele, Moacir Pedroso Junior, Paulo do Carmo Martins, Rafael Mingoti, and Rosana Guiducci (Embrapa); and Nicholas Blikstad (Scholarship holder at Embrapa).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Kanadani Campos, S., J.P. Gianatiempo, N. Jorge, V. da Fonseca Pereira, and V. Piñeiro. 2025. "What Do We Know About the Future of Agriculture in Argentia, Brazil, Paraguay, and Uruguay?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 23. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Mix Tape/Shutterstock

References

UN Comtrade Database. https://comtradeplus.un.org/

Dohlman, E., J. Hansen, and W. Chambers. 2024. *USDA Agricultural Projections to 2033*. Washington, DC: U.S. Department of Agriculture.

Global Yield Gap and Water Productivity Atlas. 2024. Accessed Aug. 30, 2024. www.yieldgap.org

Laborde, D., and V. Piñeiro. 2022. "The Impact of Changes in the Fundamental Drivers of Trade: Productivity, Trade Costs, and Trade Policies." Background paper for *The State of Agricultural Commodity Markets 2022*. Rome: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cc3135en

OECD (Organisation for Economic Co-operation and Development) and FAO (Food and Agriculture Organization of the United Nations). 2024. *Agricultural Outlook 2024–2033*. Paris: OECD Publishing; Rome: FAO. https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2024-2033_4c5d2cfb-en

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF AGRICULTURE SYSTEMS IN CHINA?

Xinru Han (IAED, CAAS), Xiangdong Hu (IAED, CAAS), and Kevin Chen (IFPRI and Zhejiang University)

Key messages

- Addressing the dual challenge of limited resources and a large population, China must prioritize sustainable agricultural practices to ensure food security and environmental sustainability.
- The shift toward a more nutritionally balanced diet by 2050 will not only improve public health but also significantly alter the demand patterns for various food commodities, increasing the need for strategic adjustments in agricultural production.
- Technological innovation in agriculture presents a critical solution to overcoming constraints of land and water, highlighting the importance of continued investment in research and development for sustainable growth.
- Future agricultural transformations will likely involve a move away from traditional small-scale farming toward more efficient and cooperative agricultural models, driven by rural demographic changes and the growth of socialized service organizations.

RECENT TRENDS AND CHALLENGES

The transformation of China's agricultural system needs to be based on two fundamental realities. The first is that China is a large country with small-scale farmers (Ji et al. 2016; Yu 2012). China has 187 million farming households (NBS 2024). According to the data from the third agricultural census, small-scale farming households account for more than 98 percent of the total agricultural business entities, and the cultivated land area operated by small-scale farming households accounts for 70 percent of the total cultivated land area in China. The second reality is food security. There is an old saying in China: "The people are the foundation of a country, and food is the primary need of the people." The enormous food demand of China's population of more than 1.4 billion cannot be expected to be fully met by relying on the international market (Han 2020; Huang and Yang 2017). While the Food and Agriculture Organization of the United Nations' (FAO) definition of food security covers several dimensions, China's food security has mainly focused on grain self-sufficiency (Huang and Yang 2017). If food self-sufficiency cannot be guaranteed, China's national development may be hindered. As residents' consumption demand shifts from "eating enough" to "eating well" and "eating nutritiously and healthily," China needs to use its limited water and land resources to promote agricultural transformation in the direction of sufficient quantity, good quality, green ecology, high efficiency, and optimal structure of food production.

China's agricultural system currently faces numerous challenges that threaten its sustainability and food security, as follows.

Resource constraints and a large population. China faces significant resource constraints in agricultural land and water per capita compared with other major agricultural producers. Despite accounting for approximately 20 percent of the global population, China has only 9 percent of the world's arable land and 6 percent of its freshwater resources (FAO 2024). In 2021, China's arable land per capita was 0.08 hectares (ha), significantly lower than the world average of 0.18 ha and that of other major producers, such as the United States (0.47 ha), Australia (1.21 ha), and Brazil (0.27 ha) (FAO 2024). Moreover, the seven major grain-producing regions in north China, which contribute 50 percent of the total grain output, have access to only 10.84 percent of the country's water resources. Depletion of groundwater in these regions due to irrigated agriculture exacerbates these resource constraints (China, Ministry of Water Resources 2022).

Growing import dependence and risks. These resource constraints are compounded by China's increasing import dependence, particularly for key commodities such as soybeans. In 2023, China's grain imports exceeded 159 million metric tons (MMT), reducing the self-sufficiency ratio to approximately 81 percent (GAC 2024; NBS 2024). Soybean imports, essential for animal feed, account for the bulk of these imports. Net grain imports in 2023 reached 159.3 MMT, a significant increase from 59.1 MMT in 2010, while the self-sufficiency rate dropped from 90.4 percent to 81.4 percent in the same years (GAC 2024; NBS 2024). Soybean imports in 2023 reached 99.4 MMT, with a self-sufficiency rate of only 17.3 percent (GAC 2024; NBS 2024). This import dependence creates vulnerabilities to geopolitical tensions and global supply chain disruptions, highlighting the insufficient risk resistance of the grain trade supply chain.

Need for improved agricultural sustainability. Intensive farming practices have taken a toll on China's already limited agricultural resources. Overuse of chemical fertilizers and pesticides is widespread, leading to the degradation of soil health. However, with the implementation of fertilizer reduction initiatives, China's fertilizer input intensity continues to decline. In 2021, the fertilizer input intensity in China was 166 kilograms (kg) per ha, significantly higher than the world average of 65 kg/ha, despite having decreased by 24 percent compared with 219 kg/ha in 2010 (FAO 2024). Agriculture is also a major contributor to greenhouse gas emissions, with crops accounting for 58.38 percent and livestock for 41.62 percent of agricultural CO_2 emissions in China in 2014 (CAAS 2023). Improving agricultural sustainability needs to be addressed to ensure the long-term viability of China's agricultural system.

Climate change and natural disasters. Climate change poses a significant threat to food production in China. The *People's Republic of China Third National Communication on Climate Change* shows that for each 1°C increase in temperature, yields of staple crops such as maize, wheat, and rice may decline by 7–8 percent in China. Meanwhile, climate warming has caused the overwintering boundaries of pests and diseases to shift northward by 1 to 3.5 latitudinal degrees, leading to an increase in their reproductive generations and thus potential crop damage.

TABLE 1 Projections of China's grain supply and demand in 2030 by major institutions or researchers, in million metric tons

Product	Item	CAAS	OECD-FAO	USDA	PRIMAFF	MARA	Huang and Xie PKU
Paddy rice	Domestic production	217.82	153*		150*	215.00	194
	Total demand	221.29	156*		151*	215.88	197
	Net imports	3.47	3*	3*	1*	0.88	3
Wheat	Domestic production	142.17	136		143*	145.41	127
	Total demand	150.34	143		149*	150.82	130
	Net imports	8.17	7	9	6*	5.41	3
Maize	Domestic production	321.35	297		309	315.01	271
	Total demand	337.75	305		319	321.95	324
	Net imports	16.40	8	20	10	6.94	54
Soybeans	Domestic production	35.51	21		22	33.44	19
	Total demand	119.91	122		124	112.78	148
	Net imports	84.40	101	127	102	79.34	129

Note: * indicates milled rice. CAAS = Chinese Academy of Agricultural Sciences; OECD-FAO = Organisation of Economic Co-operation and Development-Food and Agriculture Organization; USDA = United States Department of Agriculture; PRIMAFF = Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries; MARA = Ministry of Agriculture and Rural Affairs; PKU = Peking University.

Dietary imbalances and nutrition transition. China's traditional dietary structure and consumption habits are characterized by features such as frugality, small carbon footprint, diversity, and the use of locally available ingredients (CAAS 2024). As incomes rise, China faces the challenge of dietary imbalances driven by a nutrition transition (Fan, Yosef, and Pandya-Lorch 2020). Chinese diets are shifting in important ways from a health perspective, with an increasing proportion of calories coming from fat and oil, while traditional carbohydrates are being crowded out and the intake of some micronutrients is insufficient (Sheng et al. 2021). Compared with the standards in the *Chinese Dietary Reference Intakes Part 1: Macronutrients*, the proportion of energy supplied by carbohydrates was close to the minimum level of 50 percent, whereas the proportion of energy supplied by fat exceeded the recommended range.

LATEST FORESIGHT RESEARCH

Forecasting China's future food security has been a research focus for both Chinese and international institutions, including the Organisation for Economic Co-operation and Development and FAO (OECD-FAO 2023), the U.S. States Department of Agriculture (USDA 2023), as well as the world food supply and demand model developed by the Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries of Japan (PRIMAFF 2023), the Chinese Agricultural Policy Simulation Model (CAPSiM) from the Center for Chinese Agricultural Policy at Peking University (Huang and Xie 2022), and the China Agricultural Monitoring and Early-Warning System (CAMES) from the Market Early Warning Expert Committee of Ministry of Agriculture and Rural Affairs (China, MARA 2024). The Chinese Academy of Agricultural Sciences (CAAS) also maintains a partial equilibrium model called the China Agricultural Sector Model (CASM) to simulate the changing supply and demand dynamics of China's agricultural system. The CASM — codeveloped by the Institute of Agricultural Economics and Development (IAED) of CAAS and the International Food Policy Research Institute (IFPRI) — tracks production, consumption, trade, and prices for 33 key agricultural commodities, enabling researchers to analyze the impacts of various trends and policies on China's agricultural system (CAAS 2024). Table 1 presents the various projections for the supply of and demand for China's main grains in 2030.

TABLE 2 Recommended values of a healthy diet for each ideal dietary reference system, in kilograms/year

Food item	Actual value in 2023	Mean values of recommended values of various ideal dietary[a]	
		Original value	Adjusted value[b]
Cereals	192.95	74.83	106.89
Potatoes	41.65	27.38	30.42
Beans	11.00	23.73	23.73
Edible oil	21.60	14.31	14.31
Meat	55.67	37.80	37.80
Eggs	15.19	10.49	11.92
Milk	37.05	109.50	109.50
Aquatic products	22.22	44.26	75.01
Vegetables	136.11	146.91	168.86
Fruit	106.54	91.25	111.28

Source: CAAS 2024.

Note: a. The averages of the recommended values refer to the average of the minimum and maximum values of the recommended intake of each food for each ideal diet of the Chinese Food Guide Pagoda (2022), the EAT-Lancet dietary, the Mediterranean diet, and data from the Japanese Dietary Pagoda, among others. b. Because the healthy diet recommendation is the actual intake of major foods, such as flour and rice, consumed by residents, this study converted the data according to parameters such as the proportion of the edible portion of each food to obtain adjusted values.

By assuming that China will gradually achieve a shift toward a healthier diet by 2050, we derived a simulation for the ideal diet from a combination of recommended values from various sources, including the Chinese Food Guide Pagoda (2022), the EAT-Lancet diet, the Mediterranean diet, and data from the Japanese Dietary Pagoda, among others. Given the anticipated outcomes of this ideal diet, China is projected to see a significant increase in demand for high-quality proteins such as dairy products and aquatic items, as well as for fruits and vegetables. Conversely, a moderate decrease in demand is expected for cereals, edible oil, and meat, with a focus on achieving adequate energy intake and enhancing overall nutrition to improve national health (Table 2).

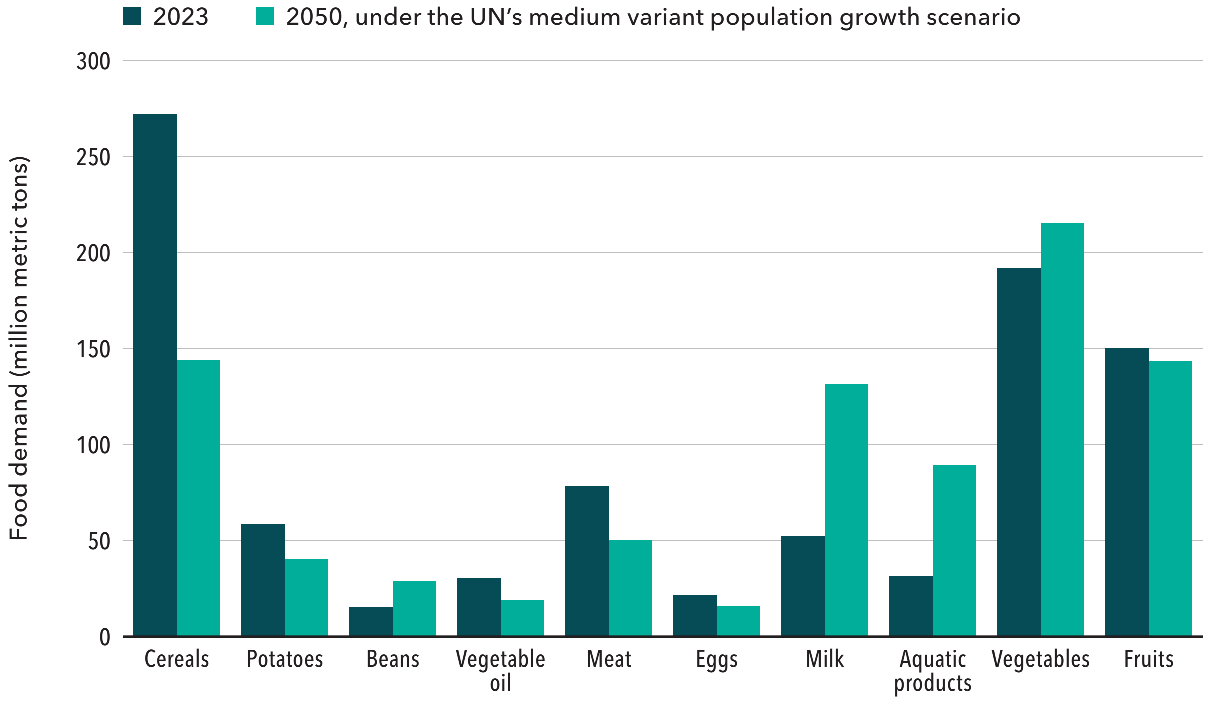
The simulation results from the CASM show that per capita food demand for meat in China is projected to decrease from 55.67 kg in 2023 to 37.80 kg in 2050 and from 21.60 kg to 14.31 kg for vegetable oil. On the other hand, per capita demand for milk is projected to increase substantially, from 37.05 kg in 2023 to 109.50 kg in 2050, although this value is still below the per capita milk intake level of the United States. Aquatic products are expected to increase significantly, from 22.22 kg to 75.01 kg.

Under the United Nation's medium variant population growth scenario, China's population will drop to 13.78 billion in 2035 and to 12.88 billion in 2050 (UN 2022). Although the impacts of total population decline and population aging on China's food demand remain unclear, our CASM simulation results find that total food demand for cereals will fall to 144 MMT, and total food demand for high-quality protein foods such as beans, milk, and aquatic products will increase significantly by 2050 (Figure 1). The food demand for milk is expected to rise to 131.49 MMT, a 151.6 percent increase from 2023, while the demand for aquatic products and beans is also expected to rise substantially. Conversely, total demand is expected to decrease, by varying degrees, for staple foods, oils and fats, meat, and eggs.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Future foresight research based on the CASM will need to comprehensively consider the impact of the following

FIGURE 1 Projection of food demand by 2050 based on the ideal diet in China



Source: CAAS 2024.

factors to better simulate and predict the transformation of China's agricultural system:

The impact of changes in agricultural production organization forms. With rural aging and the growth of cooperatives and socialized service organizations, the small-scale farming production model that has lasted for thousands of years may undergo changes in the future, leading to the scaling-up of agricultural production and higher efficiency (Guo, Lv, and Hu 2021; Huang and Yang 2017).

Potential impact of scientific and technological progress. Scientific and technological innovation is an important factor in transforming the agricultural system and a core factor in overcoming the constraints of cultivated land and water resources to achieve sustainable agricultural development (Han et al. 2024; Zhang et al. 2024).

The uncertain impact of the world market. Under the globalized market, China's agricultural transformation is interconnected with the rest of the world and will bring new opportunities for development of the world's agricultural industry. However, as trade disputes increase, uncertainty in the world agricultural product market is also increasing, affecting the agricultural transformation of countries around the world, including China (Han, Chen, and Wang 2022; Kim, Steinback, and Zurita 2024).

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Xinru Han**, a Professor at the Institute of Agricultural Economics and Development (IAED), Chinese Academy of Agricultural Sciences (CAAS); **Xiangdong Hu**, Director General and a Professor at IAED, CAAS; and **Kevin Chen**, a Senior Research Fellow at the International Food Policy Research Institute (IFPRI) and Qiushi Chair Professor at Zhejiang University, China.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Han, X., X. Hu, and K. Chen. 2025. "What Do We Know About the Future of Agriculture Systems in China?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 24. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: chinahbzyg/Shutterstock

References

CAAS (Chinese Academy of Agricultural Sciences and Ministry of Agriculture) and China. 2023. *Report on Low-Carbon Agricultural and Rural Development in China 2023*. Beijing: Social Sciences Academic Press.

CAAS. 2024. *China Agricultural Sector Development Report 2024.* Beijing: China Agricultural Science and Technology Press.

China, MARA (Ministry of Agriculture and Rural Affairs of the People's Republic of China). 2024. China Agricultural Outlook (2022–2033). Beijing: China Agricultural Science and Technology Press.

China, Ministry of Water Resources. 2022. *2021 China Water Resource Bulletin*. People's Republic of China: Ministry of Water Resources.

Fan, S.G., S. Yosef, and R. Pandya-Lorch. 2020. "Linking Agriculture to Nutrition: The Evolution of Policy." *China Agricultural Economic Review* 12 (4): 595–604. https://doi.org/10.1108/caer-03-2020-0040

FAO (Food and Agriculture Organization of the United Nations). 2024. FAOSTAT: Food and Agriculture Data. https://www.fao.org/faostat/en/#home

GAC (General Administration of Customs). 2024. *Monthly Bulletin*. http://english.customs.gov.cn/statics/report/monthly.html

Guo, S.J., X.Y. Lv, and X.D. Hu. 2021. "Farmers' Land Allocation Responses to the Soybean Rejuvenation Plan: Evidence From "Typical Farm" in Jilin, China." *China Agricultural Economic Review* 13 (3): 705–719. https://doi.org/10.1108/caer-06-2020-0118

Han, J. 2020. "Prioritizing Agricultural, Rural Development and Implementing the Rural Revitalization Strategy." *China Agricultural Economic Review* 12 (1): 14–19. https://doi.org/10.1108/caer-02-2019-0026

Han, X.R., Y.F. Chen, and X.D. Wang. 2022. "Impacts of China's Bioethanol Policy on the Global Maize Market: A Partial Equilibrium Analysis to 2030." *Food Security* 14 (1): 147–163. https://doi.org/10.1007/s12571-021-01212-5

Han, X., X. Wang, J. Wang, L. Yuan, X. Mei, and K. Wu. 2024. "Strategy for Ensuring China's Food Security Through Planting Industry in the New Era." *Chinese Journal of Engineering Science* 26 (2): 92–102. https://doi.org/10.15302/j-sscae-2023.07.034

Huang, J., and W. Xie. 2022. "China's Future Food Supply and Demand: Perspectives and Policies." [Chinese language]. *Frontiers of Science and Technology of Engineering Management* 41 (1): 17–25.

Huang, J.K., and G.L. Yang. 2017. "Understanding Recent Challenges and New Food Policy in China." *Global Food Security* 12: 119–126. https://doi.org/10.1016/j.gfs.2016.10.002

Ji, X.Q., S. Rozelle, J.K. Huang, L.X. Zhang, and T.L. Zhang. 2016. "Are China's Farms Growing?" *China & World Economy* 24 (1): 41–62. https://doi.org/10.1111/cwe.12143

Kim, D., S. Steinbach, and C. Zurita. 2024. "Deep Trade Agreements and Agri-Food Global Value Chain Integration." *Food Policy* 127: 102686. https://doi.org/10.1016/j.foodpol.2024.102686

NBS (National Bureau of Statistics). 2024. National Data. People's Republic of China: National Bureau of Statistics. https://data.stats.gov.cn/

OECD–FAO (Organization for Economic Co-operation and Development) and FAO (Food and Agriculture Organization of the United Nations). 2023. *OECD–FAO Agricultural Outlook 2023–2032.* Paris: OECD Publishing. https://openknowledge.fao.org/items/a4e5c326-37f7-43c7-9455-b35efb613827

PRIMAFF (Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries of Japan). 2023. *World Food Supply and Demand Projection to 2032: Results of the Projection Using the World Food Supply and Demand Model [M]*. Tokyo: Ministry of Agriculture, Forestry and Fisheries. https://www.maff.go.jp/primaff/e/results/projection/index.html

Sheng, F.F., J.J. Wang, K.Z. Chen, S.G. Fan, and H.X. Gao. 2021. "Changing Chinese Diets to Achieve a Win-Win Solution for Health and the Environment." *China & World Economy* 29 (6): 34–52. https://doi.org/10.1111/cwe.12393

UN (United Nations). 2022. *World Population Prospects 2022*. UN DESA/POP/2022/DC/NO. 9. New York: UN-DESA. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

USDA (U.S. Department of Agriculture). 2023. *USDA Agricultural Projections to 2032.* Washington, DC: USDA. https://www.usda.gov/sites/default/files/documents/USDA-Agricultural-Projections-to-2032.pdf

Yu, X.H. 2012. "Productivity, Efficiency and Structural Problems in Chinese Dairy Farms." *China Agricultural Economic Review* 4 (2): 168–175. https://doi.org/10.1108/17561371211224755

Zhang, Y.M., X.S. Diao, K.Z. Chen, S. Robinson, and S.G. Fan. 2020. "Impact of COVID-19 on China's Macroeconomy and Agri-Food System—An Economy-Wide Multiplier Model Analysis." *China Agricultural Economic Review* 12 (3): 387–407. https://doi.org/10.1108/caer-04-2020-0063

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD SYSTEMS IN INDIA?

Sedithippa Janarthanan Balaji (ICAR-NIAP), Pratap S. Birthal (ICAR-NIAP), and Barun Deb Pal (IFPRI)

Key messages

- Rapid growth in the livestock and fisheries subsectors, driven by increasing demand, has advanced the frontiers of agricultural growth in India.
- Irrigation plays the dual role of enhancing both productivity and resilience in agriculture, but increasing reliance on groundwater for irrigation and the consequent decline in groundwater levels impede the sustainable transformation of India's agrifood production systems.
- Although climate change is a significant challenge to the sustainability of agriculture, implementation of climate-smart interventions can significantly improve agricultural productivity and resilience.
- Changing dietary patterns reinforce the need to reshape agricultural policies to promote diversification of agriculture in favor of nutrient-dense foods, including animal-source foods and fruits and vegetables.
- Diversification may contribute to the enhanced sustainability of natural resources, mitigate risk, and augment farm income, thereby addressing nutrition insecurity and reducing farm poverty.
- Enhancing self-sufficiency in specific commodities, such as edible oils and pulses, requires technological advancements and safeguards against low-cost imports.

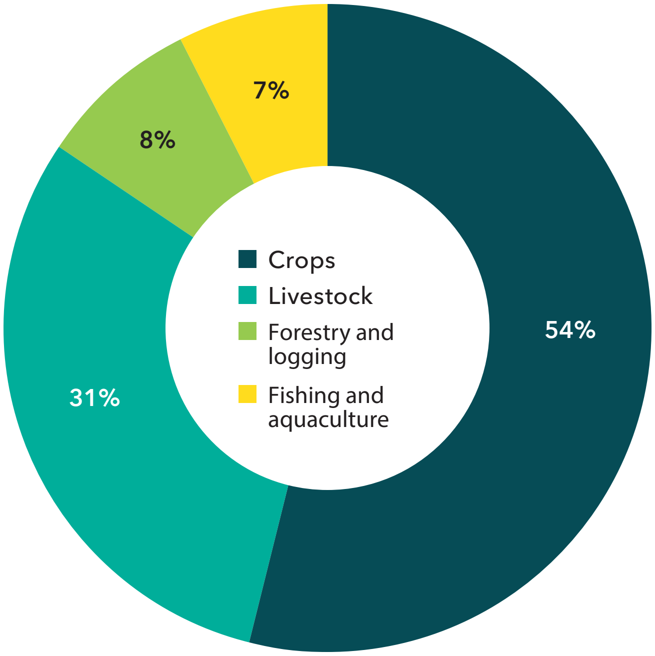
RECENT TRENDS AND CHALLENGES

The early 1990s marked a critical juncture in the Indian economy, with economic reforms signaling a departure from the historically modest rate of growth of approximately 3 percent. The economic reforms encompassed: (1) liberalization of trade by reducing import barriers and customs tariffs and devaluing the currency; and (2) liberalization of domestic markets by reducing licensing requirements for private sector investment, easing regulations, reducing corporate taxes, and decontrolling public sector monopolies to integrate the Indian economy with the global market. Consequently, the Indian economy transitioned to a higher, more sustainable growth trajectory. Since 1991, the country has experienced a robust growth rate of 6.3 percent (based on India, Ministry of Finance 2024).

India seeks to attain the status of a developed economy by 2047, coinciding with the centennial of its independence, with per capita income anticipated to increase to US$22,000 from the current US$2,500. Its strategy focuses on macroeconomic growth, but equally emphasizes inclusive development. Central to this strategy is the self-reinforcing virtuous cycle of investment, in which public sector investments are complemented by private sector initiatives. As the economy grows and disposable income increases, consumption patterns will shift toward nonfood items. However, the food basket is also expected to transition from calorie-dense cereals to pulses, fruits, vegetables, milk and meat that are richer in proteins and other nutrients. Meeting the evolving consumer preferences will necessitate changes in the food production system.

India's agriculture sector plays a vital role in economic transformation. It is crucial not only for overall economic growth, but also for the nation's food security and farmers' welfare. The sector contributes 14.5 percent to gross value added (GVA) and engages 45 percent of the total workforce. The sector has undergone substantial changes over the past six decades; the biochemical-based Green Revolution in the mid-1960s marked a pivotal moment in its development, and led to a substantial increase in food production within a short period of time. The success of the Green Revolution inspired similar transformative changes in dairying, termed the "White Revolution," and in fisheries, known as the "Blue Revolution." Poultry production too witnessed tremendous growth. The cumulative impact of these agricultural revolutions was profound, propelling India toward self-sufficiency in food production by the late 1980s, and enhancing its capacity to cope with risks to food security. Furthermore, increased agricultural production has opened new avenues for economic growth through agricultural exports. However, the country depends heavily on imports of edible oils and pulses to meet growing demand.

FIGURE 1 Composition of agriculture and allied sectors in India, 2022/23



Source: India, Ministry of Statistics and Programme Implementation (2024).

Agriculture sector performance is best understood by examining its components. While the crop subsector continues to dominate agricultural GVA (54 percent), the livestock and fisheries subsectors account for a sizable share (Figure 1). A closer look at growth trends over the past decade (2012/13 to 2022/23) reveals a dynamic shift within the agricultural landscape. The crop subsector experienced modest growth of 2.1 percent per year, versus impressive growth of 7.6 percent and 8.9 percent in the livestock and fisheries subsectors, respectively. This robust growth may be attributed to factors such as changing dietary preferences in favor of protein-rich foods.

The average landholding in India is 1.08 hectares (ha), down from 2.28 ha in 1970/71. Approximately 70 percent of landholdings are 1 ha or smaller. How has agricultural growth translated into farmers' welfare? Farmers' incomes have not increased much. Between 2012/13 and 2018/19, farmers' income in real terms increased at an annual rate of 3 percent. Nonetheless, their income sources changed. Due to the sluggish growth in farm income coupled with tiny landholdings, many farm households increasingly shifted toward wage labor during the same time period. Wage income now accounts for 40 percent of farmers' total income, surpassing income from crops (37.0 percent) and livestock (15.5 percent).

Furthermore, significant interpersonal and interregional disparities persist in agriculture. While land productivity tends to converge across regions, labor productivity does not (Balaji and Deb Pal 2014), potentially due to the relative abundance of labor compared to land. Farm income, encompassing both crop and livestock, has been gradually converging across districts, albeit at a slower rate (<1 percent), particularly among lower-income groups. The primary factors influencing these trends are irrigation, agricultural diversification, and market access. Notably, middle-income farmers tend to benefit more from these trends than their wealthiest and poorest counterparts (Balaji and Gopinath 2023).

Climate change is a major threat to both productivity and income growth. Since 1980/81, climate-related risks have reduced the country's agricultural growth by one-fourth, despite technological advancements (Birthal, Hazrana, and Negi 2021a). Sustained income growth is projected to increase India's greenhouse gas (GHG) emissions per capita by 40 percent in 2030 (Karstensen et al. 2020). Nonetheless, climate-smart agricultural practices have significant potential for reducing production risk for farmers, with studies indicating a reduction range of 12–25 percent (Deb Pal, Kumar, and Patan 2022). Practices such as crop diversification, improved water management, and soil conservation not only help farmers adapt to changing climate conditions but also contribute to mitigation by reducing GHG emissions from agricultural activities. It is noteworthy that when these practices are implemented jointly, their effect on both productivity and resilience is greater than when they are implemented in isolation (Birthal, Hazrana, and Negi 2021b). Furthermore, a nationwide program on crop insurance was implemented, although its coverage remains limited to one-third of the cropped area.

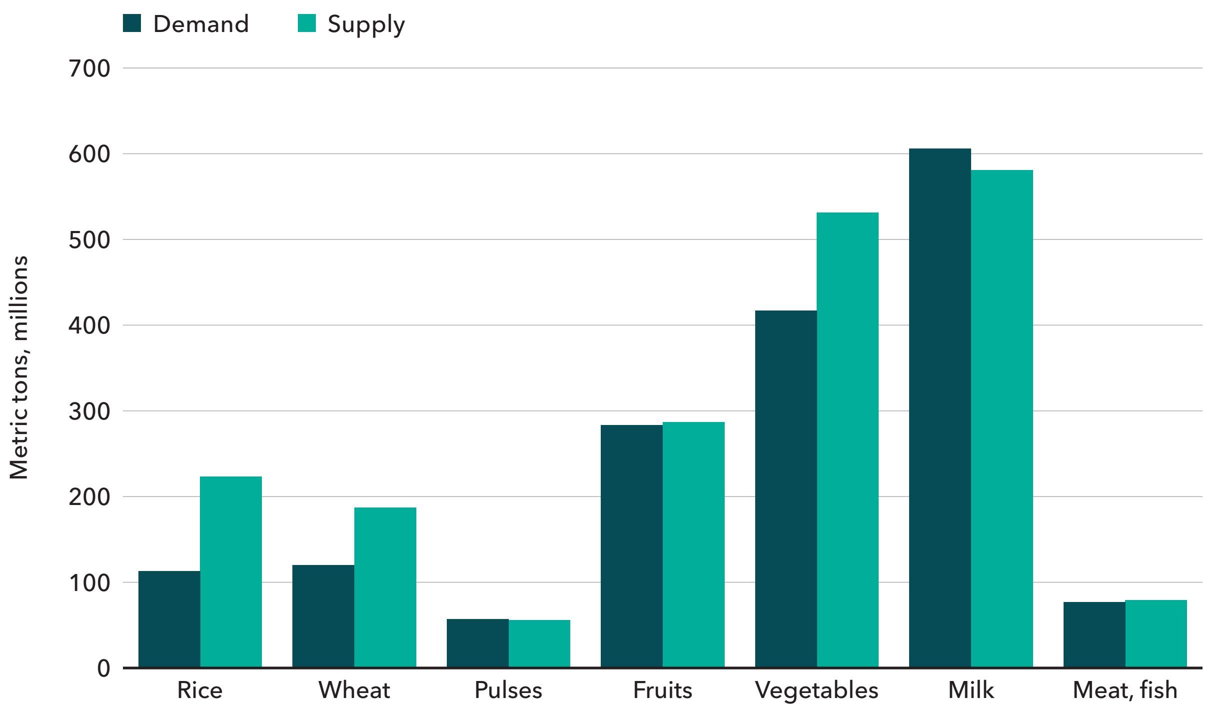
Implementation of climate-smart practices and insurance on a large-scale still face challenges, primarily because farmers lack access to financial resources. Evidence indicates that financial access significantly affects productivity and resilience. Birthal et al. (2024) find a 24 percent increase in productivity and a 16 percent reduction in downside risks when farmers have access to credit. This underscores the need for more robust and formal financial support systems to help farmers adopt technologies and practices for risk mitigation. Irrigation positively impacts agricultural productivity and its resilience, but the decline in groundwater levels — particularly in the Green Revolution states of Punjab and Haryana — raises significant concerns about the long-term sustainability of India's water use. In fact, benefits of irrigation have started tapering off (Birthal et al. 2021c). Despite various policy efforts to regulate groundwater use, measures have largely been ineffective (Kishore et al. 2024; Rosencranz et al. 2021). The Government of India has been making efforts to wean farmers away from paddy cultivation and promote micro-irrigation. However, the effectiveness of these interventions has been limited, highlighting the challenge of balancing agricultural productivity with sustainable water management.

LATEST FORESIGHT RESEARCH

Income growth and population dynamics are key drivers of food security, and significantly influence the transformation of food systems. Food consumption patterns over the past three decades indicate that cereals and pulses are no longer the predominant food items for households in India. In both rural and urban areas, cereals constitute only approximately one-tenth of total food expenditure, while only 4 percent of spending is allocated to pulses (India, Ministry of Statistics and Programme Implementation 2024). Conversely, food demand and supply projections for India suggest a surplus of rice and wheat, two major staples, by 2047/48 (Figure 2). However, projections for high-value food commodities such as fruits, milk, meat, and fish (on which a sizable share of income is spent) demonstrate only a narrow gap between demand and supply (India, NITI Aayog 2024a). This underscores the necessity for India to accelerate its transition toward a more nutrient-dense and value-based production system, achieved through both crop diversification and expansion of cultivation of these essential foods.

Ex ante research suggests that shifting cropland from staple crops like rice and wheat to nutri-cereals such as

FIGURE 2 Demand and supply projections for major food items for 2047/48 (million metric tons)



Source: GoI (2024d).

sorghum and pearl millet not only reduces farm subsidies but can also help mitigate GHG emissions (for example, if farmers adopt a millet-based cropping system) (Balaji 2024). If households return to the level of pearl millet consumption seen in the early 1990s, the government could save up to an estimated US$75 million in farm subsidies. This implies that these savings could be reinvested in agriculture to fund climate adaptation and mitigation, thereby supporting a more sustainable food system. Additionally, the transition to nutri-cereals could result in a reduction in net GHG emissions of 3.3–3.6 million metric tons of CO_2 equivalent (MMT CO_2e), contributing to both environmental sustainability and food security.

India is currently the world's largest importer of edible oil and pulses. Approximately 70 percent of domestic demand for edible oils and 10 percent for pulses are met through imports. Projections suggest that India will continue to face a shortfall in edible oil supply through 2047/48 (India, NITI Aayong 2024b). On the other hand, 12 million ha of rice-cropped area are left uncultivated in the alternate seasons. This rice-fallow land is often proposed as a potential area for pulses and oilseed cultivation, aiming to reduce India's reliance on imports. The persistent dominance of pro-liberalization policies over self-reliance strategies is frequently cited as a key factor behind such a huge dependence on imports of these commodities. If the current low-tariff regime persists, India will likely continue to rely on imports of edible oils to meet domestic demand. Interestingly, evidence indicates that even if tariffs on edible oil are increased, the impact on imports may be limited and may not lead to a significant increase in production of oilseeds and pulses (Balaji et al. 2022; Balaji, Umanath, and Arun 2021). This suggests the need for a technological breakthrough in their production.

Inflation control measures in India have often involved imposing export bans on key commodities, such as rice, wheat, and sugar. While stable trade policies can be beneficial in the long run, the uncertain impacts of climate change can disrupt the transition of the food system, particularly if sufficient investments are not made. Projections indicate that temperatures in India could rise by 1.1–5.1°C by 2100 under the SSP5 8.5 scenario (Kumar et al. 2023). This could adversely affect agricultural productivity, including paddy and wheat, two of the country's most important staples. Pulses and oilseeds, predominantly grown in rainfed areas, are also expected to face yield decline. Projections suggest that yield reductions could range from −1.8 percent to −6.6 percent under the RCP 4.5, and from −7 percent to −23 percent under the more extreme RCP 8.5 (Birthal et al. 2021d). The financial implications of climate change are particularly significant, as they can impede the necessary actions for adaptation and mitigation. In the absence of adequate financial support, climate change can exacerbate the demand for food imports, further straining the economy.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

The existing body of research has yielded valuable insights into the transformation of India's food system. However, there is a pressing need to broaden the scope of foresight research in this area. By exploring potential future scenarios, foresight research could facilitate proactive decision-making, foster innovation in agricultural ecosystems, and enhance equitable food access. For example, yields for several key crops in India – including staples, coarse cereals, pulses, and oilseeds – remain below the global average (GoI 2024f). Studies demonstrate that investments in agricultural research in India yield significant returns, with every rupee invested generating Rs 13.85 (Kandpal, Birthal, and Mishra 2024). A comprehensive foresight exercise could help project potential yield improvements of these crops and provide guidance on the means to enhance total factor productivity through research investments. This approach is equally pertinent for addressing crop yield disparities. For critical commodities such as oilseeds and pulses, on which India's import reliance is substantial, foresight research that anticipates potential shifts in future trade dynamics could inform the development of alternative strategies to safeguard the food supply and counteract the ramifications of trade disruptions.

Foresight research can provide crucial insights into addressing public health concerns. Changes in food consumption patterns have led to the rise in overweight as a public health issue, alongside the persistent challenges of undernutrition and micronutrient deficiencies (Meenakshi 2016). By employing foresight research, it may be possible to evaluate the welfare effects of a food system that emphasizes improved nutrition and promotes consumption of fruits and vegetables while restricting meat and sugar intake, particularly for low-income populations.

Exploring market reforms that promote collective action in agriculture is another area in which foresight research can contribute. Expanding collective institutions, such as farmer-producer organizations and self-help groups, and enhancing farmers' access to markets, credit, and extension services have been shown to positively impact income, yield, and product quality (Bizikova et al. 2020). Although India has made significant strides in promoting these collectives, foresight research that informs their effective scale-up and ensures their sustainability could play a crucial role in creating more inclusive and sustainable food systems in the future. The significance of foresight research extends to restructuring agricultural support systems, preserving agroclimatic diversity, and assessing the political, economic, and environmental viability of such transformations.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Sedithippa Janarthanan Balaji**, a Scientist in the National Institute of Agricultural Economics and Policy Research at the Indian Council of Agricultural Research (ICAR-NIAP); **Pratap S. Birthal**, Director at ICAR-NIAP; and **Barun Deb Pal**, a Research Coordinator in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Balaji, S.J. , P.S. Birthal, and B.Deb Pal. 2025. "What Do We Know About the Future of Food Systems in India?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 25. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Alisha Vasudev/Shutterstock

References

Balaji, S.J. 2024. "Saving Farm Subsidies with Smart Climate Interventions: The Case of Transition to a Millet-Based Agriculture." *China Agricultural Economic Review* 16 (2): 249–266. https://doi.org/10.1108/caer-05-2023-0129

Balaji, S.J., and M. Gopinath. 2023. "Spatial Growth and Convergence in Indian Agriculture." *Agricultural Economics* 54 (6): 761–777. https://doi.org/10.1111/agec.12807

Balaji, S.J., and S. Pal. 2014. "Agricultural Productivity Growth: Is There Regional Convergence?" *Economic & Political Weekly* 52 (49): 74–80.

Balaji, S.J., P. Sharma, P. Venkatesh, and K. Shreya. 2022. *Technology and Policy Options for Reducing India's Import Dependence on Edible Oils*. Policy Brief 49. New Delhi: ICAR-National Institute of Agricultural Economics and Policy Research (NIAP).

Balaji, S.J., M. Umanath, and G. Arun. 2021. "Welfare Gains of Inward-Looking: An *Ex-Ante* Assessment of General Equilibrium Impacts of Protectionist Tariffs on India's Edible Oil Imports." *Agricultural Economics Research Review* 34: 1–20. https://doi.org/10.22004/ag.econ.320455

Birthal, P.S., J. Hazrana, and D.S. Negi. 2021a. "Impacts of Climatic Hazards on Agricultural Growth in India." *Climate and Development* 13 (10): 895–908. https://doi.org/10.1080/17565529.2020.1867045

Birthal, P.S., J. Hazrana, and D.S. Negi. 2021b. "Effectiveness of Farmers' Risk Management Strategies in Smallholder Agriculture: Evidence from India." *Climatic Change* 169 (30): 3–4. https://doi.org/10.1007/s10584-021-03271-1

Birthal, P.S., J. Hazrana, D.S. Negi, and G. Pandey. 2021c. "Benefits of Irrigation against Heat Stress in Agriculture: Evidence from Wheat Crop in India." *Agricultural Water Management* 255 1–8. https://doi.org/10.1016/j.agwat.2021.106950

Birthal, P.S., J. Hazrana, D.S. Negi, and S.C. Bhan. 2021d. "Climate Change and Land Use in Indian Agriculture." *Land Use Policy* 109: 1–12. https://doi.org/10.1016/j.landusepol.2021.105652

Birthal, P.S., J. Hazrana, D. Roy, and K.J.S. Satyasai. 2024. *Can Finance Mitigate Climate Risks in Agriculture? Farm-Level Evidence from India*. Policy Paper 41. New Delhi: ICAR-National Institute of Agricultural Economics and Policy Research (NIAP). https://niap.icar.gov.in/

Bizikova, L., E. Nkonya, M. Minah et al. 2020. "A Scoping Review of the Contributions of Farmers' Organizations to Smallholder Agriculture." *Nature Food* 1 (10): 620–630. https://doi.org/10.1038/s43016-020-00164-x

Deb Pal, B., S. Kumar, and E.K. Patan. 2022. "Investment Planning to Minimize Climate Risk in Agricultural Production: An Optimization Model for a Semi-Arid Region in India." *Climate Policy* 23 (4): 477–494. https://doi.org/10.1080/14693062.2022.2118656

India, Commission for Agricultural Costs and Prices. 2024. *Price Policy for Kharif Crops of 2024–25*. New Delhi: Department of Agriculture and Cooperation, Ministry of Agriculture and Farmers Welfare. https://cacp.da.gov.in/

India, Ministry of Finance. 2024. *Economic Survey 2023-24*. New Delhi. https://www.indiabudget.gov.in/

India, Ministry of Statistics and Programme Implementation. 2024. *National Accounts Statistics 2024*. New Delhi. https://www.mospi.gov.in/

India, Ministry of Statistics and Programme Implementation. 2024. *Household Consumption Expenditure Survey: 2022-23, Fact Sheet*. New Delhi. https://www.mospi.gov.in/

India, National Institution for Transforming India (NITI Aayog). 2024a. *Working Group Report on Crop Husbandry, Agriculture Inputs, Demand and Supply*. https://www.niti.gov.in/

India, National Institution for Transforming India (NITI Aayog). 2024. *Pathways and Strategy for Accelerating Growth in Edible Oil towards Goal of Atmanirbharta*. https://www.niti.gov.in/

Kandpal, A., P.S. Birthal, and S. Mishra. 2024. *From Research to Impact: Payoffs to Investment in Agricultural Research and Extension in India*. Policy Paper 44. New Delhi: ICAR-NIAP. https://niap.icar.gov.in/

Karstensen, J., J. Roy, B. Deb Pal, G. Peters, and R. Andrew. 2020. "Key Drivers of Indian Greenhouse Gas Emissions." *Economic & Political Weekly* 55 (15): 46–53.

Kishore, P., D. Roy, P.S. Birthal, and S.K. Srivastava. 2024. *Regulation and Policy Response to Groundwater Preservation in India*. Policy Paper 43. New Delhi: ICAR-NIAP. https://niap.icar.gov.in/

Kumar, R., J. Kuttippurath, G.S. Gopikrishnan, P. Kumar, and H. Varikoden. 2023. "Enhanced Surface Temperature over India during 1980–2020 and Future Projections: Causal Links of the Drivers and Trends." *Climate and Atmospheric Science* 6 (1): 1–10. https://doi.org/10.1038/s41612-023-00494-0

Meenakshi, J.V. 2016. "Trends and Patterns in the Triple Burden of Malnutrition in India." *Agricultural Economics* 47 (S1): 115–134. https://doi.org/10.1111/agec.12304

Rosencranz, A., T.G. Puthucherril, S. Tripathi, and S. Gupta. 2021. "Groundwater Management in India's Punjab and Haryana: A Case of Too Little and Too Late?" *Journal of Energy & Natural Resources Law* 40 (2): 225–250. https://doi.org/10.1080/02646811.2021.1956181

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF THE AGRIFOOD SYSTEM IN INDONESIA?

Erizal Jamal (BRIN), Sahara Sahara (IPB University), Syahid Izzulhaq (ANU), Syarifah Amaliah (IPB University), Fahmi Salam Ahmad (IPB University), Komalawati Komalawati (BRIN), Pihri Buhaerah (BRIN), Ifan Martino (Bappenas), Wulan Metafurry (Bappenas), Dadang Jainal Mutaqin (Bappenas), Irfan Thofiq Firdaus (Bappenas), Dewi Setyawati (IPB University), Angga Pradesha (IFPRI), Vivi Yulaswati (Bappenas), Irfan Syauqi Beik (IPB University), Irwanda Wisnu Wardhana (BRIN), Jarot Indarto (Bappenas), Agus Eko Nugroho (BRIN), Bustanul Arifin (UNILA), and Tahlim Sudaryanto (BRIN and APPERTANI)

Key messages

- Productivity growth has played a dominant role in driving the growth of Indonesia's agricultural production in recent decades, but it has been accompanied by the increasing role of land expansion.
- Indonesia is projected to achieve high-income status by 2045 if the country can maintain a 6–7 percent annual economic growth rate.
- To achieve high income and economic growth, the country needs to boost investment activities by increasing national saving, foreign direct investment (FDI), and investment efficiency.
- Future foresight research should include environmental impacts such as emissions and land use change and explore long-term changes in dietary patterns and poverty alleviation.

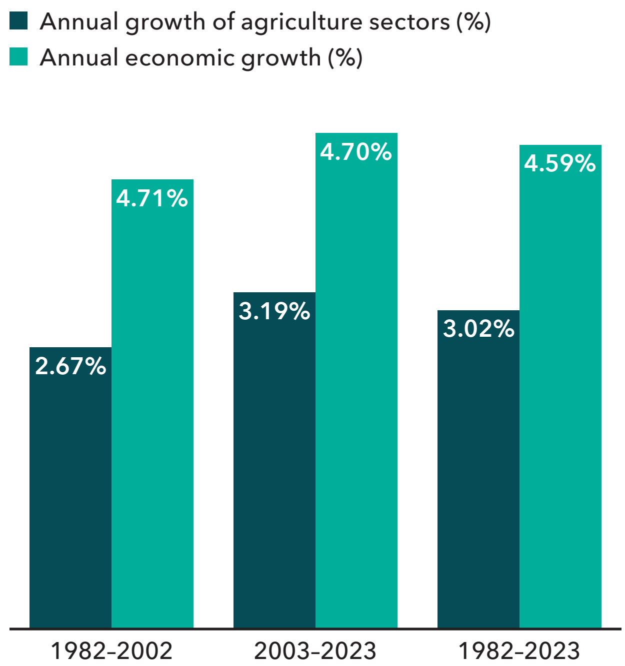
RECENT TRENDS AND CHALLENGES

Indonesia's agriculture sector experienced major shifts throughout the 1982–2023 period, growing at an average annual rate of 3.02 percent, which was slower than the overall economic growth rate of 4.59 percent (Figure 1). As a result, the agriculture sector's contribution to gross domestic product (GDP) declined significantly, from 24.02 percent in 1982 to only 12.42 percent by 2023 (Figure 2). Coinciding with this, the proportion of agricultural workers decreased from 55 percent in 1987 to 28.21 percent in 2023 (Figures 3 and 4). These decreasing trends may be attributed to "structural transformation." It is worth noting, however, that the transition away from agriculture in Indonesia is happening before manufacturing is mature (Dartanto, Yuan, and Sofiyandi 2017), so workers are more likely to be reallocated to informal services, as the manufacturing sector cannot absorb them all (Jeon 2013).

In Indonesia, food crops, especially rice, remain the main staple food source (Suhaimi et al. 2022). Rice prices thus affect inflation (Sholikhah and Anjani 2023) as well as social, economic, and political conditions in the country (Wiswayana and Pinatih 2020). For this reason, the government has made various efforts to increase rice production and its availability, with positive results: rice production growth over 1982–2020 increased 1.29 percent per year. The government has also undertaken efforts to increase maize production, for which average growth for 1982–2020 was 4.45 percent per year. Except in 2019 and 2020, the high increase in maize production in recent years was driven by the increasing use of corn as feed and by its price at the international level (FAO 2023).

Other commodities such as horticulture and plantation products and poultry show better performance. Horticulture products can also be considered staple foods and are categorized as high-value, enjoying a strong position in both domestic and export markets (Edi et al. 2023; Indrasti and Rawung 2021). Since the economic value of horticultural products is quite high, it is reasonable for farmers to switch to this subsector. Several factors play an important role in this development, such as superior varieties (Mustaffa and Kumar 2012). For plantation crops, average growth in oil palm fruit production averaged 11.30 percent per year over 1982–2020. Coffee, tea, and cocoa experienced relatively stable annual

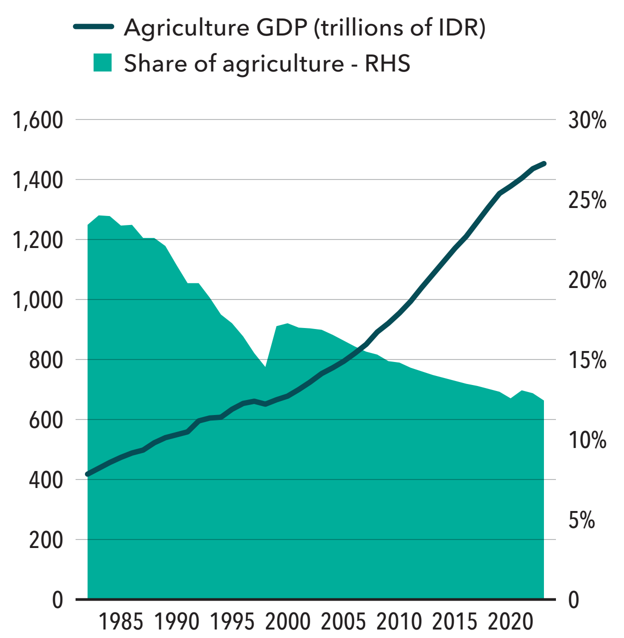
FIGURE 1 Annual agriculture and economic annual growth, 1982-2023



Source: Statistics Indonesia.

Note: Based on constant 2010 prices.

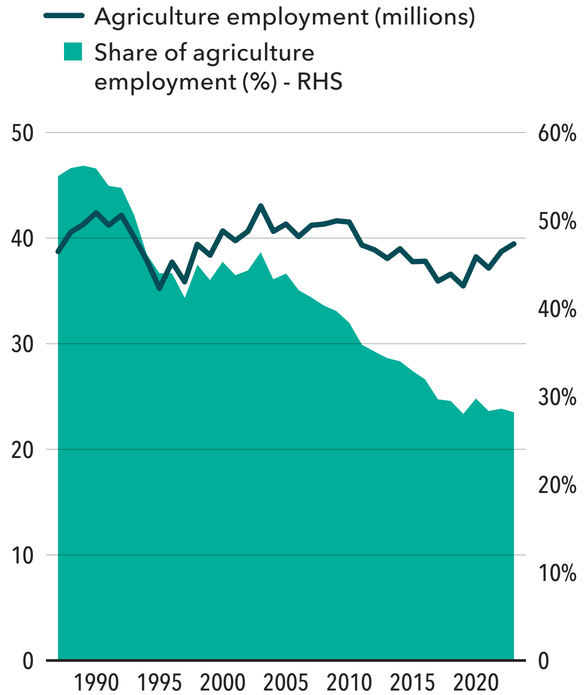
FIGURE 2 Agricultural GDP and share of total GDP, 1982-2023



Source: Statistics Indonesia.

Note: Based on constant 2010 prices.

FIGURE 3 Employment in agriculture, 1987–2023

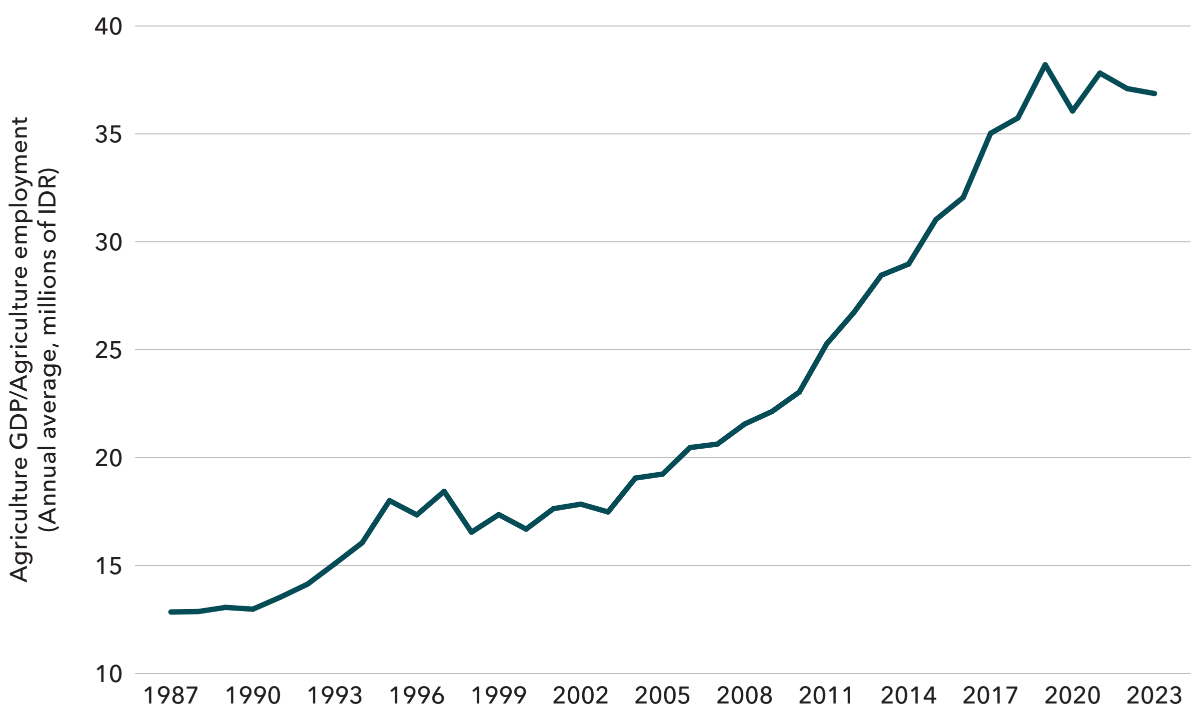


Source: Statistics Indonesia.

growth of 4.53 percent, although their production growth slowed in the 2010s. For poultry commodities, chicken and egg production grew at an average annual rate of 8.40 percent from 1982 to 2020, in line with the increase in worldwide chicken meat and egg production from pure-bred chickens and the shift to their commercial production in Indonesia (Putri and Sukandar 2023).

Our analysis shows that total factor productivity (TFP) consistently played a dominant role in the growth structure of Indonesia's agriculture production throughout the 1982–2020 period. However, we note that the role of land expansion increased as well. From 1982 to 1990, our calculations show that agricultural growth was primarily supported by TFP growth and labor expansion. More specifically, output grew by an impressive 4.87 percent per year, with TFP growth and labor expansion accounting for about 30 percent and 31 percent of this growth, respectively. In the following decades (from 1990 to 2020), TFP growth remained the primary driver, but the role of labor dropped (−0.79%), while land expansion gradually became more dominant (+0.81%).

FIGURE 4 Agricultural productivity per worker, 1987–2023



Source: Statistics Indonesia.

Our analysis at the commodity level suggests that almost all commodities relied heavily on extensification factors (that is, land and livestock expansion). For instance, output growth for rice between 1982 and 2000 averaged 2.45 percent annually and land expansion contributed 1.52 percent. However, over the 2001–2020 period, rice production grew more slowly (by only 0.42 percent) and land contracted correspondingly (by 0.4 percent). Other commodities — including maize, roots, palm oil, coffee, tea, and cocoa, and poultry and cattle — experienced a similar slowdown.

LATEST FORESIGHT RESEARCH

A study conducted by the Food and Agriculture Organization of the United Nations (FAO 2023) analyzed the impacts, synergies, trade-offs, and political feasibility of various policy interventions for agrifood systems transformation in Indonesia (Woolfrey et al. 2024). This study explored Indonesia's effort to make steady progress across several food system policy interventions. Continued economic growth and rising incomes will both contribute to declining rates of poverty and undernourishment. Increasing demand for food in Indonesia is projected to lead to a substantial increase in food production, with corresponding increases in greenhouse gas (GHG) emissions from agriculture. Rice availability in Indonesia still needs to increase, and various efforts to boost its production still need to be carried out. The government's efforts to increase maize production have borne fruit: recently, maize has been used not only for household consumption but also as a source of animal feed and as material for the food-processing industry.

However, the FAO study did not explore how the agriculture sector could contribute to achieving the government's targets associated with plans to celebrate the 100th anniversary of Indonesia's independence in 2045. The Indonesian government's long-term vision for the Golden Indonesia Era in 2045 (Indonesia Emas 2045) specifically aims to raise the country's per capita income to the level of high-income countries. A recent study by the team of the CGIAR Research Initiative on Foresight in Indonesia strives to identify how this can be achieved by investigating the country's past agricultural development and its implications for future economic growth and the agrifood system as a whole. The analysis is primarily focused on baseline projections, which serve as a critical tool for identifying existing trends, challenges, and opportunities within the agrifood system needed to understand plausible future scenarios. Specifically, this study examines major drivers of agricultural production — including intensification, extensification, and changes in TFP — and projections of economic growth pathways based on different growth drivers, using an economywide modeling framework designed to explore ways of achieving Indonesia's vision for 2045.

Departing from the historical lessons learned, we analyze the plausible future of the Indonesian economy based on low (5 percent), medium (6 percent), high (7 percent), and ambitious (8 percent) growth rate scenarios, which are aligned with the Bappenas[1] scenarios. To demonstrate how the country could reach high-income status, we compare the dynamic real income per capita growth projections[2] from our economywide modeling analysis to the World Bank's high-income country classification in 2024–2025, that is, US$14,005 gross national income (GNI) per capita (World Bank 2024).

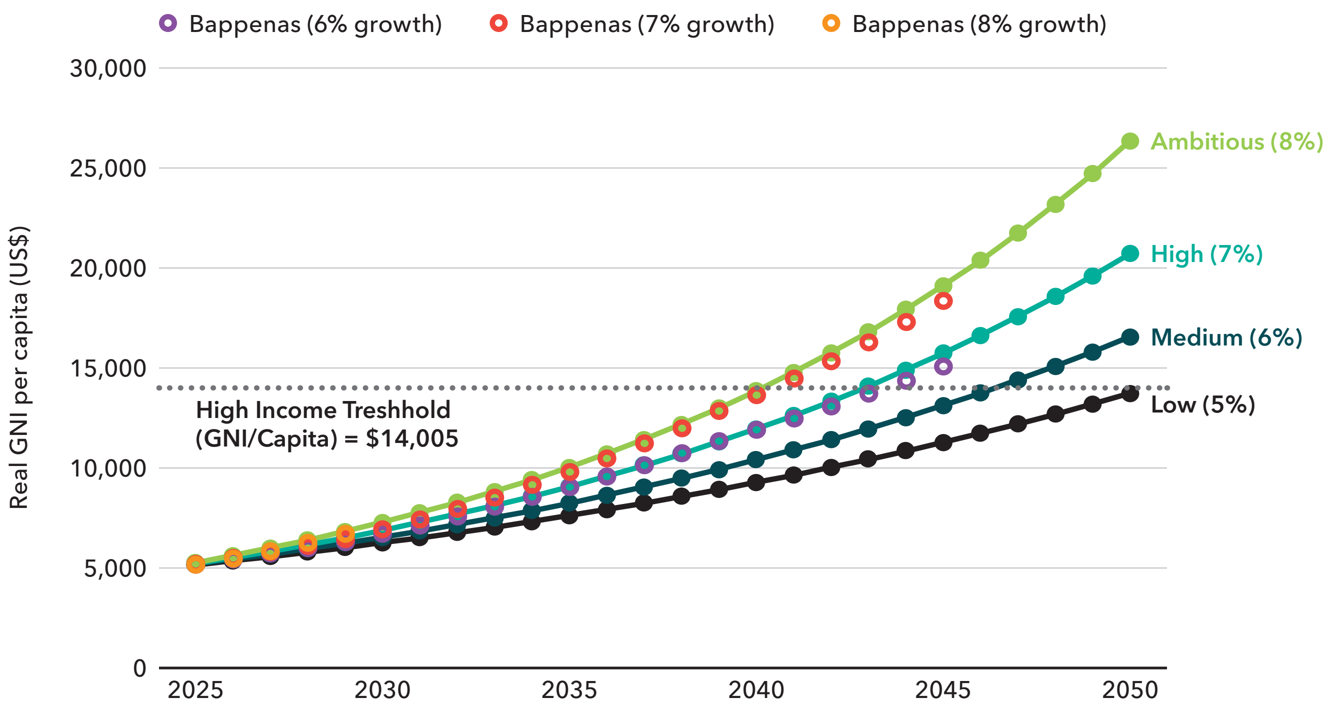
Based on model projections, Indonesia could pass this real income threshold and become a high-income country by 2040 under the ambitious-growth scenario and by 2043 under the high-growth scenario. However, the target may not be met until 2046 or 2050 if the country's growth follows the medium or low growth rate trajectories, respectively (Figure 5). To meet these growth targets for the whole economy, the agriculture sector must grow at 4.6 percent per year (ambitious growth) or 4.5 percent per year (high growth). This would require significant effort, as the sector grew by only 3.3 percent per year between 2003 and 2023. Additionally, our projections underscore the critical role of the fisheries subsector. To support the high growth target in the agriculture sector, the fisheries economy needs to grow by at least 6.4 percent annually.

We also explore pathways toward achieving an 8 percent growth rate to support the Indonesia Emas 2045 vision using China and Viet Nam as benchmarks for the change

1 Indonesia's Ministry of National Development Planning/National Development Planning Agency.

2 In this study, we proxy the real income per capita by using real gross national income (GNI) per capita (GNI of a country, adjusted for inflation and expressed on a per-person basis).

FIGURE 5 Economic growth and income projections, 2025–2050



Source: Model simulations (authors) and Bappenas growth projections (Presidential Regulation Number 12 of 2025).

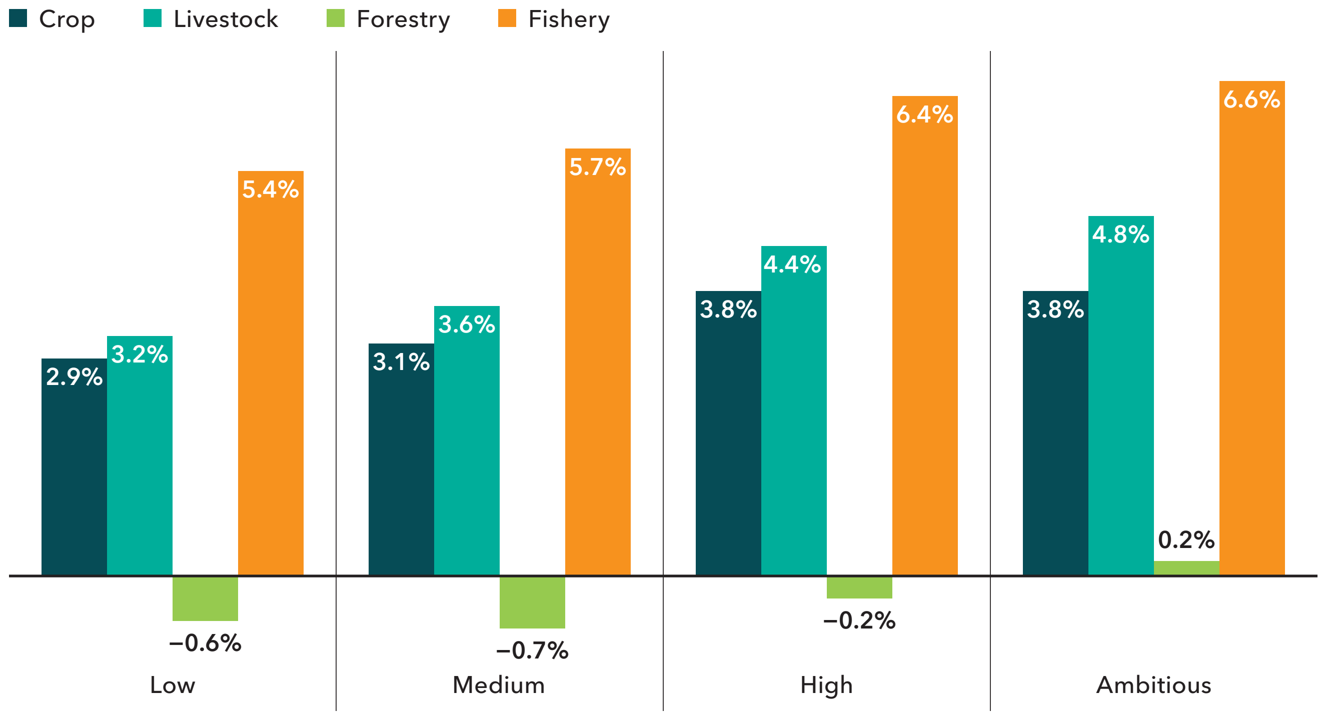
needed in Indonesia. One notable source of GDP growth that distinguishes China and Viet Nam from Indonesia is the growth of gross fixed capital formation. In the long run, national savings and FDI play key roles in boosting economic growth. Another challenge lies in Indonesia's low investment efficiency, as indicated by a high incremental capital output ratio (ICOR) of 6.2, compared with lower ratios in China (4.4), Thailand (5.0), and Viet Nam (5.2). On the supply side, the growth of input factors has been a key driver for rapid economic growth in China and Viet Nam.

The simulation results indicate the trajectory of structural transformation in Indonesia toward 2045, reflected in the agriculture sector's declining share in GDP and in employment. In the faster growth rate scenarios, the reduction in the share of agricultural employment becomes more profound. A more detailed look at the agriculture subsector projections shows that crops, livestock, and especially fisheries experience output expansion across all the scenarios. However, the forestry subsector experiences slight decreases in most scenarios through 2045 (Figure 6). At the commodity level, the distribution of agricultural outputs and employment emphasizes the ongoing importance of oilseeds and rice, while high-value agricultural products such as fruits, vegetables, and other crops gradually play a larger role (Figure 7). These findings are consistent with the transformation toward high-value agriculture commodities that is shaping a more diversified output and employment structure in the sector.

Our findings shed light on several important policy implications. First, despite potential adverse environmental effects (Nowosad and Stepinski 2019; Bengochea Paz, Henderson, and Loreau 2020), the government appears to be continuing to rely on extensification programs to boost production, such as the Food Estate program for rice production in Merauke, Papua. Second, agricultural R&D should be given greater support, as data show that Indonesia's agriculture sector R&D spending is still relatively low compared to that of other countries, especially in Asia. Third, institutional arrangements still play a crucial role in stimulating output and TFP growth. More specifically, regulations that promote economies of scale and horizontal integration through formal agreements (that is, contract farming between small and large farms) are essential to increase technical change and efficiency.

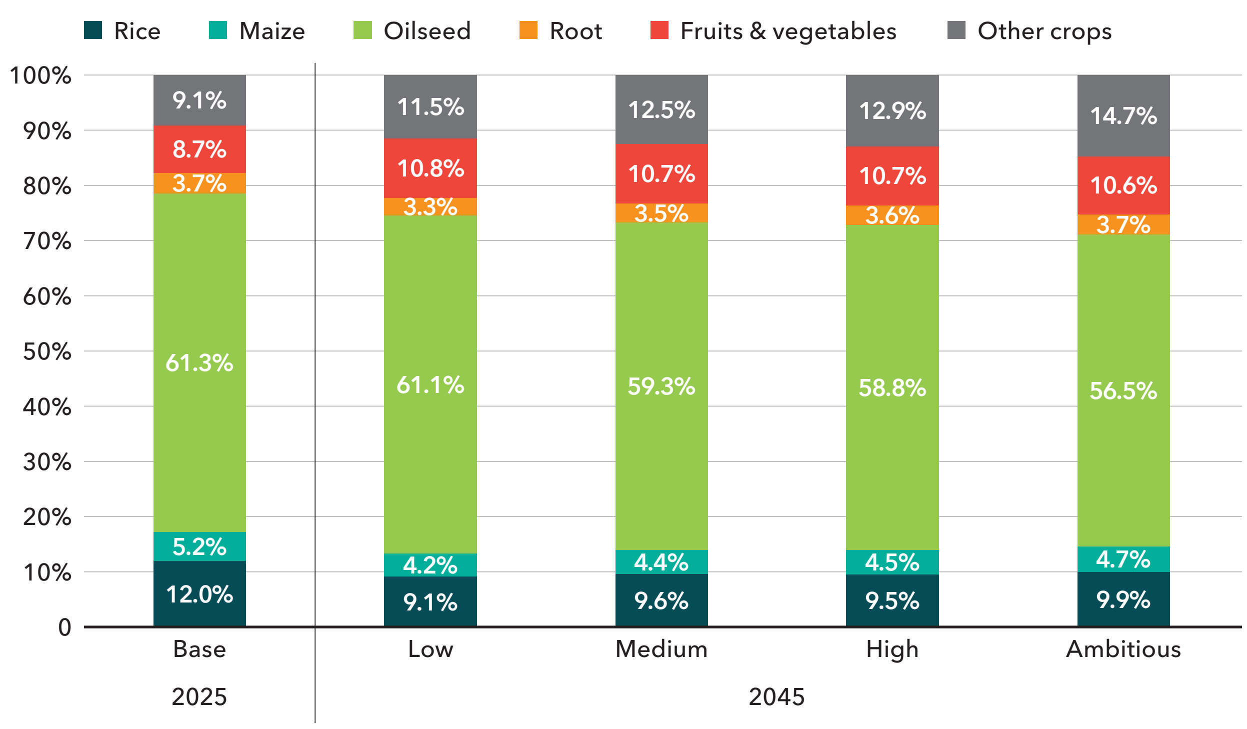
At the sector level, our analysis highlights the importance of downstream sectors in each commodity value chain.

FIGURE 6 Annual subsectoral growth in agriculture, 2025–2045



Source: Model simulations.

FIGURE 7 Share of output by commodities



Source: Model simulations.

This indicates that agriculture sector development cannot rely solely on on-farm activities. Strengthening the downstream value chain of agricultural commodities is crucial to support agrifood systems as a whole. This becomes even more pressing as structural transformation shifts labor from agriculture to non-agriculture sectors. Lastly, comprehensive transformation must be accompanied by labor market transformation in both on- and off-farm employment, suggesting that investment in agricultural human resources is essential.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Although this study illuminates several crucial aspects of agrifood system development in Indonesia, areas for future research remain. First, future foresight research should include an analysis of GHG emissions and land use change, major components of Indonesia's sustainable development agenda. How climate change will shape future developments in Indonesian agriculture is another important research question. Second, this study heavily emphasizes the supply-side drivers, but issues related to changing dietary patterns, food diversification, and poverty alleviation need more attention. Third, a critical social aspect that warrants further investigation is the impact of agrifood system transformation on rural communities, livelihoods, and social inequalities. Understanding social dynamics — such as access to resources, education, and healthcare — can provide a more comprehensive understanding of how agrifood system changes affect the broader population.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Erizal Jamal**, a Senior Agricultural Economist at the Research Center for Cooperatives, Corporations, and People's Economy at the National Research and Innovation Agency (BRIN), Indonesia; **Sahara Sahara**, a Professor in the Department of Economics and Director of International Trade Analysis and Policy Studies (ITAPS) in the Faculty of Economics and Management at IPB University, Indonesia; **Syahid Izzulhaq**, a Postgraduate Student in the Research School of Economics, College of Business and Economics at The Australian National University (ANU); **Syarifah Amaliah**, a Lecturer in the Department of Economics and Researcher in ITAPS in the Faculty of Economics and Management at IPB University; **Fahmi Salam Ahmad**, a Lecturer in the Department of Economics and Researcher in ITAPS in the Faculty of Economics and Management at IPB University; **Komalawati Komalawati**, a Senior Researcher at the Research Center for Cooperatives, Corporations, and People's Economy, BRIN; **Pihri Buhaerah**, a Senior Researcher at BRIN; **Ifan Martino**, Coordinator for Food at the Ministry of National Development Planning (Bappenas), Indonesia; **Wulan Metafurry**, a Policy Planner at Bappenas; **Dadang Jainal Mutaqin**, Director of Forestry and Water Resource Conservation at Bappenas; **Irfan Thofiq Firdaus**, a Policy Planner at Bappenas; **Dewi Setyawati**, a Researcher in ITAPS in the Faculty of Economics and Management at IPB University; **Angga Pradesha**, a Senior Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); **Vivi Yulaswati**, Deputy Minister for Economy and Digital Transformation at Bappenas; **Irfan Syauqi Beik**, Dean of the Faculty of Economics and Management, IPB University; **Irwanda Wisnu Wardhana**, Director of the Research Center for Cooperatives, Corporations and People's Economy at BRIN; **Jarot Indarto**, Director of Food and Agriculture at Bappenas; **Agus Eko Nugroho**, Chairman of the Research Organization for Governance, Economy and Community Welfare at BRIN; **Bustanul Arifin**, a Professor of Agricultural Economics at the University of Lampung (UNILA) and Senior Economist with the Institute for Development Economics and Finance (INDEF); and **Tahlim Sudaryanto**, a Senior Agricultural Economist at BRIN and Indonesian Agriculture Research Alliance (APPERTANI).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Jamal, E., S. Sahara, S. Izzulhaq, S. Amaliah, F.S. Ahmad, K. Komalawati, P. Buhaerah, I. Martino, W. Metafurry, D.J. Mutaqin, I.T. Firdaus, D. Setyawati, A. Pradesha, V. Yulaswati, I.S. Beik, I.W. Wardhana, J. Indarto, A.E. Nugroho, B. Arifin, and T. Sudaryanto. 2025. "What Do We Know About the Future of Agrifood Systems in Indonesia?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 26. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Bastian AS/Shutterstock

References

Bengochea Paz, D., K. Henderson, and M. Loreau. 2020. "Agricultural Land Use and the Sustainability of Social-Ecological Systems." *Ecological Modelling* 437: 109312. https://doi.org/10.1016/j.ecolmodel.2020.109312

Dartanto, T., E.Z.W. Yuan, and Y. Sofiyandi. 2017. "Two Decades of Structural Transformation and Dynamics of Income Equality in Indonesia." ADBI Working Paper No. 783 Asian Development Bank Institute, Tokyo. https://www.adb.org/publications/two-decades-structural-transformation-and-dynamics-income-equality-indonesia

Edi, S., Z.R. Syafri, N. Nurhayati, and A. Meilin. 2023. "Analysis of Curly Red Chili Farming at Farmer-Level in Kerinci." *IOP Conference Series: Earth and Environmental Science* 1287: 012002. https://iopscience.iop.org/article/10.1088/1755-1315/1287/1/012002

FAO (Food and Agriculture Organization of United Nations). 2023. *Food Outlook: Biannual Report on Global Food Markets*. Food Outlook Series. Rome. https://doi.org/10.4060/cc3020en

Indrasti, R., and J.B.M. Rawung. 2021. "The Assessment of Production System and Marketing of Siam Citrus in Jember Regency." *E3S Web of Conferences* 232: 02025. https://doi.org/10.1051/e3sconf/202123202025

Jeon, S. 2013. "Agricultural Transformation and the Escape from the Middle-Income-Country Trap: Challenges Facing Small Farmers in Indonesia in a Time of Green Restructuring." *Bulletin of Indonesian Economic Studies* 49 (3): 383–384. https://doi.org/10.1080/00074918.2013.850636

Mustaffa, M.M., and V. Kumar. 2012. "Banana Production and Productivity Enhancement Through Spatial, Water and Nutrient Management." *Journal of Horticultural Sciences* 7 (1): 1–28. http://dx.doi.org/10.24154/jhs.v7i1.383

Nowosad, J., and T.F. Stepinski. 2019. "Stochastic, Empirically Informed Model of Landscape Dynamics and Its Application to Deforestation Scenarios." *Geophysical Research Letters* 46 (23): 13845–13852. https://doi.org/10.1029/2019GL085952

JDIHN (National Legal Documentation and Information Network). 2025. *National Medium-Term Development Plan 2025–2029*. Presidential Regulation Number 12 of 2025. Jakarta: Ministry of Tourism and Creative Economy. https://peraturan.bpk.go.id/Details/314638/perpres-no-12-tahun-2025

Putri, W.A.K., and D. Sukandar. 2023. "Forecasting of Chicken Meat and Eggs to Realize Food Security in Central Java through Protein Adequacy from Animal Sources." *Journal of Nutritional Science and Dietetics* 2 (3): 149–159. https://journal.ipb.ac.id/index.php/jgizidietetik/article/view/47607

Sholikhah, M., and M.D. Anjani. 2023. "Kebijakan Pemerintah dalam Mengatasi Kenaikan Harga Beras di Indonesia." *Journal of Economics and Social Sciences* 2 (2): 122–130. https://doi.org/10.59525/jess.v2i2.311

Suhaimi, A., S. Syahfari, S. Ramayana, A. Saihani, and R.V. Royensyah. 2022. "Food Consumption Patterns and Child Stunting in the Lowland Region." *Slovak Journal of Food Sciences* 16: 790–799. https://potravinarstvo.com/journal1/index.php/potravinarstvo/article/view/1789

Wiswayana, W.M., and N.K.D.A Pinatih. 2020. "Pandemi dan Tantangan Ketahanan Nasional Indonesia: Sebuah Tinjauan Kritis." *Jurnal Lembaga Ketahanan Nasional Republik Indonesia* 8 (2): 93–100. https://doi.org/10.55960/jlri.v8i2.312

Woolfrey, S., L. Bizikova, C. Henning, et al. 2024. *Modelling the Impacts of Policy Interventions for Agrifood Systems Transformation in Indonesia*. Governance and Policy Support Report. Rome: FAO. https://doi.org/10.4060/cd1119en

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF THE AGRIFOOD SYSTEM IN SOUTH AFRICA?

Ferdi Meyer (BFAP and University of Stellenbosch), Louw Pienaar (BFAP and University of Stellenbosch), Tracy Davids (BFAP and University of Stellenbosch), and Mmatlou Kalaba (BFAP and University of Stellenbosch)

Key messages

- South Africa's primary agriculture sector witnessed profound productivity growth in recent decades, yet structural transformation is stalling due to a combination of sluggish nonfarm growth and persistent structural challenges that inhibit wider societal progress.
- Looking ahead, the agrifood system is well placed to increase the supply of goods at competitive prices but requires consistency in policymaking and an investment-friendly environment, as well as stronger domestic demand for products.
- Given the complexity and interconnectedness of the country's agrifood system, future foresight research should focus on better understanding cross-sector productivity gains and how the entire system can be reoriented to support greater agricultural transformation.

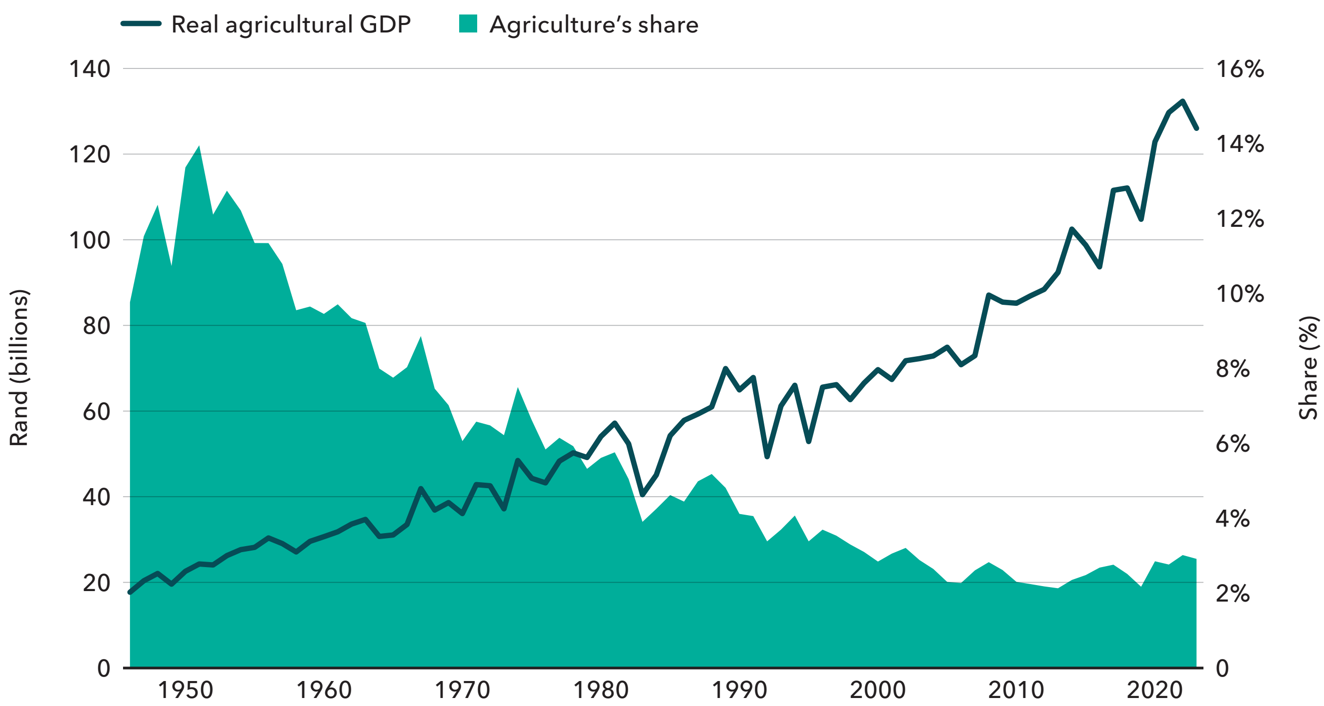
RECENT TRENDS AND CHALLENGES

South Africa recently celebrated 30 years since the start of its liberal democracy in 1994, marking an opportune moment to evaluate the performance of the country's agriculture and related value chains in contributing to national progress and development. The country's agrifood system is unique within the African context, shaped by various development phases, distinct past policy interventions, and more recent economic drivers both locally and internationally. Although more industrialized and globally competitive compared to many of its emerging market peers in Africa, South Africa faces persistent structural economic challenges and lags in achieving societal and developmental outcomes that would normally be associated with a country on a pathway toward agricultural transformation. This section details some insights about South Africa's current agrifood system and its likely future. It highlights the pressing need to explore alternative agricultural transformation pathways that can enhance productivity, sustainability, and competitiveness to the benefit of all actors who depend on the agrifood system for income and livelihoods.

The definition employed to assess South Africa's agrifood system is derived from multiple sources (FAO 2024; De Weerdt et al. 2023; Fanzo et al. 2020; UN 2021). In short, it encompasses a network of different actors who are interconnected by their various roles in supplying, using, and governing agrifood products, which are in turn influenced by factors like globalization, trade, urbanization, population growth, and changing climatic conditions. We estimate that in 2021, about 13–16 percent of South Africa's gross domestic product (GDP) could be attributed to all economic activities involving the agrifood system and close to 14 percent of the country's population is involved in some form of agricultural production, be it commercial, semi-commercial, or subsistence activities. On the consumption side of the economy, 19.5 million households spend around 16 percent of their final expenditure on food and beverages (StatsSA 2025). Thus, the structure, performance, competitiveness, and economic outcomes associated with the agrifood system play a critical role in South Africa, which has undergone significant structural changes over the past century.

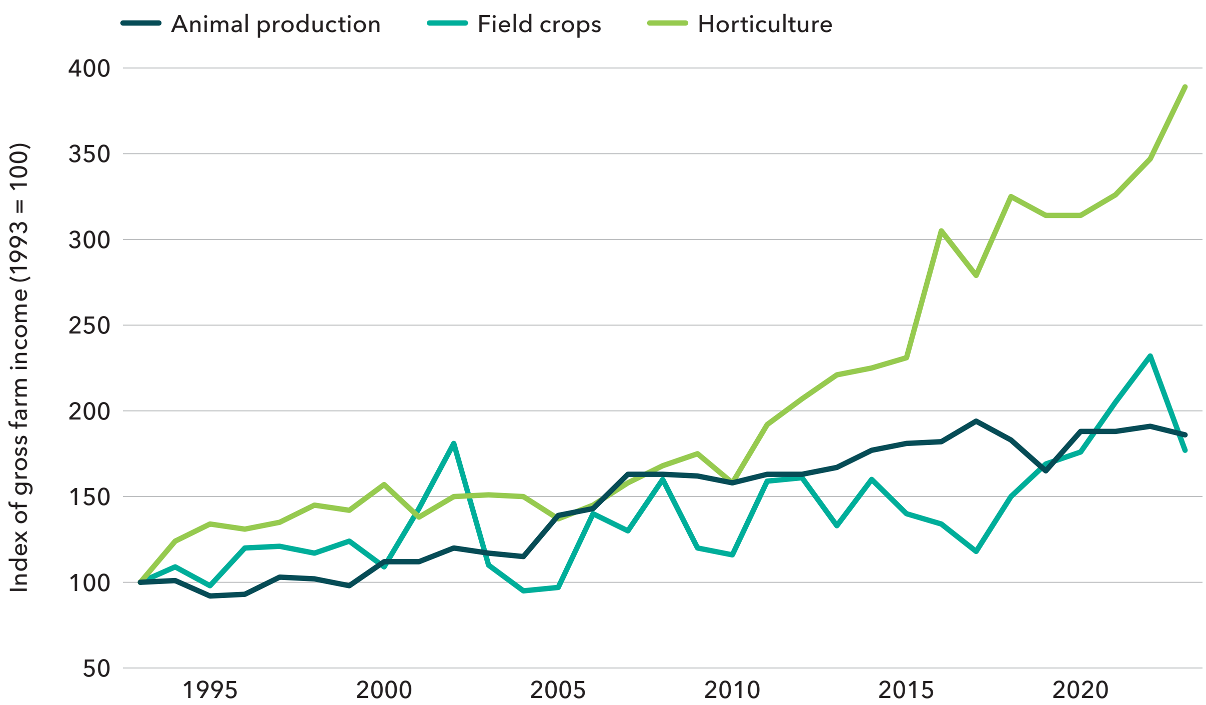
Within the agriculture sector, the size of farming units has increased, while the overall number declined, reflecting a process of consolidation that started in the

FIGURE 1 Real agricultural GDP and contribution to the economy, 1946–2023



Source: StatsSA (2024).

FIGURE 2 Index of real farm income, by subsector, 1993–2023



Source: South Africa, DALRRD (2024).

1950s (Liebenberg 2013). Up until 1994, the sector was heavily subsidized for long periods, through government market interventions as well as direct and indirect support to producers. A sudden policy shift in the 1990s to deregulation and liberalization of trade exposed the sector to global market forces for the first time in decades. Despite these significant changes, Figure 1 reflects strong performance in the primary agriculture sector's GDP. Its real growth rate has exceeded that of the rest of the South African economy, such that in the past decade agriculture's share contribution to GDP started to reverse its previously declining trend. At the same time, the decline in the number of jobs in agriculture started to reverse in recent years. Based on these two factors, one could argue that South Africa is experiencing a reversal in its agricultural transformation process.

This highlights the structural dynamics currently at play in the South African economy, where sluggish economic growth in nonfarm sectors is stalling structural transformation, despite strong productivity gains in the primary sector. Figure 2 shows the relative growth in real gross farm income since 1994 across the different agricultural subsectors, which indicates the importance of external demand. Export-led growth benefited the horticulture sector, with strong demand for products, such that 42 percent of total horticulture income was generated from exports in 2021. South Africa's strong position as a counterseasonal, Southern Hemisphere exporter of fresh fruit to developed economies underpinned growth in the agriculture sector as a whole. In contrast, the livestock and field crop industries are much more dependent on the South African economy, the purchasing power of its population, and the demand-pull from food manufacturers. The country is also an important surplus producer of maize, which is Africa's most important staple. Maize producers have benefited from supplying grain to the sub-Saharan African region for many years. Some countries in the region are projected to become larger net importers of staple crops, suggesting that exports will remain an important contributor to growth for the sector. While most agricultural subsectors have experienced significant growth in productivity levels, the country's industrial sectors are struggling to compete, largely due to the same factors that hinder faster growth in agriculture.

Too many South Africans are unemployed, poor, and indebted, and are operating in an economic environment with severe structural challenges, some of which are remnants of Apartheid-era policies. Yet with three decades of liberal democracy behind the country, it is worth asking whether many of the policies designed to address the triple problem of unemployment, poverty, and inequality have been successful. As with the rest of the economy, fundamental preconditions are needed to unlock further development in the country's agri-food system. First, a stable and conducive policy and investment environment that enables inclusive growth requires strong property rights and security of tenure. Comprehensive and effective state support programs are needed to rid the agriculture sector of its dualism, characterized by a large gap between mostly black and subsistence-oriented farmers and the often larger and modernized operations of white farmers. Emerging farmers require adequate services that are currently critically lacking. These include consistent electricity supply, market access, management of ports and rail, veterinary and biosecurity services, and agricultural research, to name a few. Among the biggest challenges to the agrifood system are:

- Management of animal diseases, which hamper productivity growth and limit export opportunities in livestock industries.

- Vast tracts of land that have become unproductive under the current land reform program, with minimally effective producer support and extension services. This land could enable expansion of field crop production by Black farmers, but comprehensive producer support and access to credit and insurance safety nets are essential to unlock growth in this segment of the market.

- Despite significant investment to expand fruit exports, the slow opening of new markets through bilateral trade negotiations has favored South Africa's competitors such as Chile, Mexico, and Peru, which have been more successful in opening trade with China and India.

LATEST FORESIGHT RESEARCH

For the past 20 years, South Africa's Bureau for Food and Agricultural Policy (BFAP) has presented a 10-year outlook for agricultural production, consumption, prices, and trade, referred to as the BFAP Baseline. This foresight research, generated using BFAP's system of models, is based on assumptions about a range of economic, technological, environmental, climatic, political, institutional, social, and international market factors. These can reflect the megatrends shaping the future of the agri-food system, which will not only drive the magnitude of change over time but also the direction in which it moves. South Africa's population is expected to increase from 64 million in 2024 to 79 million by 2050, with significant growth in the share of people living in urban areas (UNCTAD 2024). This will likely accelerate current trends that have shaped consumer spending patterns more recently, such as the move to more healthy diets, convenience-driven options, and the composition of food baskets more generally.

Looking 10 years ahead, our foresight projections suggest continued slow growth in agriculture due to the persistent challenges facing the economy. Despite ongoing urbanization, relatively strong population growth, and slightly better economic growth prospects, projected real GDP growth remains too slow to unlock rapid demand growth for agricultural and food products. Although many observers are hopeful that the new coalition government could fast-track growth-enabling interventions, our current baseline projections estimate real growth of only 0.4 percent per year in the agriculture sector over the next decade. For field crops, the transmission of lower global prices into local markets will likely reduce farmers' earnings, although the lower feed grain prices will benefit intensive livestock operations. In the absence of growth in meat export opportunities and likely further reduction in future fiscal stimulus supporting poor households, the livestock sector will remain under pressure. Projected consumption growth of 24 percent for poultry products, 22 percent for pork products, 13 percent for beef, 35 percent for processed dairy products, and 36 percent for eggs by 2035 relative to 2024 reflects the growing population, with minor per capita gains. Horticultural revenue is projected to grow consistently over the outlook period, as most of the area planted in the recent past will come into full production. It is expected that expansion of the area under horticulture will be much slower in the coming decade, due in part to strong competition in export markets putting pressure on farming margins in recent years and limits to additional arable land (and water) to expand area.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Foresight studies on South Africa's agrifood system have been limited and mainly focused on policy shocks, using scenario planning and exploring means to unlock future growth. A large gap exists within the policy space in understanding the complexities and interconnectedness between different segments of the agrifood system and the extent to which they are affected by different policy decisions. Also, it is not clear how to halt and reverse the country's de-industrialization trend, which has a bearing on how to ensure that the agricultural transformation process advances to ensure widespread progress for participants. South Africa is in a unique position in that the bulk of its farming sector is unlocking productivity growth, while the nonfarm agrifood system urgently requires solutions to improve its slow growth. By addressing these gaps, future research can contribute to making South Africa's agrifood system more resilient and sustainable.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Ferdi Meyer**, Managing Director of the Bureau for Food and Agriculture Policy (BFAP) and Professor Extraordinary in the Department of Agricultural Economics, University of Stellenbosch, South Africa; **Louw Pienaar**, a Senior Analyst at BFAP and Research Fellow in the Department of Agricultural Economics, University of Stellenbosch; **Tracy Davids**, Executive Director of BFAP and Research Fellow in the Department of Agricultural Economics, University of Stellenbosch; and **Mmatlou Kalaba**, Research Director of BFAP and Research Fellow in the Department of Agricultural Economics, University of Stellenbosch.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Meyer, F., L. Pienaar, T. Davids, and M. Kalaba. 2025. "What Do We Know About the Future of the Agrifood System in South Africa?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 27. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: dubes sonego/Shutterstock

References

De Weerdt, J., X. Diao, J. Duchoslav, M. Ellis, K. Pauw, and J. Thurlow. 2023. *Malawi's Agrifood System: Structure and Drivers of Transformation*. Agrifood System Diagnostics Country Brief 8. Lilongwe, Malawi: CGIAR; IFPRI. https://hdl.handle.net/10568/131438

Fanzo, J., L. Haddad, R. McLaren, Q. Marshall, C. Davis, A. Herforth, A. Jones, et al. 2020. "The Food Systems Dashboard is a New Tool to Inform Better Food Policy." *Nature Food* 1 (5): 243–246. https://doi.org/10.1038/s43016-020-0077-y

FAO (Food and Agriculture Organization of the United Nations). 2024. *Evaluation at FAO: Evaluating Agri-Food Systems*. Rome. https://www.fao.org/evaluation/highlights/agri-food-systems/en

Liebenberg, F. 2013. "South African Agricultural Production, Productivity and Research Performance in the 20th Century." PhD Thesis. Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, Pretoria, South Africa. https://www.proquest.com/openview/0bd06229ae21f2697b3a22b671dc6413/1?cbl=2026366&diss=y&pq-origsite=gscholar

South Africa, DALRRD (Department of Agriculture, Land Reform and Rural Development). 2024. Statistic & Economic Analysis: Abstract of Agricultural Statistics. Pretoria, South Africa. https://nda.gov.za/index.php/publication/332-statistical-abstract

StatsSA. 2024. *Gross Domestic Product (GDP) – P0041*. Pretoria, South Africa: Statistics South Africa.

StatsSA. 2025. *Income and Expenditure of Households 2022/2023*. Statistical Release PO100. Pretoria, South Africa: Statistics South Africa. https://www.statssa.gov.za/publications/P0100/P01002022.pdf

UN (United Nations). 2021. *Food Systems Summit 2021: About the Summit.* https://www.un.org/en/food-systems-summit/about

UNCTAD (United Nations Trade and Development). 2024. *Total and Urban Population, Annual*. Geneva: Data Hub, UNCTAD. https://unctadstat.unctad.org/datacentre/reportInfo/US.PopTotal

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF SELECTED FOOD COMMODITIES?

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF ANIMAL-SOURCE FOODS AND FOOD SYSTEMS?

Dolapo Enahoro (ILRI), Daniel Mason-D'Croz (Cornell University), Mario Herrero (Cornell University), Charles Mensah (University of Ghana), and Isabelle Baltenweck (ILRI)

Key messages

- Urbanization and income growth lead to more diverse diets and increased consumption of animal-source foods (ASF) in lower-income countries, while in some higher-income countries, consumer preferences may slowly be shifting away from ASF.
- A significant shift in diets is projected for lower-income countries, with the demand for ASF expected to increase by 20 percent in absolute kcal/person/day terms under conditions of baseline socioeconomic trends to 2050.
- Projected shifts in ASF consumption will disrupt local-to-global food production and distribution, but most attention has focused on its implications for nutrition and health, climate, and the environment, with less attention to socioeconomic and livelihood impacts.
- Strategies proposed for addressing the complex and multidimensional future impacts of changes in ASF demand, production, and distribution need further exploration.

RECENT TRENDS AND CHALLENGES

In a reflection of the persisting challenge to achieve the Sustainable Development Goal target of zero hunger, around 733 million people, or 1 in 11 globally, faced hunger in 2023. This is according to the 2024 United Nations report on the state of global food security (FAO et al. 2024). That report also indicated that up to 2.33 billion people experienced moderate to severe food insecurity in 2023, and, if current trends persist, a projected 582 million people will be chronically undernourished in 2030. Despite these recent setbacks in global food security, in many places where the consumption of protein from animal sources has been historically low, including among vulnerable populations within Africa and Asia, higher intakes of animal-source foods (ASF) contribute to reducing chronic challenges of calorific hunger and hidden hunger; that is, too-low intakes of foods of high nutritional value (Adesogan et al. 2019; UN-Nutrition 2021).

Following decades of high consumption in higher-income countries and regions, per capita demand for ASF types such as beef and mutton declined in many regions over the last decade (Table 1). Whereas issues of price and affordability dominate trends of ASF consumption in countries where average incomes are still very low, heightened concerns about potential negative impacts on human health and the environment, among other issues, have been influencing a slow dietary shift toward reduced consumption of meat in higher-income countries (Mathijs 2015). At the global level, however, demand for ASF has increased, driven by strong growth in demand for poultry (Table 1). Beyond the global statistics, changes in ASF demand are occurring in different directions (that is, up and down), and at varied rates for different locations and ASF types (Herrero et al. 2023). For example, while per capita demand for poultry meat increased in all regions over the last decade (although to varying degrees), pork demand per capita increased in the Americas, Asia, and Africa, but declined in Europe.

Rapid urbanization and income growth, among other changes, lead to more diverse diets and consumption of higher quantities of ASF, legumes, fruits, vegetables, and processed foods in developing economies (FAO et al. 2023). These dietary changes have direct effects on food security and nutrition, and — through changes in demand, production, and trade — drive major transformations in local to global food systems. This chapter examines selected key issues in the transformation of livestock-based ASF systems.

LATEST FORESIGHT RESEARCH

Demand, production, and distribution

In a report simulating responses of the global agricultural and food system to changes in population, income, and prices from 2020 to 2050, global calorie demand per person is projected to increase by 8.4 percent between 2020 and 2050 under a baseline scenario; that is, a continuation

TABLE 1 Change in annual meat demand (in kilograms) per capita between 2012 and 2022, selected regions

Region	Beef	Mutton/Lamb	Pork	Poultry	Meat
World	0.26	0.18	0.27	2.63	3.34
United States	0.96	0.28	2.57	3.89	7.70
Europe	(1.83)	(0.22)	(0.28)	2.56	0.23
South America	(4.41)	(0.06)	3.99	5.50	5.02
Africa	(1.07)	(0.19)	0.44	1.21	0.39
Asia	1.78	0.34	0.58	3.07	5.77

Source: Authors' calculations based on published statistics (FAOSTAT 2024).

Note: The numbers presented are the difference between per capita demand for the various meat products in the selected regions between 2022 (the most recent year for which data are available) and a decade prior (that is, 2012). Negative values are presented in parentheses, indicating a decline in per capita demand between 2012 and 2022.

FIGURE 1 Overview of the livestock sector's links to nutrition, health, the environment, and livelihoods

FOOD-NUTRITION-HEALTH

- Meat, milk and eggs provide protein, and essential micronutrients that may not be readily available in plant-based foods. They are highly valued in poor households subsisting primarily on high-starch diets, for children in their first 1,000 days of life, and among nutritionally vulnerable populations such as children, and women of reproductive age.
- Overconsumption of animal source foods can contribute to overweight and obesity and has been linked to higher incidences of non-communicable diseases.

ENVIRONMENT-HEALTH

- Livestock production contribute to more optimal use of all the planet's biomass, exploiting the earth's full ecological potential and supporting circularity in food production systems.
- Livestock are a major contributor to greenhouse gas emissions and a driver of environmental pollution through the land, water, and chemical use associated with producing animal feeds.
- Livestock animals and can be transmitters of zoonotic diseases that spread between animals and humans.

LIVELIHOODS

- Millions of producers and other value chain actors are gainfully employed in the global livestock sector while millions more poor households in rural and peri-urban settings and developing countries rely on livestock for their livelihoods and incomes.
- Livestock contributes a major share of agricultural and national income in many developed countries, while its importance in economic development is growing in many low-and-middle-income countries.

Source: Adapted from ILRI (2019).

of current socioeconomic and climate trends (Rosegrant et al. 2024). Developing countries will mainly drive this result, with per person calorie demand in this bloc increasing by 10 percent to 2050, from 2,560 to 2,816 kcal/person/day. The absolute changes in food demand in lower-income countries are also projected to be accompanied by a significant diversification of diets, wherein the share of cereals in calorie demand will decline by 4 percentage points, to be replaced by increases in the shares of other food commodities, including ASF. According to these projections, demand for ASF will increase by 20 percent in absolute kcal/person/day terms in lower-income countries.

Projected future trends of ASF demand are expected to disrupt patterns of ASF production and distribution, with important environmental and social impacts in both high- and low-income countries (Fukase and Martin 2020). Livestock production systems will need to respond to changing ASF demand and are known to be intricately linked to indicators of human nutrition and health, livelihoods, and the environment (Figure 1). Agricultural value chains are also expected to undergo significant changes that mirror global shifts in food demand. In low- and middle-income countries (LMICs), agricultural and livestock value chains could become more structured and important to countries' economies (Barrett et al. 2022). Production and processing of ASF in LMICs may also see more rapid intensification in poultry, pork, and dairy than in beef systems (ILRI 2019). These changes have implications for climate and other indicators within countries facing rapid changes in their livestock value chains. Other studies suggest that under business-as-usual trends for ASF demand that are not accompanied by interventions to stimulate increased domestic production, demand for ASF (mainly poultry) could increase substantially in many LMICs, including across Africa, to outstrip domestic production (Enahoro et al. 2021). In this scenario, local demand for many ASF types could increasingly be met through imports.

Climate and environmental impacts

The ongoing patterns of ASF demand and supply have been linked to climate and environmental impacts. For example, livestock (including feeds) production is estimated to contribute 14–20 percent of total greenhouse gas (GHG) emissions and up to 60 percent of emissions related to agriculture and food systems, including from the processing, retail, and consumption of ASF products (Xu et al. 2021). Since livestock production can account for up to one-half of the agriculture sector's technical potential to mitigate climate change (Herrero et al. 2016), various demand- and supply-side strategies have been proposed to manage the growth in ASF demand and to facilitate the sector's transition toward sustainable food systems (Herrero et al. 2023). These include improving the management of rangelands and switching to the use of livestock feed options with reduced environmental impacts (for example, feed additives containing nitrogen to reduce ruminant methane) (Havlik et al. 2014; Herrero et al. 2016). Pikaar et al. (2018) projected that alternative animal-feed supply routes based on industrial production of microbial proteins can, by 2050, replace 10–19 percent of conventional crop-based animal-feed protein demand, resulting in agricultural GHG emissions decreases of around 6–9 percent. A different report showed that increased environmental optimization of feed compositions, a shift from beef production to more productive systems, and land restoration could enable GHG emissions reductions of 34–85 percent annually without increasing costs (Castonguay et al. 2023).

While changes in ASF demand and production will potentially influence climate change, the converse is also anticipated. Anthropogenic climate change is projected to have major impacts on ASF production, including through increased heat stress in animals in both intensive and extensive livestock systems, potentially affecting weight gain, animal yields (for example, milk), and fertility (Thornton et al. 2021). Thornton et al. (2022) estimated that losses from climate-induced heat stress in cattle could reach almost US$40 billion per year by the end of the century, or nearly 10 percent of the value of production of cattle meat and milk in 2050. That work showed that losses due to climate impacts are projected to be far greater in tropical regions, where they are also more challenging to address, again highlighting the need to focus on LMICs. The effects of climate change will not be negative everywhere, however, and will be experienced at varying levels in different livestock systems and geographies (Thornton et al. 2009).

Demand-side strategies for climate mitigation

Although ASF intake could be increased for nutritionally disadvantaged communities and among vulnerable groups such as children, pregnant women, and the elderly (ILRI 2019; UNEP 2023), in other populations, where current intake is considered too high, demand-side strategies should focus on lowering ASF consumption. Proposed strategies for reducing ASF intake, where that is the appropriate option, include the costing of ASF products to reflect their negative environmental impacts and the substitution of animal protein in human diets with alternatives such as plant-based meats and cultured meat (Herrero et al. 2023; UNEP 2023). Studies have shown the potential to: (1) reduce (by up to 13.5 percent) the carbon footprint of US food production through dietary changes that reduce the number of beef animals (Mason-D'Croz et al. 2022); and (2) address animal welfare and environmental concerns of global ASF consumption through the adoption of novel plant-based meat, cultivated meat, and fermentation-derived foods (UNEP 2023). Using a forward-looking quantitative analysis, Kozicka et al. (2023) show that a combination of strategic dietary changes and agricultural land restoration could lead to substantial reductions in global environmental impacts (for example, a 31 percent reduction in GHG emissions) by 2050.

The economic costs and benefits of many identified mitigation strategies are largely unknown, as are some social, environmental, and nutrition and health implications (Herrero et al. 2016; UNEP 2023). While studies would suggest that lower quantities of (for example) bioavailable iron and other essential nutrients make plant-based alternatives less suitable as substitutes for animal proteins in the diets of nutritionally vulnerable populations (such as children, women, and the elderly), very few studies have attempted to quantitatively measure the long-term effects on human nutrition and health (Alonso, Dominguez-Salas, and Grace 2019; UNEP 2023). It is generally accepted, though, that prospects for strategies such as reduction in the consumption of ASF are better suited to some regions (for example, higher-income countries) than to others (Herrero et al. 2023; UNEP 2023).

Wider socioeconomic impacts

Demand-induced changes in ASF production and value chains also interact with social and economic indicators such as prices, national income, employment, and livelihoods. In an analysis exploring potential future demand for ASF, Komarek et al. (2021) highlighted that consumer preferences are reducing ASF consumption in higher-income countries, leading to lower prices. The lower prices induce increases in demand for ASF in (importing) lower-income countries, but also in higher-income countries, although this price response is more muted in the latter as higher-income consumers are less price-sensitive. Results such as this suggest that price effects are still important in regulating global ASF consumption and can be important in strategies for managing environmental impacts. Pricing and demand-based policies will need to be employed with some caution (ILRI 2019; Springmann et al. 2017). Mason-D'Croz et al.'s (2022) analysis of the long-term potential impacts on the US cattle industry of wide-scale replacement of beef with plant-based alternatives found small positive impacts on the national gross domestic product due to a more resource-efficient food system. Nevertheless, disruptions in agricultural supply chains from the adoption of plant-based alternatives could challenge the livelihoods of the more than 1.5 million people employed in beef value chains in the United States. Similar concerns arise in other countries that a shift in consumption from ASF toward alternative proteins could pose serious threats to the livelihoods and incomes of ASF producers, but not many studies have applied quantitative analyses to explore these dynamics.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Key foresight studies agree on the need to consider nutrition, livelihoods, and other impacts on the poor and in lower-income countries associated with proposed strategies to mitigate the negative impacts of high levels of ASF demand and production. However, it will be important to distinguish between impacts that would be relevant to specific actors in ASF supply chains and specific geographies and communities that rely on these activities, and major impacts for societies overall. While Mason-D'Croz et al.'s (2022) study on the United States indicated the potential for a serious challenge for those in the beef sector, particularly if the simulated changes occur quickly, it did not highlight major concerns for the overall economy. This narrative is not unique to the ASF sector, as it holds true in general for disruptions brought about by events such as the introduction of major new technologies or major shifts in the patterns and volumes of international trade.

More work is needed in quantitative assessments of the future of ASF demand, production, and (local to global) trade, particularly with respect to economic (and non-economic) costs and benefits, trade-offs, and the varied roles and effects of, for example, smallholder producers and other actors at different nodes (for example, production, processing, retail) in animal-source food value chains. Major advancements in quantitative foresight modeling (such as the integration of different modeling platforms), increased availability (and effective use) of big data, and innovations in the use of artificial intelligence are just a few technologies that may make it easier to quantify the multidimensional factors and trade-offs around ASF consumption, production, and their impacts in the future. These prospects hold promises for better decision-making in and for the livestock sector from a local to global scale.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors are grateful for the research funding received (by DE and CM) for this work and for the constructive feedback and support from Keith Wiebe, Nicola Cenacchi, and other contributors to the CGIAR Foresight Initiative.

The authors of this chapter are **Dolapo Enahoro**, a Senior Agricultural Economist at the International Livestock Research Institute (ILRI); **Daniel Mason-D'Croz**, a Senior Research Associate in the Department of Global Development at Cornell University and a PhD Candidate with the Agricultural Economics and Rural Policy Group at Wageningen University and Research; **Mario Herrero**, Professor, Cornell Atkinson Scholar, and Nancy and Peter Meinig Family Investigator in the Life Sciences in the Department of Global Development at Cornell University; **Charles Mensah**, a PhD student in the Department of Agricultural Economics and Agribusiness, University of Ghana, and formerly a Research Officer at ILRI; and **Isabelle Baltenweck**, a Program Leader at ILRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Enahoro, D., D. Mason-D'Croz, M. Herrero, C. Mensah, and I. Baltenweck. 2025. "What Do We Know About the Future of Animal-Source Foods and Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 28. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Wassana Panapute/Shutterstock

References

Adesogan, A.T., A.H. Havelaar, S.L. McKune, M. Eilittä, and G.E. Dahl. 2019. "Animal Source Foods: Sustainability Problem or Malnutrition and Sustainability Solution? Perspective Matters." *Global Food Security* 35: 100325. https://doi.org/10.1016/j.gfs.2019.100325

Alonso, S., P. Dominguez-Salas, and D. Grace. 2019. "The Role of Livestock Products for Nutrition in the First 1,000 Days of Life." *Animal Frontiers* 9 (4): 24–31. https://doi.org/10.1093/af/vfz033

Barrett, C.B., T. Reardon, J. Swinnen, and D. Zilberman. 2022. "Agri-Food Value Chain Revolutions in Low- and Middle-Income Countries." *Journal of Economic Literature* 60 (4): 1316–1377. http://dx.doi.org/10.1257/jel.20201539

Castonguay, A.C., S.H. Polasky, M. Holden et al. 2023. "Navigating Sustainability Trade-Offs in Global Beef Production." *Nature Sustainability* 6 (3): 284–294. https://doi.org/10.1038/s41893-022-01017-0

Enahoro, D., S. Bahta, C. Mensah, S. Oloo, and K.M. Rich. 2021. "Current and Future Trade in Livestock Products." Scientific and Technical Review 40 (2): 395–411. https://doi.org/10.20506/rst.40.2.3232

FAO (Food and Agriculture Organization of the United Nations), IFAD (International FUnd for Agricultural Development), UNICEF, WFP (World Food Program), and WHO (World Health Organization). 2023. *The State of Food Security and Nutrition in the World 2023: Urbanization, Agrifood Systems Transformation and Healthy Diets across the Rural–Urban Continuum*. Rome: FAO. https://doi.org/10.4060/cc3017en

FAO, IFAD, UNICEF, WFP, and WHO. 2024. *The State of Food Security and Nutrition in the World 2024: Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms*. Rome: FAO. https://doi.org/10.4060/cd1254en

FAO (Food and Agriculture Organization of the United Nations. 2024. *FAOSTAT Statistical Databases: Food Balances*. Accessed December 9, 2024. https://www.fao.org/faostat/

Fukase, E., and W. Martin. 2020. "Economic Growth, Convergence, and World Food Demand and Supply." *World Development* 132: 104954. https://doi.org/10.1016/j.worlddev.2020.104954

Havlik, P., H. Valin, M. Herrero et al. 2014. "Climate Change Mitigation Through Livestock System Transitions." *PNAS* 111 (10): 3709–3714. https://doi.org/10.1073/pnas.1308044111

Herrero, M., B. Henderson, P. Havlík et al. 2016. "Greenhouse Gas Mitigation Potentials in the Livestock Sector." *Nature Climate Change* 6: 452–461. https://doi.org/10.1038/nclimate2925

Herrero, M., D. Mason-D'Croz, P.K. Thornton et al. 2023. "Livestock and Sustainable Food Systems: Status, Trends, and Priority Actions." In *Science and Innovations for Food Systems Transformation*, edited by J. von Braun, K. Afsana, L.O. Fresco, and M.H.A. Hassan, 375–399. Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-031-15703-5_20

ILRI (International Livestock Research Institute). 2019. "Meat: The Future Series—Options for the Livestock Sector in Developing and Emerging Economies to 2030 and Beyond." White Paper. Geneva: World Economic Forum. https://www3.weforum.org/docs/White_Paper_Livestock_Emerging%20Economies.pdf

Komarek, A.M., S. Dunston, D. Enahoro et al. 2021. "Income, Consumer Preferences, and the Future of Livestock-Derived Food Demand." *Global Environmental Change* 70: 102343. https://doi.org/10.1016/j.gloenvcha.2021.102343

Kozicka, M., P. Havlík, H. Valin et al. 2023. "Feeding Climate and Biodiversity Goals with Novel Plant-Based Meat and Milk Alternatives." *Nature Communications* 14: 5316. https://doi.org/10.1038/s41467-023-40899-2

Mason-D'Croz, D., A. Barnhill, J. Bernstein et al. 2022. "Ethical and Economic Implications of the Adoption of Novel Plant-Based Beef Substitutes in the USA: A General Equilibrium Modelling Study." *The Lancet Planetary Health* 6 (8): e658-e669. https://doi.org/10.1016/S2542-5196(22)00169-3

Mathijs, E. 2015. "Exploring Future Patterns of Meat Consumption." *Meat Science* 109: 112–116. https://doi.org/10.1016/j.meatsci.2015.05.007

Pikaar, I., S. Matassa, B.L. Bodirsky et al. 2018. "Decoupling Livestock from Land Use Through Industrial Feed Production Pathways." *Environmental Science & Technology* 52 (13): 7351–7359. https://doi.org/10.1021/acs.est.8b00216

Rosegrant, M.W., T.B. Sulser, S. Dunston et al. 2024. "Food and Nutrition Security Under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Springmann, M., D. Mason-D'Croz, S. Robinson, K. Wiebe, H.C.J. Godfray, M. Rayner, and P. Scarborough. 2017. "Mitigation Potential and Global Health Impacts from Emissions Pricing of Food Commodities." *Nature Climate Change* 7 (1): 69–74. https://doi.org/10.1038/nclimate3155

Thornton, P.K., G. Nelson, D. Mayberry, and M. Herrero. 2021. "Increases in Extreme Heat Stress in Domesticated Livestock Species During the Twenty-First Century." *Global Change Biology* 27 (22): 5762–5772. https://doi.org/10.1111/gcb.15825

Thornton, P.K., J. van de Steeg, A. Notenbaert, and M. Herrero. 2009. "The Impacts of Climate Change on Livestock and Livestock Systems in Developing Countries: A Review of What We Know and What We Need to Know." *Agricultural Systems* 101 (3): 113–127. https://doi.org/10.1016/j.agsy.2009.05.002

Thornton, P., G. Nelson, D. Mayberry, and M. Herrero. 2022. "Impacts of Heat Stress on Global Cattle Production during the 21st Century: A Modelling Study." *Lancet Planetary Health* 6 (3): e192–e201. https://doi.org/10.1016/S2542-5196(22)00002-X

UNEP (United Nations Environment Programme). 2023. *What's Cooking? An Assessment of the Potential Impacts of Selected Novel Alternatives to Conventional Animal Products*. Frontiers 2023. Nairobi: UNEP. https://doi.org/10.59117/20.500.11822/44236

UN-Nutrition. 2021. "Livestock-Derived Foods and Sustainable Healthy Diets." UN Nutrition Discussion Paper, June, Rome. https://www.unnutrition.org/library/publication/livestock-derived-foods-and-sustainable-healthy-diets

Xu, X., P. Sharma, S. Shu et al. 2021. "Global Greenhouse Gas Emissions from Animal-Based Foods Are Twice Those of Plant-Based Foods." *Nature Food* 2: 724–732. https://doi.org/10.1038/s43016-021-00358-x

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF AQUATIC FOODS IN GLOBAL AGRIFOOD SYSTEMS?

Chin Yee Chan (WorldFish), Nhuong Tran (HSB-VNU and ANU), Yan Hoong (S&P Global), Timothy B. Sulser (IFPRI), and Yee Mon Aung (Yezin Agricultural University)

Key messages

- Demand for aquatic foods has increased rapidly due to population growth, rising incomes, and enhanced appreciation for the health benefits of fish. The rapid growth of aquaculture in the past two decades has been the key contributor to meeting the increasing demand for aquatic foods.
- Aquatic foods are nutrient-rich, generate low emissions and impacts on land and water, and contribute to the human health, well-being, and livelihoods of rural communities.
- The latest fish foresight studies provide multifaceted insights into future scenarios of technological progress, climate change, population growth, diet transformation, urbanization, investments, and policy shifts in the fish sector and the potential for fish to provide nutrition-sensitive interventions to combat food insecurity and malnutrition at the global, regional, and national level.
- Further foresight studies are needed to inform policymaking and develop a deeper understanding of the role aquatic foods can play in addressing the nutritional, social, and environmental food systems challenges while navigating the trade-offs of pursuing these different goals.

RECENT TRENDS AND CHALLENGES

Food, land, and water systems are facing unprecedented change. Nourishing 9.8 billion people with a healthy and sustainable diet by 2050 and within planetary boundaries is recognized as one of the biggest challenges facing humanity (Springmann et al. 2018; United Nations 2022). Aquatic foods offer significant potential in the transformation of food systems toward healthy and sustainable diets, sustaining livelihoods, and generating income for women and youth (Chan et al. 2021; FAO 2022; Simmance et al. 2021; Tigchelaar et al. 2022), and are accessible to these vulnerable populations even in the face of political shocks and market failures, such as those brought about by COVID-19 (Béné 2020). Yet the role of aquatic foods has been largely overlooked and remains remarkably absent from many contemporary food system discussions and policies (Chan et al. 2021; Crona et al. 2023).

Demand for aquatic foods has increased rapidly due to population growth, rising incomes, and enhanced appreciation for the health benefits of fish consumption (Aung et al. 2022; Naylor et al. 2021b; Wang et al. 2022). The rapid growth of aquaculture in the past two decades has been the key contributor to meeting the increasing demand for aquatic foods. Some aquaculture systems are associated with environmental drawbacks, highlighting the need for new approaches to sustainability (Le Gouvello, Brugere, and Simard 2022; Naylor et al. 2021a). Also, expanding production of food from the sea will bring co-benefits and trade-offs and will require national and interregional governance, as well as local capacity, to ensure equity and sustainability (Costello et al. 2020). The productivity, biodiversity, and carbon-sequestering functions of aquatic ecosystems are threatened by multiple factors, including pollution, the proliferation of disease outbreaks, climate change, competing water demands, lack of effective fisheries management to combat illegal, unreported, and unregulated fishing, habitat degradation, and infrastructure development and land use change (Long et al. 2020; Tran et al. 2022; Tweddle et al. 2015). Carefully managed aquatic food systems that include "nature-based solutions" can deliver better impacts on "ecological, economic, and social needs, as well as increased employment and food security" (Theuerkauf et al. 2019).

LATEST FORESIGHT RESEARCH

In recent years, aquatic foods have become more integrated into foresight models of the agriculture and land use sectors. To date, fish commodities have been included in several partial equilibrium economic models, including the International Model for Policy Analysis of Agriculture Commodities and Trade (IMPACT) (Chan et al. 2021; Chan et al. 2019; Kobayashi et al. 2015; World Bank 2013), the AgLINK-COSIMO model (Lem, Bjorndal, and Lappo 2014; OECD/FAO 2021), the Global Biosphere Management Model (GLOBIOM), and the Common Agricultural Policy Regionalised Impact (CAPRI) model (Chang, Witzke, and Latka 2018; Deppermann et al. 2019; Heckelei et al. 2018; Latka et al. 2018). These economic models focus on analyzing the future supply and demand of fish by simulating the impacts of external drivers such as technological progress, population and income growth, and climate change on fish production, consumption, and trade at the national, regional, and global level. Some studies using the CAPRI model focus on simulating the economic impact of fisheries policies on aquafeed production and different fish commodities. Overall, these comprehensive models focus on medium- or long-term projections at the global and regional level. Other partial equilibrium modeling approaches developed by WorldFish, such as the AsiaFish model (Dey et al. 2016; Tran et al. 2023; Tran et al. 2017) and the multispecies–multisector equilibrium model (Tran et al. 2019, 2022), provide more disaggregated projections of the fish sector at the country level. Historical data, in conjunction with stakeholder consultation inputs, are used to generate projections that mirror past trends while giving direction to future projections.

Foresight analyses using the IMPACT, AgLINK-COSIMO, GLOBIOM, and CAPRI fish models have projected the future of fish supply and demand across different fish types around the world under various scenarios (Cardon 2020; Chan et al. 2019, 2021; Delgado et al. 2003; Latka et al. 2018; Lem, Bjorndal, and Lappo 2014; OECD/FAO 2021; World Bank 2013). Globally, nominal fish prices are projected to increase at a rate of between 0.8 percent and 1.6 percent per year over the 2021–2030 period, with a stronger increase in 2022, when the negative effects of COVID-19 on markets are expected to end (OECD/FAO 2021). The ASEAN (Association of Southeast Asian Nations) region is projected to account for nearly one-quarter of global fish production in the coming decades (Chan et al.

2017). Despite the relatively fast expansion of the aquaculture sector, capture fisheries will remain a dominant fish source in the region. Compared to the rest of Asia, the ASEAN region exhibits remarkably high per capita fish consumption, more than doubling over the past four decades and double the world average (Chan et al. 2017). Africa has the lowest per capita fish consumption compared to other global regions, with an extraordinary potential for growth (Chan et al. 2019). In Africa, aquaculture development has significant potential to contribute to the goal of reducing food and nutrition insecurity. However, Africa will continue to be a net fish-importing continent to fulfill the required demand, representing important opportunities for fish sector entrepreneurs (Chan et al. 2019). Sustained investment is important to support sustainable fish sector growth for food system transformation toward healthy diets (Chan et al. 2021). In Europe, the GLOBIOM model estimates that the total fish production will increase to 6.3 million metric tons by 2030, of which 82 percent will come from capture fisheries (Latka et al. 2018). Both the GLOBIOM and CAPRI models project that Europeans will consume approximately 10 million tons of fish by 2030, with the balance coming from imports.

Alternative scenarios of future potential risks have been explored through country-level foresight analysis. For example, disease outbreaks could considerably reduce future aquaculture production in Bangladesh, Egypt, and Indonesia (Tran et al. 2017, 2022, 2023). In addition, the share of fishery stocks within biologically sustainable levels declined to 65 percent in 2019 due to overfishing, pollution, poor management, and other factors (FAO 2022), resulting in stagnant or slightly declining capture fisheries. Consequently, per capita fish consumption fell as consumer prices rose due to the reduction in fish availability. Another major challenge, climate change, is likely to constrain a rise in aquaculture production, due to impacts on water quality, pH level, and salinity (Tran et al. 2022).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

The role of aquatic foods in food system transformation has remained relatively overlooked due to the limited scientific data and evidence to inform aquatic foods investment planning and priority setting. Compared to other food commodities, substantial uncertainties persist regarding the quantification of greenhouse gas emissions associated with aquatic foods. As these foods are a relatively underdeveloped realm for foresight modeling, it is imperative to enhance the quality of modeling projections and incorporate these improvements for a more complete and accurate view of food systems. Aquatic food systems are highly heterogenous and complex, thus disaggregated foresight modeling studies should be conducted to capture the diversity of trends within specific subsectors at the global, regional, and national level. Such analyses are important for developing intervention options for sustainable fishery sector development. Additional analyses are needed to explore future potential for outcomes in additional areas of interest, such as poverty alleviation, nutrition, gender equity, and environmental sustainability, while effectively navigating trade-offs (Chan et al. 2021).

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Chin Yee Chan**, a Scientist at WorldFish; **Nhuong Tran**, a Senior Researcher and Lecturer at Hanoi School of Business and Management, Vietnam National University (HSB-VNU), and Honorary Associate Professor in the Crawford School of Public Policy at The Australian National University (ANU), and formerly an Applied Economic Senior Scientist at WorldFish; **Yan Hoong**, an Economist at S&P Global, and formerly a Research Analyst at WorldFish; **Timothy B. Sulser**, a Senior Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); and **Yee Mon Aung**, a Lecturer at Yezin Agricultural University, Myanmar.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Chan, C.Y., N. Tran, Y. Hoong, T.S. Sulser, and Y.M. Aung. 2025, "What Do We Know About the Future of Aquatic Foods in Global Agrifood Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 29. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Chosa Mweemba/WorldFish

References

Aung, Y.M., L.Y. Khor, N. Tran, M. Akester, and M. Zeller. 2022. "A Disaggregated Analysis of Fish Demand in Myanmar." *Marine Resource Economics* 37 (4): 369–514. https://doi.org/10.1086/721054

Béné, C. 2020. "Resilience of Local Food Systems and Links to Food Security—A Review of Some Important Concepts in the Context of COVID-19 and Other Shocks." *Food Security* 12: 805–822. https://doi.org/10.1007/s12571-020-01076-1

Cardon, V. 2020. "Bounded Futures: Growing a Boundary Foreknowledge Infrastructure in Food Security Research." *Science, Technology & Society* 25 (1): 38–66. https://doi.org/10.1177/0971721819889918

Chan, C.Y., N. Tran, K.C. Cheong, T.B. Sulser, P.J. Cohen, K. Wiebe, and A.M. Nasr-Allah. 2021. "The Future of Fish in Africa: Employment and Investment Opportunities." *PLoS ONE* 16 (12): e021615. https://doi.org/10.1371/journal.pone.0261615

Chan, C.Y., N. Tran, C.D. Dao, et al. 2017. *Fish to 2050 in the ASEAN Region*. Working Paper: 2017–01. WorldFish, Penang; IFPRI, Washington, DC. https://hdl.handle.net/20.500.12348/111

Chan, C.Y., N. Tran, S. Pethiyagoda, C.C. Crissman, T.B. Sulser, and M.J. Phillips. 2019. "Prospects and Challenges of Fish on Food Security in Africa." *Global Food Security* 20: 17–25. https://doi.org/10.1016/j.gfs.2018.12.002

Chang, C.Y., H.P. Witzke, and C. Latka. 2018. *A Model for Data Consolidation of the Fish Market in CAPRI*. 58th Annual Conference, Kiel, Germany, September 12–14. German Association of Agricultural Economists (GEWISOLA). https://ideas.repec.org/p/ags/gewi18/275842.html

Costello, C., L. Cao, S. Gelcich, et al. 2020. "The Future of Food From the Sea." *Nature* 588: 95–100. https://doi.org/10.1038/s41586-020-2616-y

Crona, B.I., E. Wassenius, M. Jonell et al. 2023. "Four Ways Blue Foods Can Help Achieve Food System Ambitions Across Nations." *Nature* 616: 104–112. https://doi.org/10.1038/s41586-023-05737-x

Delgado, C.L., N. Wada, M.W. Rosegrant, S. Meijer, and M. Ahmed. 2003. *Fish to 2020: Supply and Demand in Changing Global Markets*. WorldFish Center Technical Report 62. Washington, DC: IFPRI. https://hdl.handle.net/20.500.12348/2203

Deppermann, A., H. Valin, M. Gusti et al. 2019. *Towards Sustainable Food and Land-Use Systems: Insights From Integrated Scenarios of the Global Biosphere Management Model (GLOBIOM)*. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA). https://pure.iiasa.ac.at/id/eprint/16091/

Dey, M.M., M.W. Rosegrant, K. Gosh, O.L. Chen, and R. Valmonte-Santos. 2016. "Analysis of the Economic Impact of Climate Change and Climate Change Adaptation Strategies for Fisheries Sector in Pacific Coral Triangle Countries: Model, Estimation Strategy, and Baseline Results." *Marine Policy* 67: 156–163. https://doi.org/10.1016/j.marpol.2015.12.011

FAO (Food and Agricultural Organization of the United Nations). 2022. *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation*. Rome. https://doi.org/10.4060/cc0461en

Heckelei, T., M. Batka, C.Y. Chang, et al. 2018. *Enhanced Modelling of Sustainable Food and Nutrition Security: Food Supply and Use of Scarce Resources*. Deliverable 9.3. The Hague: SUSFAN.

Kobayashi, M., S. Msangi, M. Batka, S. Vannuccini, M.M. Dey, and J.L. Anderson. 2015. "Fish to 2030: The Role and Opportunity for Aquaculture." *Aquaculture Economics & Management* 19: 282–300. https://doi.org/10.1080/13657305.2015.994240

Latka, C., T. Heckelei, M. Batka et al. 2018. *The Potential Role of Producer and Consumer Food Policies in the EU to Sustainable Food and Nutrition Security*. Deliverable No. 10.3: SUSFANS Project H2020/SFS-19 - 2014: Sustainable Food And Nutrition Security Through Evidence Based EU Agro-Food Policy GA No. 633692. Wageningen, Netherlands: SUSFAN. https://edepot.wur.nl/464089

Le Gouvello, R., C. Brugere, and F. Simard. 2022. *Aquaculture and Nature-based Solutions: Identifying Synergies Between Sustainable Development of Coastal Communities, Aquaculture, and Marine and Coastal Conservation*. Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2022.02.en

Lem, A., T. Bjorndal, and A. Lappo. 2014. *Economic Analysis of Supply and Demand for Food up to 2030—Special Focus on Fish and Fishery Products*. FAO Fisheries and Aquaculture Circular No. 1089. Rome: FAO. https://openknowledge.fao.org/server/api/core/bitstreams/aa6175f4-2359-4daf-b634-b183dc39ca72/content

Long, T., S. Widjaja, H. Wirajuda, and S. Juwana. 2020. "Approaches to Combatting Illegal, Unreported and Unregulated Fishing." *Nature Food* 1: 389–391. https://doi.org/10.1038/s43016-020-0121-y

Naylor, R.L., R.W. Hardy, A.H. Buschmann et al. 2021a. "A 20-year Retrospective Review of Global Aquaculture." *Nature* 591: 551–563. https://doi.org/10.1038/s41586-021-03308-6

Naylor, R.L., A. Kishore, U.R. Sumaila et al. 2021b. "Blue Food Demand Across Geographic and Temporal Scales." *Nature Communications* 12: 5413. https://doi.org/10.1038/s41467-021-25516-4

OECD/FAO (Organisation for Economic Co-operation and Development/Food and Agriculture Organization). 2021. OECD-FAO Agricultural Outlook 2021–2030. Paris: OECD Publishing. https://doi.org/10.1787/19428846-en.

Simmance, F.A., P.J. Cohen, C. Huchery, et al. 2021. "Nudging Fisheries and Aquaculture Research Towards Food Systems." *Fish and Fisheries* 23 (1): 34–53. https://doi.org/10.1111/faf.12597

Springmann, M., M. Clark, D. Mason-D'Croz, et al. 2018. "Options for Keeping the Food System Within Environmental Limits." *Nature* 562: 519–525. https://doi.org/10.1038/s41586-018-0594-0

Theuerkauf, S.J., J.A. Morris Jr., T.J. Waters, L.C. Wickliffe, H.K. Alleway, and R.C. Jones. 2019. "A Global Spatial Analysis Reveals Where Marine Aquaculture Can Benefit Nature and People." *PLoS One* 14 (10): e0222282. https://doi.org/10.1371/journal.pone.0222282

Tigchelaar, M., J. Leape, F. Micheli, et al. 2022. "The Vital Roles of Blue Foods in the Global Food System." *Global Food Security* 33: 100637. https://doi.org/10.1016/j.gfs.2022.100637

Tran, N., C.Y. Chan, Y.M. Aung, et al. 2022. "Foresighting Future Climate Change Impacts on Fisheries and Aquaculture in Vietnam." *Frontiers in Sustainable Food Systems* 6: 829157. https://doi.org/10.3389/fsufs.2022.829157

Tran, N., L. Chu, C.Y. Chan, S. Genschick, M.J. Phillips, and A.S. Kefi. 2019. "Fish Supply and Demand for Food Security in Sub-Saharan Africa: An Analysis of the Zambian Fish Sector." *Marine Policy* 99: 343–350. https://doi.org/10.1016/j.marpol.2018.11.009

Tran, N., L. Chu, C.Y. Chan, J. Peart, A.M. Nasr-Allah, and H. Charo-Karisa. 2022. "Prospects of Fish Supply-Demand and Its Implications for Food and Nutrition Security in Egypt." *Marine Policy* 146: 105333. https://doi.org/10.1016/j.marpol.2022.105333

Tran, N., U.P. Rodriguez, C.Y. Chan, et al. 2023. "Future Scenarios of Fish Supply and Demand for Food and Nutrition Security in Bangladesh: An Analysis With the AsiaFish Model." *Aquaculture* 568: 739288. https://doi.org/10.1016/j.aquaculture.2023.739288

Tran, N., U.P. Rodriguez, C.Y. Chan, et al. 2017. "Indonesian Aquaculture Futures: An Analysis of Fish Supply and Demand in Indonesia to 2030 and Role of Aquaculture Using the Asiafish Model." *Marine Policy* 79: 25–32. https://doi.org/10.1016/j.marpol.2017.02.002

Tweddle, D., I. Cowx, R. Peel, and E. Weyl. 2015. "Challenges in Fisheries Management in the Zambezi, One of the Great Rivers of Africa." *Fisheries Management and Ecology* 22 (1): 99–111. https://doi.org/10.1111/fme.12107

United Nations. 2022. *World Population Prospects 2022: Data Sources*. UN DESA/POP/2022/DC/NO. 9. New York: UN-DESA. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2022_wpp-data_sources.pdf

Wang, P., N. Tran, D. Enahoro, et al. 2022. "Spatial and Temporal Patterns of Consumption of Animal-Source Foods in Tanzania." *Agribusiness* 38 (2): 328–348. https://doi.org/10.1002/agr.21729

World Bank. 2013. *Fish to 2030: Prospect for Fisheries and Aquaculture*. World Bank Report Number 83177-GLB. Washington, DC. http://documents1.worldbank.org/curated/en/458631468152376668/pdf/831770WP0P11260ES003000Fish0to02030.pdf

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF MAIZE VALUE CHAINS IN A CHANGING CLIMATE AND AGRIFOOD SYSTEM?

Kindie Tesfaye Fantaye (AGRA), Kai Sonder (CIMMYT), Diego Pequeno (CIMMYT), Faaiqa Hartley (IFPRI), and Sika Gbegbelegbe (IITA)

Key messages

- Population growth, changing diets, and a rapidly growing feed sector are contributing to a sharp increase in global maize demand, which is expected to double by 2050 relative to 2010.
- Average global maize yield is projected to decrease by 11 percent under a global warming scenario of 2°C (2060–2084) relative to the 1986–2005 period (in the absence of technological change, adaptation, or market adjustments).
- The feed demand for maize is expected to grow faster in the coming few decades, largely driven by rapid economic growth and diet shifts in highly populated regions in Asia, the Middle East, and Latin America.
- Meeting the growing demand for maize will require dramatic increases in production, marketing, use, and resilience of maize-based farming systems.
- While the supply of maize over the coming decades will be constrained by climate change and limited availability of land and water, technological and policy innovations will bring new opportunities.
- The combined challenges of increasing food demand, persistent poverty and malnutrition, natural resource depletion, and climate change will require the world to double the productivity and boost the sustainability and resilience of maize-based farming systems within planetary boundaries.

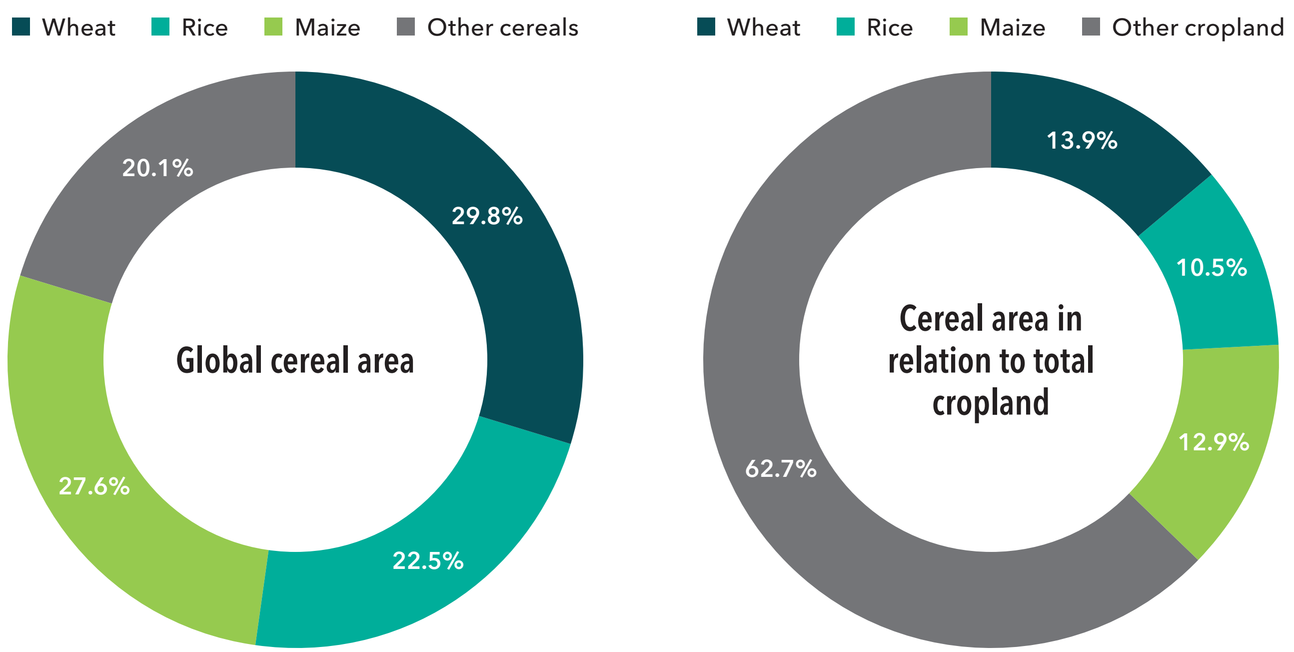
RECENT TRENDS AND CHALLENGES

Maize is the world's most multipurpose crop and continues to be the leading global cereal in terms of production (more than 1.2 billion metric tons a year), area coverage (more than 202 million hectares), and utilization (food, feed, and industrial input) (Erenstein et al. 2022; FAO 2024). Maize is produced across temperate and tropical zones on all continents, representing 27.6 percent of the global cereal area, and is grown on 12.9 percent of the total cropland available (Figure 1) (FAO 2024). Maize value chains are influenced by various global, regional, national, and subnational drivers, among which the following are the most significant.

Rising incomes, growing urban population, and dietary changes. Rising income levels and urbanization – especially in densely populated developing countries where dietary preferences are diversifying – are driving up demand for maize significantly in both the food and feed sectors (Grote et al. 2021). This surge in demand competes with alternative uses such as industrial and biofuel applications. Due to the strong demand for livestock feed – driven mainly by dietary shifts to animal products, and particularly noticeable in Asia – global demand for maize is expected to outpace that for other major cereals (Erenstein et al. 2022).

Declining land and water resources and a growing need for intensification. Area expansion has been one of the means to increase maize production, particularly in the developing world (Cairns et al. 2021). Thus, a decline in the availability of land and water resources due to land degradation and mismanagement and constraints to expansion to new areas will negatively affect maize value chains. Land availability for future maize expansion is limited in many parts of the world, although there is perceived land availability in Africa and East Asia. Even if new land is available, conversion to cropland will generate environmental costs in terms of increased land degradation, CO_2 emissions, and biodiversity loss (van Ittersum et al. 2016). Globally, most freshwater is withdrawn by agriculture, reaching up to 90 percent of the total freshwater use in fast-growing economies. Increasing global water scarcity is limiting the prospects of developing irrigation systems in many parts of the world's agricultural lands (Grote et al. 2021). Given increasing temperatures and low water management capacities, future maize production is most likely to be affected by water scarcity in Africa and South Asia. On the other hand, intensification

FIGURE 1 Shares of cereals globally and relative to total cereal area and total cropland, 2020–2022 average



Source: FAOSTAT.

of maize production is expected to free existing marginal land and reduce pressure on natural ecosystems from agricultural conversion (Stevenson et al. 2013). Sustainable intensification has been found to increase maize yields in rainfed and irrigated systems and will likely be the future means to bolster both the maize supply and the nutritional diversity of maize-based farming systems (Grote et al. 2021).

Climate variability and change. Climate change is expected to strongly affect the supply, price, and nutritional quality of maize due to increasing temperatures, frequent extreme weather events (for example, droughts and floods), changing agroecological conditions (for example, crop seasons), and shrinking suitable cultivated areas (Thornton et al. 2014; Grote et al. 2021; Gbegbelegbe et al. 2024). Moreover, climate change reduces maize production by increasing the incidence and severity of existing and emerging diseases and insect pests (Elad and Pertot 2014; Cairns and Prasanna 2018; Deutsch et al. 2018). The recent emergence of maize lethal necrosis disease (Sileshi and Gebeyehu 2021) and the fall armyworm (De Groote et al. 2020) in African maize systems and the havoc and damage these caused in the region are poignant examples of the potential consequences of climate change. In many areas of sub-Saharan Africa and the Indo-Gangetic Plains, climate variability accounts for over 50 percent of the total variation in maize yields (Ray et al. 2015). The negative impact of climate change and variability on maize yields in major exporting countries is expected to further destabilize global grain trade and international grain prices, affecting close to 1 billion people living in extreme poverty, who are the most vulnerable to food price spikes (Tigchelaar et al. 2018).

Technological and digital innovations. Improved seeds have the potential to transform maize value chains. Breeding techniques that employ modern technologies such as gene editing and marker assisted selection, as well as traditional breeding, are helping in the development of maize varieties that are resistant to heat, drought, disease, and pests (Cairns and Prasanna 2018; Prasanna et al. 2021), with significant benefits to both producers and consumers (Kostandini, La Rovere, and Abdoulaye 2013). Precision agriculture — which is gaining a foothold in much of the developed world, with potential expansion to the developing world — provides another prospective technological revolution for maize production (Grote et al. 2021). Digital innovations are facilitating precision maize farming in many regions, including in smallholder systems, by offering diverse digital solutions for smallholder farmers and the food industry sector (Tsan et al. 2019). Digital solutions are expected to bring effectiveness, efficiency, and resilience to future maize value chains.

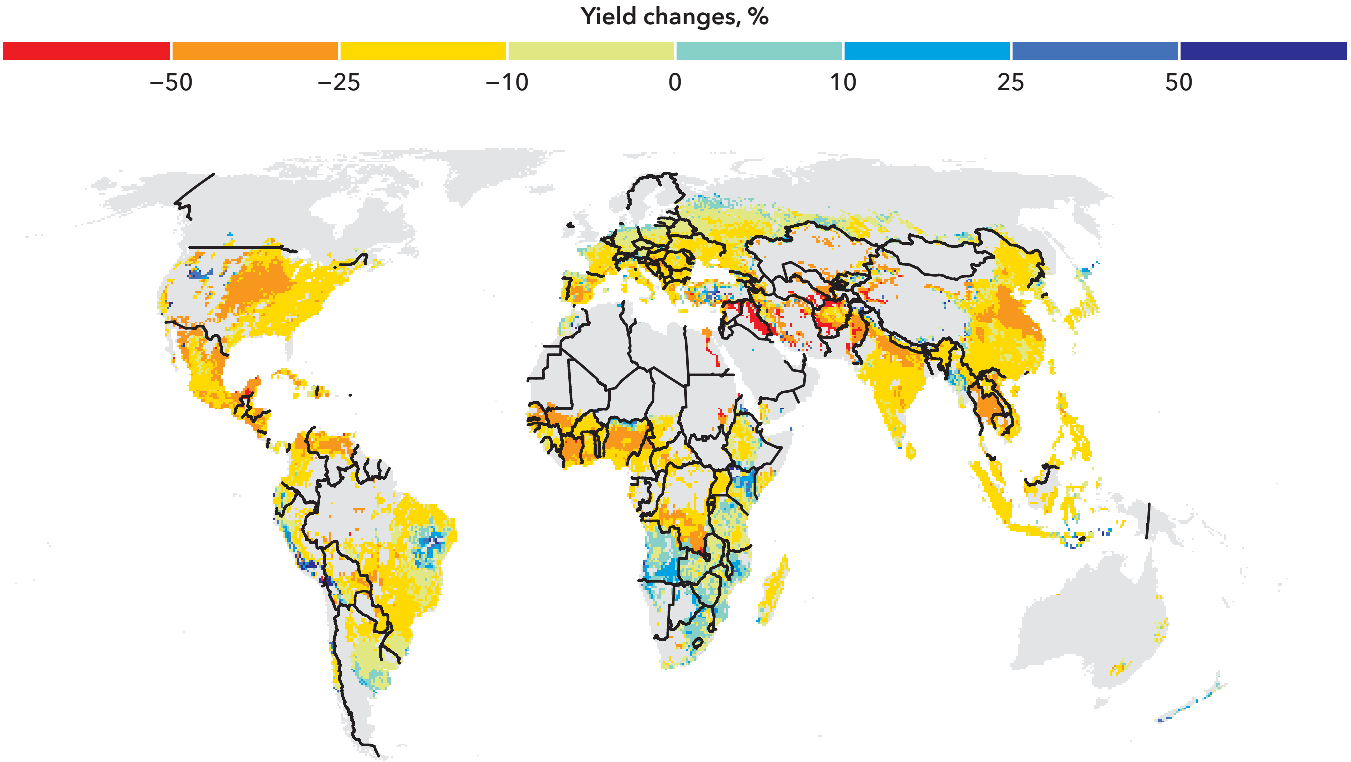
LATEST FORESIGHT RESEARCH

Only a few recent foresight studies address maize specifically, although there are many on cereals generally. This chapter considers the studies of Kruseman et al. (2020), who looked at maize in relation to rural transformation, and Ignaciuk and Mason-D'Croz (2014), who included maize results in their modeling of adaptations to climate change, together with three recent studies that presented climate change projections on maize and implications for food security (Tigchelaar et al. 2018; Jägermeyr et al. 2021; Li et al. 2022).

Employing an IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model with a moderate economic growth scenario across world economies under the drivers of population and income, Kruseman et al. (2020) project a near-doubling of global maize consumption between 2010 and 2050, and changes in maize utilization (food versus feed) in the coming years. Most of the maize in South Asia is projected to be allocated to livestock feed, increasing from 34 percent in 2010 to an estimated 72 percent in 2050. The shift away from human consumption to animal feed is also expected to expand in other regions, such as the former Soviet Union, Latin America, sub-Saharan Africa, the Middle East, and North Africa (Kruseman et al. 2020). The rise in demand and dietary changes are expected to increase global maize prices. Simulation studies using the IMPACT model indicate that even in the absence of climate change, the real price of maize may increase by 50 percent by 2050 compared to 2005 prices. The surge is attributed to increased demand for both food and feed, driven by the growth in population and income, shifts toward protein-rich diets, and increased demand for biofuels from the energy sector (Ignaciuk and Mason-D'Croz 2014).

Incorporating the effects of climate change, the growth in global maize production is anticipated to only increase to 36 percent between 2010 and 2050, a considerable difference from the 72 percent growth expected

FIGURE 2 Projected global maize yield changes toward the end of the century under RCP 8.5, in the absence of technological change, adaptation, or market adjustments



Source: Authors based on data from Jägermeyr et al. (2021).

without climate change, with the impact varying across geographies. Maize consumption is also projected to decrease globally under the climate change scenario, while maize use patterns would remain consistent until 2050 (Kruseman et al. 2020). Furthermore, the real price of maize is expected to surge by up to 30 percent in 2050, specifically under the most extreme climate change scenario (Ignaciuk and Mason-D'Croz 2014).

Recent improved climate and crop model projections indicate a reduction of mean global maize productivity ranging from 6–24 percent by 2099 (in the absence of technological change, adaptation, or market adjustments), with the impacts starting as early as 2030 (Jägermeyr et al. 2021). By the end of the century, some 10–74 percent of current global maize cultivation areas are projected to undergo yield reductions compared to the baseline period (1983–2013) (Jägermeyr et al. 2021) (Figure 2). The biggest losses in suitable maize production area are expected in Africa and Asia (Grote et al. 2021), contributing to the projected 11 percent global average maize yield reduction by 2060–2084 relative to 1986–2005 (Li et al. 2022). Results from a study of two scenarios of warming (2°C and 4°C) show that rising instability in global grain trade and international grain prices under the warmer scenario will affect more than 800 million people who are already the most vulnerable to food price spikes (Tigchelaar et al. 2018). Given that a handful of countries dominate global maize production and trade, the occurrence of simultaneous production shocks in these countries due to rising temperatures could have tremendous impacts on global markets. These impacts, particularly increased input costs and diminished maize supplies, would pose severe challenges for people in developing countries (Tigchelaar et al. 2018).

Meeting the increasing demand for maize, adapting to changing diets, and addressing the impacts of climate change require continuous innovations across the entire maize value chain. This includes implementing innovative policies, advancing genetic and crop management techniques, fostering regional market collaborations, and amplifying investments in research and development (Erenstein et al. 2022).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Although foresight studies on the future of cereals in general exist, only a few focus specifically on maize, mainly considering production and demand. Some research gaps related to maize value chains that merit further foresight research include: (1) the role of maize and maize-based farming systems in changing food systems that focus on nutrition, health, and inclusivity; (2) the technological, economic, and social dimensions of genetic, agronomic, and food fortification of maize on food and nutrition security, particularly in the developing world; (3) the impacts of the shifting maize demand from food to feed on the environment, nutrition, and sustainability; (4) the effects of climate change and extreme events on the quality of maize food and feed and the performance of maize supply chains; (5) cropland use shifts considering crop adaptation and profitability; and (6) the influence of green maize (maize used for food before it fully matures) on food, nutrition, and employment opportunities, particularly in sub-Saharan Africa.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Kindie Tesfaye Fantaye**, Head of Climate Adaptation and Resilience at AGRA, and formerly a Principal Scientist at the International Maize and Wheat Improvement Center (CIMMYT); **Kai Sonder**, Head of the Geographic Information System Unit in the Sustainable Agrifood Systems Program at CIMMYT; **Diego Pequeno**, a Scientist and Wheat Crop Modeler in the Sustainable Agrifood Systems Program at CIMMYT; **Faaiqa Hartley**, a Scientist in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); and **Sika Gbegbelegbe**, an Agricultural Economist at the International Institute of Tropical Agriculture (IITA).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Tesfaye Fantaye, K., K. Sonder, D. Pequeno, F. Hartley, and S. Gbegbelegbe. 2025. "What Do We Know About the Future of Maize Value Chains in a Changing Climate and Agrifood System?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 30. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Neil Palmer/CIAT

References

Cairns, J.E., J. Chamberlin, P. Rutsaert, et al. 2021. "Challenges for Sustainable Maize Production of Smallholder Farmers in Sub-Saharan Africa." *Journal of Cereal Sciences* 101 (September): 103274. https://doi.org/10.1016/j.jcs.2021.103274

Cairns, J.E., and B.M. Prasanna. 2018. "Developing and Deploying Climate-Resilient Maize Varieties in the Developing World." *Current Opinion in Plant Biology* 45B (October): 226–230. https://doi.org/10.1016/j.pbi.2018.05.004

Deutsch, C.A., J.J. Tewksbury, M. Tigchelaar, et al. 2018. "Increase in Crop Losses to Insect Pests in a Warming Climate." *Science* 361 (6405): 916–919. https://doi.org/10.1126/science.aat3466

Elad, Y., and I. Pertot. 2014. "Climate Change Impacts on Plant Pathogens and Plant Diseases." *Journal of Crop Improvement* 28 (1): 99–139. https://doi.org/10.1080/15427528.2014.865412

Erenstein, O., M. Jaleta, K. Sonder, K. Mottaleb, and B.M. Prasanna. 2022. "Global Maize Production, Consumption and Trade: Trends and R&D Implications." *Food Security* 14 (5): 1295–1319. https://doi.org/10.1007/s12571-022-01288-7

FAO (Food and Agriculture Organization of the United Nations). 2024. FAOSTAT Crops and Livestock Products. Accessed October 2024. https://www.fao.org/faostat/en/#data/QCL

De Groote, H., S.C. Kimenju, B. Munyua et al. 2020. "Spread and Impact of Fall Armyworm (*Spodoptera frugiperda* J.E. Smith) in Maize Production Areas of Kenya." *Agriculture, Ecosystems and Environment* 292 (April): 106804. https://doi.org/10.1016/j.agee.2019.106804

Gbegbelegbe, S., D. Chikoye, A. Alene, S. Kyei-Boahen, and G.Chigeza. 2024, "Strategic Foresight Analysis of Droughts in Southern Africa and Implications for Food Security." *Frontiers in Sustainable Food Systems* 7: 1159901. https://doi.org/10.3389/fsufs.2023.1159901

Grote, U., A. Fasse, T.T. Nguyen, and O. Erenstein. 2021. "Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia." *Frontiers in Sustainable Food Systems* 4: 1–17. https://doi.org/10.3389/fsufs.2020.617009

Ignaciuk, A., and D. Mason-D'Croz. 2014. "Modelling Adaptation to Climate Change in Agriculture." OECD Food, Agriculture and Fisheries Papers, no. 70. Paris: OECD. http://dx.doi.org/10.1787/5jxrclljnbxq-en

Jägermeyr, J., C. Müller, A.C. Ruane et al. 2021. "Climate Impacts on Global Agriculture Emerge Earlier in New Generation of Climate and Crop Models." *Nature Food* 2 (11): 873–885. https://doi.org/10.1038/s43016-021-00400-y

Kostandini, G., R. La Rovere, and T. Abdoulaye. 2013. "Potential Impacts of Increasing Average Yields and Reducing Maize Yield Variability in Africa." *Food Policy* 43: 213–226. https://doi.org/10.1016/j.foodpol.2013.09.007

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-Food Systems." *Global Food Security* 26 (May): 100441. https://doi.org/10.1016/j.gfs.2020.100441

Li, K., J. Pan, W. Xiong, W. Xie, and T. Ali. 2022. "The Impact of 1.5 °C and 2.0 °C Global Warming on Global Maize Production and Trade." *Scientific Reports* 12: 17268. https://doi.org/10.1038/s41598-022-22228-7

Prasanna, B.M., J.E. Cairns, P.H. Zaidi et al. 2021. "Beat the Stress: Breeding for Climate Resilience in Maize for the Tropical Rainfed Environments." *Theoretical and Applied Genetics* 134 (6): 729–1752. https://doi.org/10.1007/s00122-021-03773-7

Ray, D.K., J.S. Gerber, G.K. MacDonald, and P.C. West. 2015. "Climate Variation Explains a Third of Global Crop Yield Variability." *Nature Communications* 6: 5989. https://doi.org/10.1038/ncomms6989

Sileshi, G.W., and S. Gebeyehu. 2021. "Emerging Infectious Diseases Threatening Food Security and Economies in Africa." *Global Food Security* 28 (March): 100479. https://doi.org/10.1016/j.gfs.2020.100479

Stevenson, J.R., N. Villoria, D. Byerlee, T. Kelley, and M. Maredia. 2013. "Green Revolution Research Saved an Estimated 18 to 27 Million Hectares from Being Brought into Agricultural Production." *PNAS* 10 (21): 8363–8368. https://doi.org/10.1073/pnas.1208065110

Thornton, P.K., P.J. Ericksen, M. Herrero, and A.J. Challinor. 2014. "Climate Variability and Vulnerability to Climate Change: A Review." *Global Change Biology* 3313–3328. https://doi.org/10.1111/gcb.12581

Tigchelaar, M., D.S. Battisti, R.L. Naylor, and D.K. Ray. 2018. "Future Warming Increases Probability of Globally Synchronized Maize Production Shocks." *PNAS* 115 (26): 6644–6649. https://doi.org/10.1073/pnas.1718031115

Tsan, M., D.S. Totapally, D.M.C. Hailu, and B.K.C. Addom. 2019. *The Digitalization of African Agriculture Report 2018–2019*. Wageningen, Netherlands: Technical Centre for Agricultural and Rural Cooperation. https://hdl.handle.net/10568/101498

van Ittersum, M.K., L.G.J. van Bussel, J. Wolf, et al. 2016. "Can Sub-Saharan Africa Feed Itself?" *PNAS* 113 (52): 14964–14969. https://doi.org/10.1073/pnas.1610359113

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF PULSES IN GLOBAL AND REGIONAL AGRIFOOD SYSTEMS?

Sika Gbegbelegbe (IITA), Wupe Msukwa (IITA), Swamikannu Nedumaran (ICRISAT), and Arega Alene (IITA)

Key messages

- Low- and middle-income countries (LMICs) account for about 55 percent of global pulse production. Nearly one-half (48 percent) of global production occurs in 16 low- and lower-middle income countries in the drylands of South Asia and sub-Saharan Africa.
- The gap between pulse demand and supply is increasing in South Asia.
- Most recent foresight studies on pulses are focused on climate change impacts, adaptation, and mitigation.
- Future foresight studies on specific pulse crops should target regions where these pulses are important in human diets.
- Pulse trade should be promoted between countries that encompass the drylands of South Asia and sub-Saharan Africa.

RECENT TRENDS AND CHALLENGES

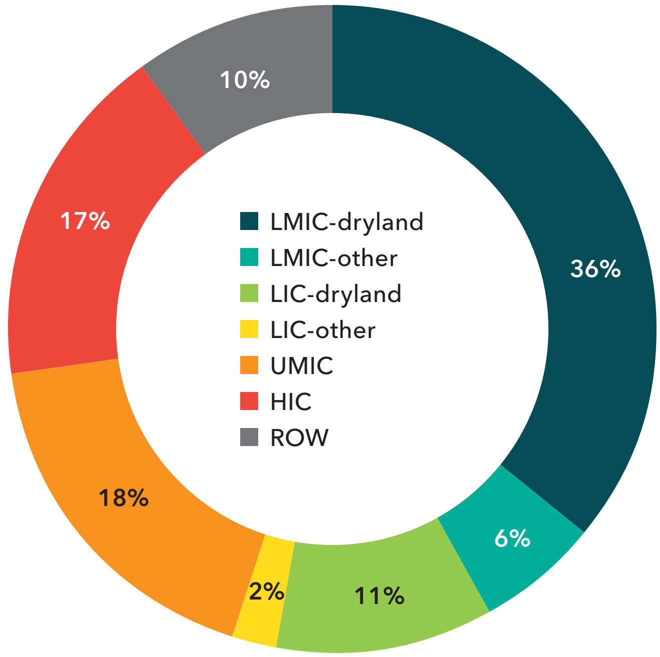
Global production of pulses averaged around 87.7 million metric tons annually between 2019 and 2021, with 39 countries accounting for 90 percent and India alone accounting for 27 percent of the total volume (Figure 1). Among the 39 major pulse producers, 8 high-income countries account for 17 percent of global production. Another 8 upper-middle-income countries account for 18 percent of global production. Low-income and lower-middle-income countries account for about 55 percent of global production. Most of these countries encompass the drylands in South Asia and sub-Saharan Africa. More specifically, 11 low-income countries account for 13 percent of global pulse production; 8 of them encompass drylands in sub-Saharan Africa and together account for 11 percent of global pulse production. Similarly, 12 lower-middle-income countries account for 43 percent of global pulse production, but 8 of them encompass the drylands in South Asia and sub-Saharan Africa. Together, these 8 countries account for 37 percent of global production (Figure 1).

Between 2000 and 2021, world pulse production increased by about 60 percent, while the world population increased by about 30 percent. For the countries encompassing the drylands of sub-Saharan Africa and South Asia, population has grown by about 50 percent since 2000 (Figure 2). By contrast, pulse production in these regions doubled over the same period, although this growth was subject to higher variability over the years, as pulses here are primarily grown in low-input, rainfed conditions. An interesting trend is that the growth in the value of pulse production was slightly higher than that of the volume of production over the last two decades in South Asia, reflecting a persistent supply-demand gap for pulses there (Figure 2). This supply-demand gap reflects increasing scarcity, which pushes local prices up. Net pulse imports for South Asia stood at around 400,000 tons in 2000; by 2021, net imports had risen to about 4 million tons, equivalent to about 14 percent of pulse production for the region.

In West Africa – which accounts for about 20 percent of pulse production in the countries encompassing the drylands in sub-Saharan Africa and South Asia – population increased by about 75 percent between 2000 and 2021. In contrast, pulse production nearly tripled over the same period. Changes in the value of pulse production closely followed those of the volume of pulse production between 2000 and 2021, reflecting the region's self-sufficiency in pulses. By 2021, the region's net imports amounted to about 53,000 tons, equivalent to less than 0.6 percent of its pulse production.

In East Africa – which also accounts for about 20 percent of pulse production in the countries encompassing the drylands in sub-Saharan Africa and South Asia – population increased by about 80 percent between 2000 and 2021, while the production of pulses more than doubled. Between 2000 and 2009, growth in pulse production was lower than that of the population for most years; from 2010 to 2021, growth in production was generally higher than that of the population (Figure 2). Growth in the value of pulse production in the region has been slightly smaller

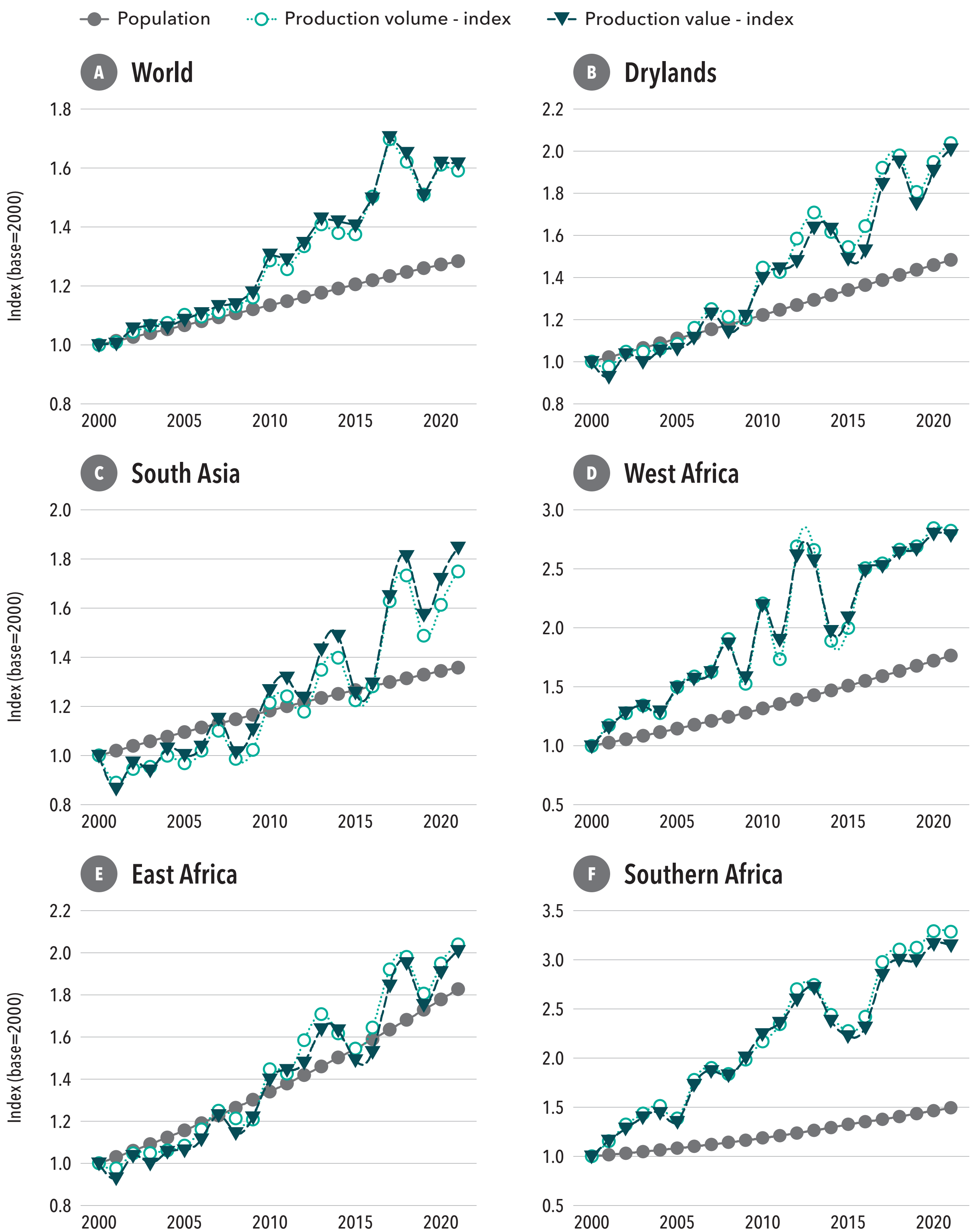
FIGURE 1 Distribution of world pulse production, 2019–2021 (average)



Source: Data from FAOSTAT.

Note: LMIC-dryland: lower-middle-income countries encompassing the drylands of sub-Saharan Africa (SSA) and South Asia (SA); these countries are among the world countries accounting for 90 percent of pulse production. LMIC-other: other lower-middle-income countries among the world countries accounting for 90 percent of pulse production. LIC-dryland: low-income countries that encompass drylands in SSA and SA; these countries are among the world countries accounting for 90 percent of pulse production. LIC-other: other low-income countries among the world countries accounting for 90 percent of pulse production. UMIC: upper-middle-income countries among the world countries accounting for 90 percent of pulse production. HIC: High-income countries among the world countries accounting for 90 percent of pulse production. ROW: Rest of the World.

FIGURE 2 Growth trends in global and regional human population, pulse production volume, and pulse production value



Source: Authors' estimations using data on population from World Bank and other data from FAOSTAT.

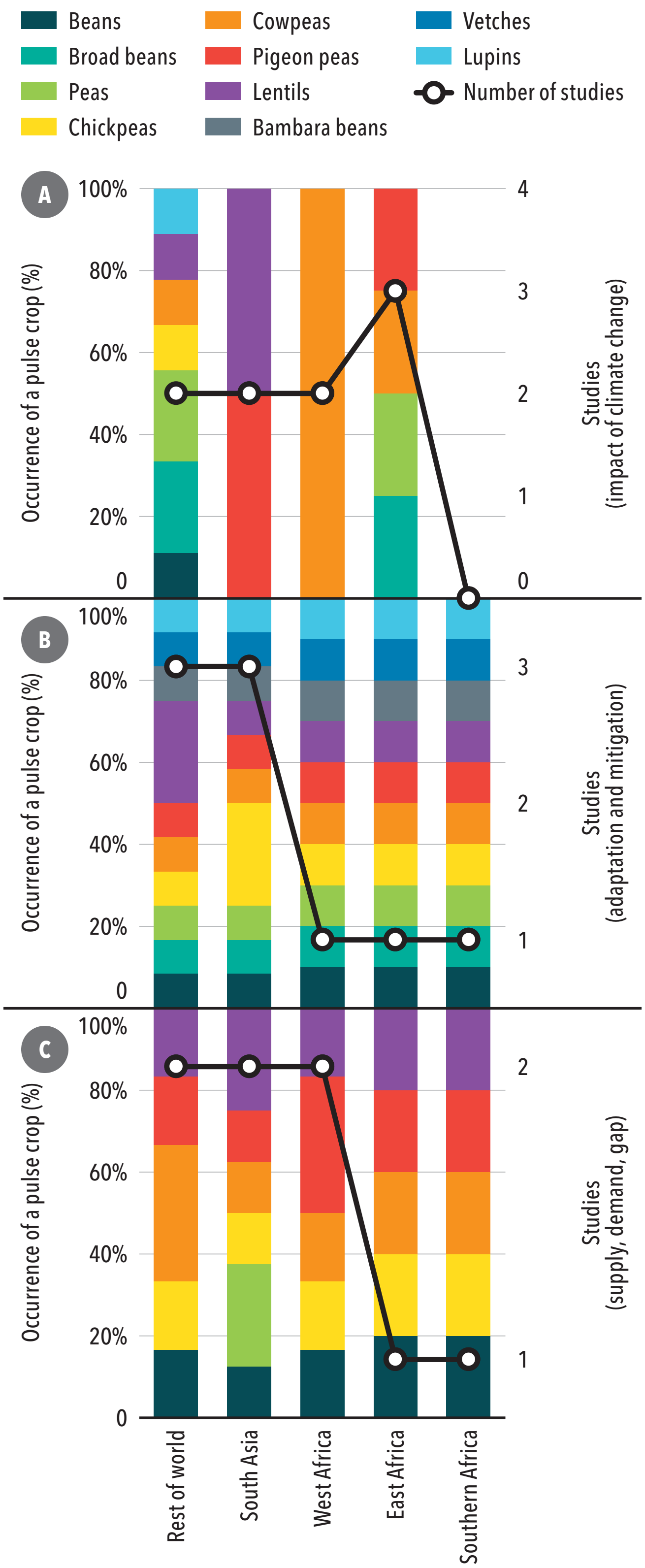
than the growth in volume for most years since 2000. This gap reflects a net surplus in the region, where pulse production tends to exceed consumption levels. Indeed, East Africa has been a rising net exporter of pulses since 2010. By 2021, its net exports amounted to 5 percent of its total production. A similar pattern is found in Southern Africa, also a net pulse exporter since 2011. As of 2021, its net exports amounted to 24 percent of pulse production. The volume and value of pulse production in that region more than tripled between 2000 and 2021, although the growth in value was slower than growth in volume from 2016 onward. In that region, population growth has been slower than that of production volume since 2000 (Figure 2).

LATEST FORESIGHT RESEARCH

The latest foresight research on pulses includes 26 publications covering various regions of the world (Figure 3). The pulses considered include dry beans, dry broad beans (fava beans), dry peas, chickpeas, cowpeas, pigeon peas, lentils, Bambara beans, vetches, and lupins (GPC n.d.). All relevant studies can be classified into three themes: the impact of climate change on pulse production; climate change adaptation and/or mitigation strategies related to pulses; and future projections on the supply, demand, or supply-demand gaps for pulses.

Two studies targeted high-income countries (Europe, France). The other studies mainly targeted the countries that encompass the drylands of sub-Saharan Africa and South Asia. More specifically, three studies targeted East Africa, and two studies targeted West Africa and South Asia. Among the studies targeting high-income countries, one aimed to quantify the impact of climate change on crop suitability in Europe for common beans, broad (fava) beans, chickpeas, lentils, lupins, peas, and cowpeas (Manners, Varela-Ortega, and van Etten 2021). The study projected that northern Europe becomes more favorable for pulse production, unlike southern Europe. The other study targeted yields of peas and broad beans in France; it projected increasing yields for both crops under most climate change models (Falconnier et al. 2020). The studies for South Asia targeted lentils and pigeon peas. The study on lentils targeted a specific site/soil in West Bengal, India (South Asia); it projected yield reductions of 12 percent to 31 percent by mid-century

FIGURE 3 Number of pulse crop studies and types of pulse targeted, by world region



Source: Authors, using data extracted from literature.

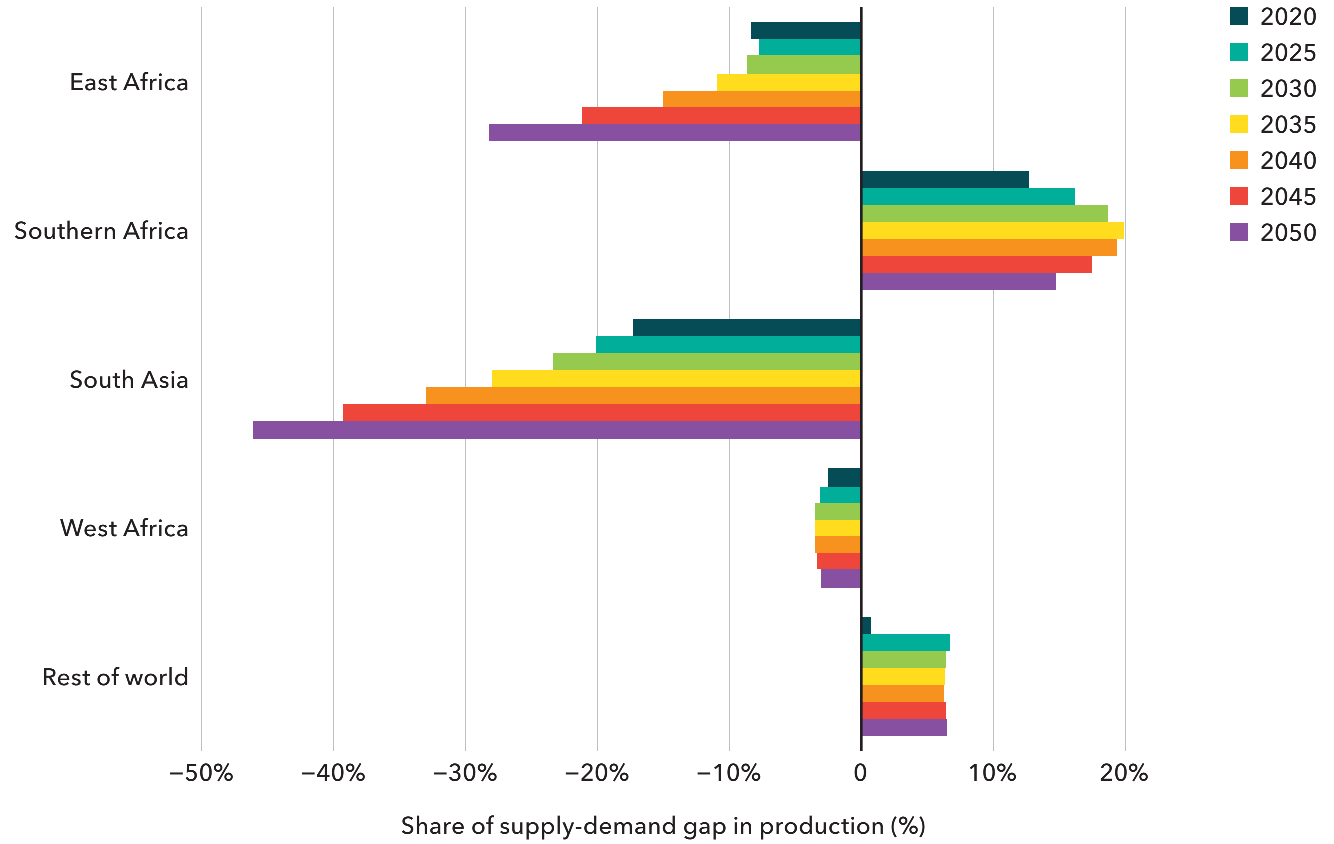
(2050s) (Chandran et al. 2022). The other site-specific study in northern India also projected decreasing yields for pigeon peas (Yadav et al. 2021). Both studies for West Africa were on cowpeas only, and both projected increases in yield and biomass under long-term climate change (Adusei et al. 2022; Alvar-Beltrán et al. 2023). Studies in East Africa targeted four pulses: dry broad beans, dry peas, cowpeas, and pigeon peas. A geospatial study in Ethiopia found that the total amount of land suitable for cowpea production is projected to decrease slightly under climate change by the 2050s (−4.9 to −6.9 percent) and 2070s (−1.9 to +3 percent) compared to the current acreage (Kagnew, Assefa, and Degu 2021). A site-specific study in Kenya projected decreasing yields for pigeon peas under long-term climate change (Kwene et al. 2021). For dry broad beans, a site-specific modeling study in Welmera district in the Oromia Regional State of Ethiopia (East Africa) found mixed results on the performance of early- and late-maturity varieties under long-term climate change (Bogale et al. 2021). For mung bean (dry pea), a geospatial study in Ethiopia (East Africa) projected an increase (0.21 percent to 3.00 percent) in the land suitable for mung bean production under long-term climate change (Kagnew, Assefa, and Degu 2021).

In terms of climate change adaptation and mitigation, one study targeted all pulse crops across all regions of the world. It showed that legumes in general could play a substantial role in climate change mitigation if they become the major source of dietary protein for humans (Semba et al. 2021). Another study had a similar finding for lentils in Canada (Chaudhary and Tremorin 2020). For Europe and Turkey, a study used predictive learning to identify rust-resistant populations of lentils, which are also likely to remain rust-resistant under long-term climate change (Civantos-Gómenz et al. 2022). Two other studies targeted chickpeas in Iran (South Asia). The first showed that dormant deeding management combined with mid-maturity varieties of chickpeas was a potential strategy to increase grain yield and water use efficiency for chickpeas in northwest Iran (Amiri, Deihimfard, and Eyni-Nargeseh 2020). The other study projected increasing chickpea yields under climate change in Iran, and showed that the right combination of cultivars and management under long-term climate change (genotype x environment x management) could enhance yields (Amiri et al. 2021).

Future projections of supply, demand, and supply-demand gaps targeted many pulses and all world regions. One study used results from IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model to estimate future supply-demand gaps for targeted legumes in all world regions (Nigam et al. 2021). For each pulse, the study identified key countries and regions that would be most affected by a supply-demand gap by mid-century if mitigation policies maintain temperature and precipitation in 2050 at levels equivalent to the early 2000s. The authors recommended that future research on improved varieties should target countries and regions with the largest gaps. Another study projected an increasing supply-demand gap to 2025 for all pulses in the Assam region of India, except for two: black gram and peas (Barman et al. 2020). The authors proposed various options for reducing the supply-demand gap: bringing more pulse area under irrigation; increasing adoption of recommended farm technologies; and replacing lentils with black gram for dal (food) processing. A study on pigeon peas in Oyo state in Nigeria projected slight increases in the size of pigeon pea farms and called for additional institutional support to promote pigeon pea production in the region (Fatokimi and Tanimonure 2021).

Updated results from the IMPACT model project that the supply–demand gap for pulses in South Asia will increase over the years, assuming a reference scenario involving climate change and middle-of-the-road changes in socioeconomic trends (Figure 4) (IFPRI 2024). The pulse supply-demand gap would reach 17 percent of total pulse production in South Asia by 2025; it would then continue to increase to reach about 46 percent of production by 2050. Similarly, the pulse supply-demand gap in West Africa is projected to remain small up to 2050; this opens possibilities for boosting production in that region to meet demand in other parts of the world. Southern Africa is projected to remain a net exporter of pulses up to 2050; however, East Africa is projected to become a net importer of pulses, with a widening supply-demand gap over the years. The supply-demand gap in the rest of the world is projected to remain small and constant up to 2050. These projections do not consider the abiotic and biotic stresses brought on by climate change. Nevertheless, they highlight the importance of trade in filling the gap between food supply and demand and enhancing food security in the drylands where these crops are important. Increasing food production requires adoption of improved varieties that can increase land productivity coupled with improved crop management that reduces yield gaps.

FIGURE 4 **Projected share of the pulse supply-demand gap in production, by world region**



Source: Authors using data from IFPRI (2024).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

The most obvious research gap is related to targeting pulse crop research toward regions where they are important in human diets. For example, most pulses in the countries encompassing the drylands of sub-Saharan Africa and South Asia are produced for local consumption; they are not exported (Figure 2). Hence, foresight studies on pulses, which are important in local diets within these dryland areas, are required to support policies to enhance food and nutrition security in these regions. Between 2020 and 2022, foresight studies in East Africa focused on broad beans and mung beans, yet the most produced pulses in the region are dry beans, representing about 50 percent of pulse production, followed by broad beans (about 14 percent). Similarly, in West Africa, cowpeas account for about 80 percent of pulse production, followed by dry beans (12 percent), yet no foresight study in this region has targeted dry beans. Similar mismatches exist for the other regions, including South Asia.

Another gap relates to some regions being neglected in foresight research. Thus, South Asia and East Africa used to be among the least studied dryland regions for foresight on legume (Gbegbelegbe et al. 2021). However, since 2020 South Asia has become the focus region for this research, with five studies undertaken. It is closely followed by East and West Africa, with four studies each. Conversely, Southern Africa remains the least studied region, with only one study conducted between 2020 and 2022.

Future studies should also tackle the issues of trade and demand shifts in the dryland regions. If recent trends are to continue under climate change, some regions and countries within the drylands will experience substantial supply-demand gaps in the near future (Figure 2) and by mid-century (Nigam et al. 2021). Future studies should identify tailored policies to enhance trade between dryland regions and encourage shifts in consumer demand. More specifically, some pulses that are more suitable for production should replace less suitable ones in human diets.

Future studies should also quantify the impact of climate-induced biotic stresses and weather extremes on pulse production to identify options for mitigating the negative impacts of such events. To date, no foresight-related study has analyzed the impact on pulses and adaptation options for the pests, diseases, and weeds related to climate change. Similarly, no study has assessed the impact of weather extremes on pulses.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Sika Gbegbelegbe**, an Agricultural Economist at the International Institute of Tropical Agriculture (IITA); **Wupe Msukwa**, a Research Associate at IITA; **Swamikannu Nedumaran**, a Principal Agricultural Economist in the Global Research Program on Enabling Systems Transformation at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); and **Arega Alene**, an Agricultural Economist (Principal Scientist) and Program Leader for Foresight, Impact Assessment, and Scaling at IITA.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Gbegbelegbe, S., W. Msukwa, S. Nedumaran, and A. Alene. 2025. "What Do We Know About the Future of Pulses in Global and Regional Agrifood Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 31. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Jordi Ruiz Cirera/Panos Pictures

References

Adusei, G., M.K. Aidoo, A.K. Srivastava, J.Y. Asibuo, and T. Gaiser. 2022. "The Impact of Climate Change on the Productivity of Cowpea (*Vigna unguiculata*) under Three Different Socio-Economic Pathways." *Italian Journal of Agronomy* 17 (4): 2118. https://doi.org/10.4081/ija.2022.2118

Alvar-Beltrán, J., C. Dibari, R. Ferrise, N. Bartoloni, and A. Dalla Marta. 2023. "Modelling Climate Change Impacts on Crop Production in Food Insecure Regions: The Case of Niger." *European Journal of Agronomy* 142: 126667. https://doi.org/10.1016/j.eja.2022.126667

Amiri, S., R. Deihimfard, and H. Eyni-Nargeseh. 2020. "Toward Dormant Seeding of Rainfed Chickpea as an Adaptation Strategy to Sustain Productivity in Response to Changing Climate." *Field Crops Research* 247: 107674. https://doi.org/10.1016/j.fcr.2019.107674

Amiri, S., H. Eyni-Nargeseh, S. Rahimi-Moghaddam, and K. Azizi. 2021. "Water Use Efficiency of Chickpea Agro-Ecosystems Will Be Boosted by Positive Effects of CO_2 and Using Suitable Genotype × Environment × Management under Climate Change Conditions." *Agricultural Water Management* 252: 106928. https://doi.org/10.1016/j.agwat.2021.106928

Barman, N., J.P. Hazarika, U. Talukdar, and N. Deka. 2020. "Supply-Demand Projection and Gap Analysis for Major Pulses in Assam." *Economic Affairs* 65 (4): 619–625. https://doi.org/10.46852/0424-2513.4.2020.18

Bogale, G.A., G. Hadgu, G. Asefa Bogale, M. Mengesha Maja, and H. Gebreyohannes. 2021. "Modelling the Impacts of Climate Change on Faba Bean (*Vicia faba* L.) Production in Welmera Area, Central Ethiopia." *Heliyon* 7 (10): e08176. https://doi.org/10.1016/j.heliyon.2021.e08176

Chandran, M.A.S., S. Banerjee, A. Mukherjee, M.K. Nanda, and V.V. Kumari. 2022. "Evaluating the Long-Term Impact of Projected Climate on Rice-Lentil-Groundnut Cropping System in Lower Gangetic Plain of India Using Crop Simulation Modelling." *International Journal of Biometeorology* 66 (1): 55–69. https://doi.org/10.1007/s00484-021-02189-8

Chaudhary, A., and D. Tremorin. 2020. "Nutritional and Environmental Sustainability of Lentil Reformulated Beef Burger." *Sustainability* 12 (17): 6712. https://doi.org/10.3390/su12176712

Civantos-Gómez, I., M.L. Rubio Teso, J. Galeano, D. Rubiales, J.M. Iriondo, and J. García-Algarra. 2022. "Climate Change Conditions the Selection of Rust-Resistant Candidate Wild Lentil Populations for In Situ Conservation." *Frontiers of Plant Science* 13: 1010799. https://doi.org/10.3389/fpls.2022.1010799

Falconnier, G., A. Vermue, E. Journet, M. Christina, L. Bedoussac, and E. Justes. 2020. "Contrasted Response to Climate Change of Winter and Spring Grain Legumes in Southwestern France." *Field Crops Research* 259: 107967. https://doi.org/10.1016/j.fcr.2020.107967

FAOSTAT. n.d. Statistical databases on global crop production, value and trade. Accessed 2023. https://www.fao.org/statistics/

Fatokimi, E.O., and V.A. Tanimonure. 2021. "Analysis of the Current Situation and Future Outlooks for Pigeon Pea (*Cajanus Cajan*) Production in Oyo State, Nigeria: A Markov Chain Model Approach." *Journal of Agriculture and Food Research* 6: 100218. https://doi.org/10.1016/j.jafr.2021.100218

Gbegbelegbe, S.D., S. Nedumaran, A. Frija, and A. Alene. 2021. "The Future of Climate-Smart Dryland Cereals and Legumes in South Asia and Sub-Saharan Africa." https://doi.org/10.31219/osf.io/m8ywq

GPC (Global Pulse Confederation). n.d. "What Are Pulses?" Accessed 2023. https://pulses.org/what-are-pulses

IFPRI (International Food Policy Research Institute). 2024. IMPACT Projections of Food Production, Area and Demand to 2050 with climate change. IMPACT model, version 3.4. Washington, DC.

Kagnew, B., A. Assefa, and A. Degu. 2021. "Modeling the Impact of Climate Change on Sustainable Production of Two Legumes Important Economically and for Food Security: Mungbeans and Cowpeas in Ethiopia." *Sustainability* 15 (1): 600. https://www.mdpi.com/2071-1050/15/1/600

Kwena, K.M., G.N. Karuku, F.O. Ayuke, and A.O. Esilaba. 2021. "Impact of Climate Change on Maize and Pigeonpea Yields in Semi-Arid Kenya." In *Environmental Issues and Sustainable Development*, eds. S. Sarvajayakesavalu and P. Charoensudjai. First Edition. London: IntechOpen. https://doi.org/10.5772/intechopen.93321

Manners, R., C. Varela-Ortega, and J. van Etten. 2021. "Protein-Rich Legume and Pseudo-Cereal Crop Suitability under Present and Future European Climates." *European Journal of Agronomy* 113: 125974. https://doi.org/10.1016/j.eja.2019.125974

Nigam, S.N., S. Chaudhari, K.C. Deevi, K.B. Saxena, and P. Janila. 2021."Trends in Legume Production and Future Outlook." In *Genetic Enhancement in Major Food Legumes: Advances in Major Food Legumes*, eds. K.B. Saxena, R.K. Sacena, and R.K. Varshney, 7–48. Springer International Publishing.

Semba, R.D., R. Ramsing, N. Rahman, K. Kraemer, and M.W. Bloem. 2021. "Legumes as a Sustainable Source of Protein in Human Diets." *Global Food Security* 28: 100520. https://doi.org/10.1016/j.gfs.2021.100520

World Bank. n.d. "Population." World Development Indicators. Accessed 2023. https://databank.worldbank.org/

Yadav, M.K., C. Patel, R.S. Singh et al. 2021. "Assessment of Climate Change Impact on Different Pigeonpea Maturity Groups in North Indian Condition." *Journal of Agrometeorology* 23 (1): 82–92. https://doi.org/10.54386/jam.v23i1.92

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF RICE IN RELATION TO FOOD SYSTEMS?

Harold Glenn Valera (BSP), Valerien Olivier Pede (IRRI), and Ronald Jeremy Antonio (BSP)

Key messages

- Global rice production remained more stable than maize and wheat production in recent years, while rice consumption continues to increase, albeit at a slower pace.
- Rice production and consumption are projected to increase worldwide, with Asia to continue as the world's leading source of rice through 2050.
- Southeast Asia's rice surplus will increase by 2040 by closing the exploitable yield gap by one-half.
- The global rice sector will experience an increasing economic surplus with faster productivity growth and will contribute to a decline in the number of undernourished children and people at risk of hunger.
- Demographic changes and rice trade policy reforms will be key drivers of rice demand and prices in different countries.

RECENT TRENDS AND CHALLENGES

Rice production increased significantly in the past five decades with the efforts of research centers and national governments (Mishra et al. 2022). Globally, rice production was more stable than maize and wheat production in the past two decades. An upward trend in rice consumption occurred during the same period, though growth slowed in recent years. Globally, about 90 percent of current rice production and 85 percent of both consumption and exports are from Asia, while Africa accounts for about 4 percent of production and 8 percent of consumption (USDA 2022). The world rice market remains thin, accounting for just 8–11 percent of global production. Rice prices are also more stable now than in the 1990s and 2000s.

The global rice sector faces a challenge in meeting future demand due to a growing population, which is expected to increase from 8.9 billion to 10.6 billion by 2050 (United Nations 2019). Such a growing population relies on rice for calories and nutrients, and meeting future rice demand requires an acceleration in productivity (Mishra et al. 2022). But prospects for future growth in production are uncertain as rice is susceptible to natural disasters. Furthermore, climate change is expected to have a serious impact on the rice sector by changing the patterns of droughts and floods and spreading more pests and diseases (Kruseman et al. 2020). Food security has also become more fragile since the COVID-19 pandemic, with some major rice-exporting countries occasionally restricting exports for food security reasons.

LATEST FORESIGHT RESEARCH

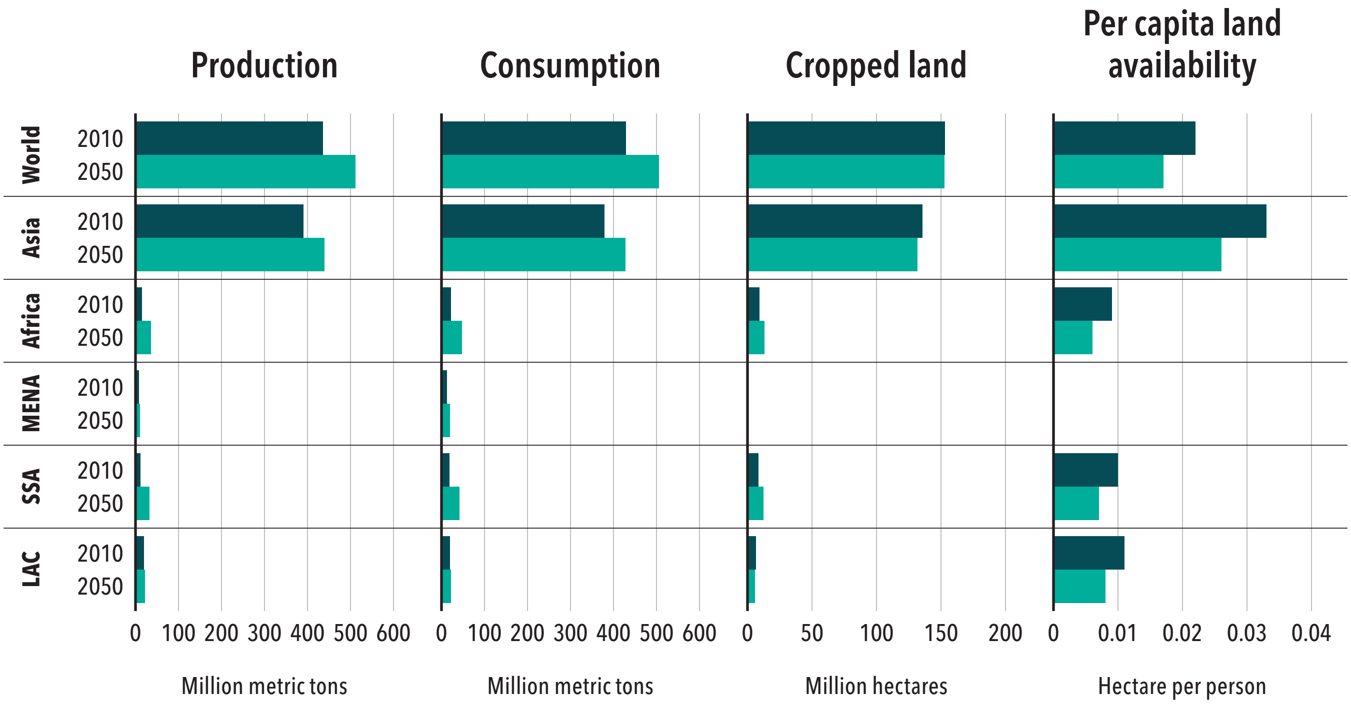
This brief reviews seven studies that provide forward-looking perspectives to support improving food security, reducing poverty, and initiating policy reform. Using the IMPACT-GLOBE model, Wiebe et al. (2021) analyzed the global and regional impacts of a 25 percent increase in yield growth in rice and 19 other food crops from 2015 to 2030 and examined the changes in the value of production and economywide income. Perspectives on rice and other major cereals systems based on the IMPACT model were also provided by Kruseman et al. (2020). The authors examined the impacts of six productivity enhancement scenarios on rice production, consumption, cropped land, and per capita land availability globally and across regions. Using the International Rice Research Institute (IRRI) Global Rice Model (IGRM), Pede et al. (2024) provided projections of supply and demand of rice economies over the next three decades, while Mishra et al. (2024) estimated the impact of the Russia-Ukraine war on fertilizer prices and the impacts of rising fertilizer prices on rice prices and trade.

Yuan et al. (2022) focused on the impact of rice production potential on rice surplus by 2040 in six Southeast Asian countries. The authors estimated the yield potential for irrigated and rainfed lowland rice and per capita rice demand based on the relative change in their average values between 2019–2020 and 2040. They compared the current yield base scenario with continuation of the current yield trend and full and half closures of the exploitable yield gap. At a country level, Mottaleb et al. (2021) estimated the total consumption of rice and wheat and other food commodities in Uganda in 2030 using the Living Standards Measurement Study datasets. Their analysis simulated three scenarios based on high, medium, and low fertility rates of population growth. From the perspective of rice trade policy reform, Balié and Valera (2020) used the IGRM in analyzing rice tariffication scenarios in the Philippines combined with higher yield and support price scenarios to quantify the potential impacts on prices, production, consumption, and imports by 2025.

Figure 1 displays projections of global rice production, consumption, cropped land, and per capita availability of cropped land (Kruseman et al. 2020). Under the reference scenario with climate, global rice production and consumption are projected to increase by 18 percent from 2010 to 2050 (Kruseman et al. 2020). The projected increase in global rice production and consumption is mainly attributed to population growth (Kruseman et al. 2020). Asia is expected to be the world's leading source of rice as production and consumption are expected to reach 439 million and 427 million metric tons in 2050, respectively. In the case of Africa, Kruseman et al. (2020) showed that the region's rice consumption would double by 2050 because of changing diets driven by higher income.

According to the faster agricultural productivity growth scenario in Wiebe et al. (2021), global gross production value (GPV) of rice would increase by 75 percent, from US$95.9 billion in 2015 to US$129.2 billion in 2030. Because of the increase in GPV, economic surplus is

FIGURE 1 Projected production, consumption, cropped land, and per capita availability of cropped land



Source: Based on Kruseman et al. (2020).

Note: MENA = Middle East and North Africa, SSA = Sub-Saharan Africa, LAC = Latin America and the Caribbean.

estimated to reach as much as US$59.3 billion in 2030, while the global poverty rate would decline from 20.7 percent in 2015 to 18.8 percent in 2030. In terms of nutrition outcomes, Wiebe et al. (2021) estimated that faster productivity growth would lead to a reduction in global numbers of undernourished children by 361,000 (0.3 percent) and in the population at risk of hunger by 10.6 million (2.1 percent).

Using the IGRM, Pede et al. (2024) found that due to increasing population, an additional 75 million tons of rice will be needed in 2050 to meet global demand. The study noted potential in Africa, where both cultivated rice area (18.3 percent) and yields (55.3 percent) are expected to increase from 2022 to 2050. Asia is also projected to remain the major rice-producing region, albeit with lower increases in rice area (0.2 percent) and yields (8.0 percent). Using the same model, Mishra et al. (2024) estimated the impacts of increasing fertilizer prices due to the Russia-Ukraine war. Their findings show that yields would reduce by 0.5 percent to 1.3 percent, which would lead to a 7 percent to 23 percent increase in rice prices between 2022 and 2025. The increase in world fertilizer prices may have reduced harvests in the short term, but since their peak in April 2022, urea prices have plunged sharply.

Yuan et al. (2022) showed that, if the current yield stagnation in Southeast Asia continues until 2040, the self-sufficiency ratio (SSR) at a regional level would decline from 1.10 to 1.03, and the region's rice surplus would be nearly eliminated. Assuming a full closure of the exploitable yield gap by 2040, these authors estimated a regional SSR of 1.55 and a total rice surplus of 100 million tons. The Southeast Asia regional SSR would increase to 1.29, with the rice surplus estimated to reach as much as 54 million tons when half closure of the exploitable yield gap is assumed.

In their country-level foresight analysis, Mottaleb et al. (2021) projected that the combined total demand for rice and wheat in Uganda would significantly increase by 2030 in line with its projected increase in income and population. Taking into account adjustments in per capita consumption, the authors projected that the combined consumption of rice and wheat in 2030 would range between 3.9 million and 4.0 million tons for low and high fertility rates of population growth, respectively.

Assuming constant per capita consumption, they estimated that consumption of rice and wheat in 2030 would be in the vicinity of 1.3 million tons (low fertility) and 1.39 million tons (high fertility).

In the Philippines, the government started implementing its rice tariffication policy in March 2019. Under the tariffication and higher rice yield scenario, imports are estimated to reach 3 million tons by 2025 (Balié and Valera 2020), while farm and retail prices are expected to decline by 30.1 percent and 17.4 percent, respectively. The same scenario estimated that per capita and total rice consumption would reach 132 kilograms and 16 million tons, respectively.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

The above analyses of the future of rice consumption and production assume the prevailing paradigm of feeding the world with abundant and cheap agricultural produce from sustained intensification. But the paradigm of agricultural research in the recent decade has been shifting to incorporate food systems, considering economic, social, and environmental sustainability with food and nutrition security under a climate change imperative. This has shifted the focus of funding for technological development and other innovations in the food system to healthy, affordable, and sustainably produced food. However, populations in developing and emerging economies continue to lack diet diversity, leading to micronutrient deficiencies (for example, iron and zinc). Thus, foresight research should give considerable attention to the analysis of the future of nutritional rice varieties: low-glycemic index rice, high-zinc rice, high-iron rice, and rice with high protein content. Existing studies on the impact of the increase in demand from population expansion and income growth are outdated and also need a fresh look.

Another major gap in foresight research is the estimation of impacts of existing rice trade policies currently in place in major rice markets, as well as trade agreements already set to take effect in the medium term for some countries. Studies also need to factor in the potential effects of disruptions caused by possible future pandemics, as well as more frequent natural disasters due to climate change.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Harold Glenn Valera**, a Principal Researcher in the BSP Research Academy at the Bangko Sentral ng Pilipinas (BSP) in Manila, the Philippines, and formerly a Scientist at the International Rice Research Institute (IRRI); **Valerien Olivier Pede**, a Senior Agricultural Economist at IRRI; and **Ronald Jeremy Antonio**, a Bank Economist IV in the BSP Department of Economic Research at BSP in Manila, the Philippines, and formerly an Assistant Scientist at IRRI.

Jhoana Alcalde, Ellanie Cabrera, and Orelie Delas Alas also contributed to this work.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Valera, H.G., V.O. Pede, and R.J. Antonio. 2025. “What Do We Know About the Future of Rice in Relation to Food Systems?” In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 32. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Gwendolyn Stansbury/IFPRI

References

Balié, J., and H.G. Valera. 2020. "Domestic and International Impacts of the Rice Trade Policy Reform in the Philippines." *Food Policy* 92: 101876. https://doi.org/10.1016/j.foodpol.2020.101876

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Mishra, A.K., V.O. Pede, A. Arouna, et al. 2022. "Helping Feed the World with Rice Innovations: CGIAR Research Adoption and Socioeconomic Impact on Farmers." *Global Food Security* 33: 100628. https://doi.org/10.1016/j.gfs.2022.100628

Mishra, A.K., H.G. Valera, T. Yamano, and V. Pede. 2024. "The Russian Invasion of Ukraine, Fertilizer Prices, and Food Security: Evidence from Rice-Producing Economies in Asia." ADB Economics Working Paper No. 724. Asian Development Bank, Manila. http://dx.doi.org/10.22617/WPS240233-2

Mottaleb, K.A., F.A. Fatah, G. Kruseman, and O. Erenstein. 2021. "Projecting Food Demand in 2030: Can Uganda Attain the Zero Hunger Goal?" *Sustainable Production and Consumption* 28: 1140–1163. https://doi.org/10.1016/j.spc.2021.07.027

Pede, V.O., H.G. Valera, A.K. Mishra, and J. Balié. 2024. "Future of Rice in Asia: Perspectives and Opportunities, 2050." *Food Security Issues in Asia*, ed. Paul Teng, 108–138. Singapore: World Scientific Publishing Co. https://doi.org/10.1142/13469

United Nations. 2019. *World Population Prospects 2019*. New York.

USDA (U.S. Department of Agriculture). 2022. "Production, Supply, and Distribution." https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery

Wiebe, K., T.B. Sulser, S. Dunston, M.W. Rosegrant, K. Fuglie, D. Willenbockel, and G.C. Nelson. 2021. "Modeling Impacts of Faster Productivity Growth to Inform the CGIAR Initiative on Crops to End Hunger." *PloS ONE* 16 (4): e0249994. https://doi.org/10.1371/journal.pone.0249994

Yuan, S., A.M. Stuart, A.G. Laborte, et al. 2022. "Southeast Asia Must Narrow Down the Yield Gap to Continue to Be a Major Rice Bowl." *Nature Food* 3 (3): 217–226. https://doi.org/10.1038/s43016-022-00477-z

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF ROOTS, TUBERS, AND BANANAS IN RELATION TO FOOD SYSTEMS?

Evelyne Kihiu (CIP), Guy Hareau (CIP), Sika Gbegbelegbe (IITA), Robert Andrade (CIAT), Athanasios Petsakos (Bioversity International), and Arega Alene (IITA)

Key messages

- Root, tuber, and banana (RT&B) crops are vital for food and nutrition security, providing quick calories, buffering against food crises, and offering opportunities for gender empowerment, particularly in seed systems. Their resilience to adverse weather and their sustainable integration into diverse farming systems enhance productivity while minimizing environmental impact.

- Production and consumption of fresh and processed RT&B crops are projected to increase by 17 percent and 9 percent, respectively, by 2050 in developing countries. Total RT&B production could reach almost 1.4 billion tons, with sub-Saharan Africa (SSA) emerging as the world's leading supplier of RT&B crops.

- RT&Bs are mostly nontraded crops, although opportunities exist in some areas, such as intraregional exports of bananas from some SSA countries and cross-border trade of fresh potatoes between countries in Africa and Asia.

- Improving foresight research on biotic and abiotic stresses, trade, labor, and the efficiency of processing capacity and reducing post-harvest losses in RT&B crops could contribute to stabilizing their supply in the developing world, lowering import reliance, and creating local economic opportunities.

RECENT TRENDS AND CHALLENGES

The food security and environmental importance of root, tuber, and banana (RT&B) crops continues to grow globally in the transformation of food systems. These crops form an important component of the global food system, particularly in developing countries, due to their scale of production and consumption (Table 1).

In Africa, RT&B crops contribute to 18 percent of the total food intake, with this share increasing to 40–70 percent in countries including the Democratic Republic of the Congo, Burundi, Rwanda, and Ghana. In contrast, their contribution to total food intake in other regions is relatively modest: 4.4 percent in the Americas, 3.9 percent in Asia, 4.3 percent in Europe, and 7.1 percent in Oceania. Given the agricultural challenges of the 21st century – such as climate change, rising pressure on natural resource use (land and water), and shifting consumer preferences – increasing the productivity of RT&B crops in developing countries is crucial.

LATEST FORESIGHT RESEARCH

Global demand for RT&Bs, like other food crops, is largely influenced by population growth and income changes, while supply fluctuations are primarily driven by climate factors (Nelson et al. 2018). However, technological advances offer opportunities to mitigate these effects (FAO and UNFCCC 2024).

Several studies have analyzed the long-term outlook for RT&B crops through 2050, considering potential changes in population, income, and climate. These projections provide policymakers with critical insights into production trends and food security, helping to assess not only the direction but also the magnitude of change (Robinson et al. 2024).

Under a "middle-of-the-road" scenario – characterized by moderate population and income growth – alongside rapid climate change, Rosegrant et al. (2017) suggest that while average RT&B crop yields are expected to improve between 2010 and 2050, projected yields in 2050 will be lower under climate change scenarios compared to a no-climate-change scenario. By 2050, yield reductions are projected to range from 0.5 percent for cassava in East Asia and the Pacific (EAP) to 28.3 percent for potatoes in sub-Saharan Africa (SSA) compared to a no-climate-change scenario. Overall, among the six CGIAR focus regions,[1] yield projections for the RT&B crops indicate that SSA is expected to experience the most severe yield declines, followed by South Asia and Latin America and the Caribbean (LAC).

Despite the climate change challenges, RT&B production is expected to increase in most regions, albeit at a slower pace under climate change. In SSA and South Asia, production is projected to more than double, aligning with anticipated growth in both harvested area and population. Rosegrant et al. (2017) project global population to reach 9.2 billion by 2050, with average incomes increasing by over 150 percent from 2010 levels, reaching

1 Central and West Asia and North Africa (CWANA); East and Southern Africa (ESA); Latin America and the Caribbean (LAC); Southeast Asia and the Pacific, including East Asia (SEA); West and Central Africa (WCA); and South Asia (SA).

TABLE 1 Trends in area, production, and yields for RT&B crops, 1961–2022

	Area (million hectares)			Production (million tons)			Yield (tons/hectare)		
	1961–1980	1981–2000	2001–2022	1961–1980	1981–2000	2001–2022	1961–1980	1981–2000	2001–2022
Africa	12.3	18.3	35.0	76.6	135.8	288.5	39.7	44.1	52.7
Americas	6.2	6.7	6.7	79.8	94.6	114.5	68.4	73.3	90.4
Asia	17.7	17.9	18.9	190.4	266.4	373.0	63.5	84.2	114.3
Europe	15.2	10.6	5.9	215.8	164.0	118.2	62.2	76.0	83.1
Oceania	0.2	0.3	0.3	2.3	3.3	4.6	66.3	78.5	91.8

Source: FAO (2024).

approximately US$25,000 per person. This income growth is expected to exert upward pressure on food demand.

Further analysis of RT&B-specific results in Rosegrant et al. (2017) shows that, under a "business-as-usual" future scenario, RT&B crop production can reach 1.4 billion tons (Petsakos et al. 2019). The greatest supply and demand gains are expected in Africa. Under the same scenario, the study also suggests a 19.2 percent increase in per capita RT&B consumption in developing countries, with regional variation —15.4 percent in Africa, 6.8 percent in Asia, and 3.4 percent in LAC — while Europe and North America will experience a decline of 6.9 percent. Enhancing yields through wider adoption of available innovations in RT&B crops can have significant economic and poverty reduction effects, particularly in the poorer countries of Africa and Asia (Pemsl et al. 2022).

These projections align with estimates by Scott (2021), which forecast global root and tuber crop (R&T) production reaching 1.101 billion tons by 2050 — a 14.5 percent increase from 2030. The highest production increases are projected in SSA (rising from 294 million tons in 2016–2018 to 449 million tons by 2050), followed by Asia and the Pacific (from 304 million tons to 379 million tons over the same period). Per capita consumption is expected to rise by 2 percent in SSA between 2010 and 2050, whereas in Asia and the Pacific, population growth is projected to outpace production, resulting in a 3 percent decline in per capita consumption.

Under a scenario of moderate economic growth, population expansion, and climate adaptation challenges, more recent updates from IFPRI's global partial equilibrium International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model project global R&T production to reach 1,082 million tons by 2050, a 32 percent increase from 2020. West and Central Africa (WCA) is expected to emerge as the world's leading consumer and supplier of R&T crops (Figure 1) (Rosegrant et al. 2024).

The number of people involved in RT&B-dominated agrifood systems could more than double by the end of the 21st century, most of it in SSA (Thiele et al. 2022). While the expected production increases are likely to help meet the growing domestic demand for RT&Bs, regional disparities in demand and supply for specific commodities eventually result in differences in comparative advantage and net trade (Scott 2021; Petsakos et al. 2019).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

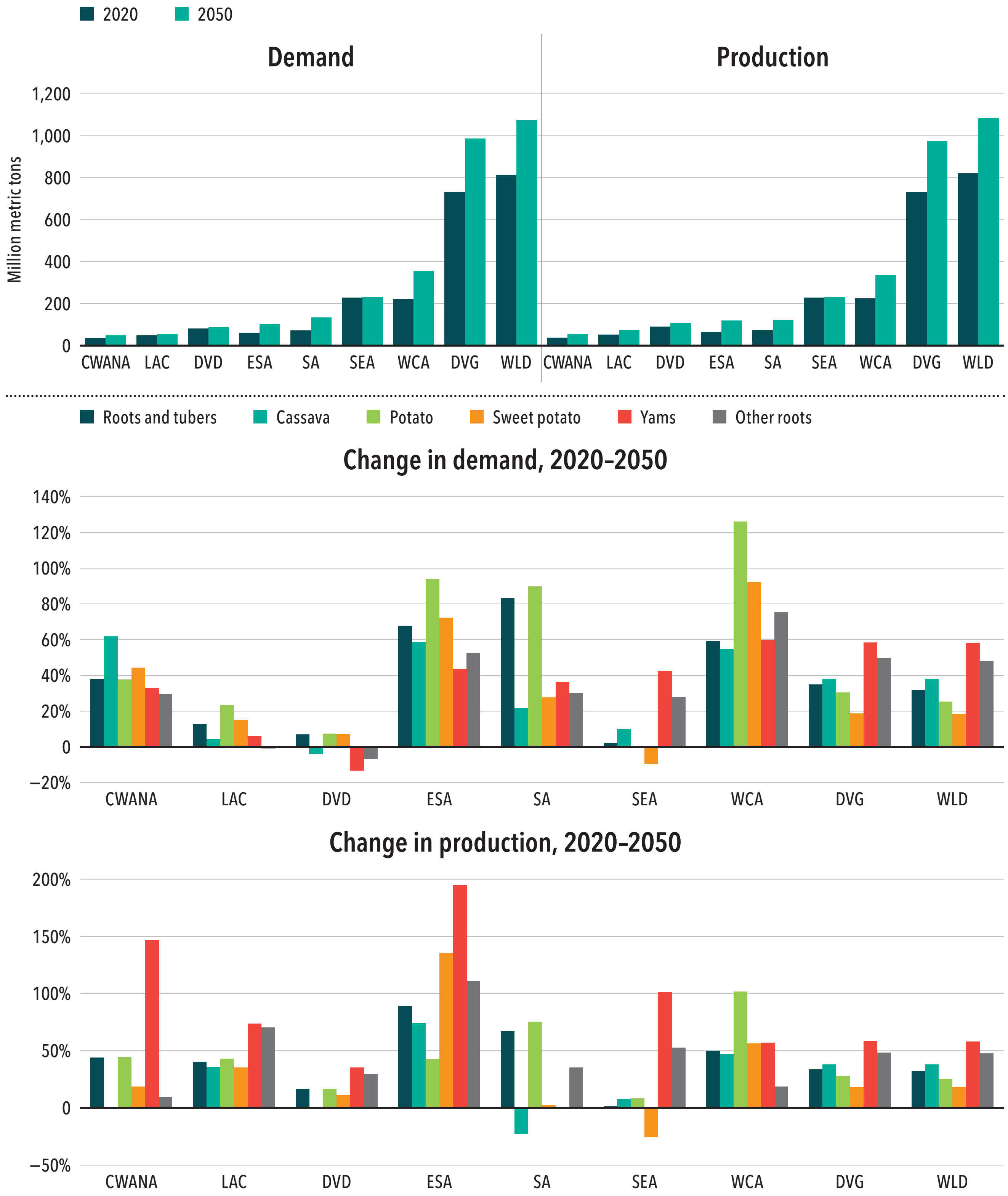
While significant progress has been made in understanding RT&B production and trade, key gaps remain, offering opportunities for further foresight research. One critical area is the labor trade-offs associated with increased RT&B productivity, particularly in developing countries where female labor participation is relatively high (Gatto, Petsakos, and Hareau 2020; Palacios-Lopez, Christiaensen, and Kilic 2017). More hired and family labor will be required, competing with other on- and off-farm economic activities and risking the potential to increase drudgery. Further foresight research to improve understanding of these dynamics is essential for designing policies that increase adoption rates of RT&B innovations, enhancing both productivity and gender equity (Thiele et al. 2021).

Another important area is the potential for intraregional trade. Export-oriented production, such as cassava in Southeast Asia and bananas in Latin America, will most likely continue to grow. However, trade in other RT&B crops in developing countries is still a minor share of total production. This is true especially in Africa, where despite growing production, persistent seasonal supply and demand imbalances force countries to rely on costly imports from neighboring countries. Foresight analysis to better understand how these imbalances may evolve in the future could help strengthen regional trade networks, improve trade balances (Petsakos et al. 2019), promote RT&B trade — including nontraditional crops — and enhance food security by optimizing local production capacities.

Climate change will impact RT&Bs and drive change of, for example, production suitability areas. It will also impact RT&B crops by increasing the variability and incidence of pests and diseases. Improving the speed and spatial resolution of foresight analysis on these biotic and abiotic stresses can facilitate more rapid adaptation through innovations and policies aimed at enhancing future production of RT&Bs.

Finally, weak linkages between RT&B crops and Africa's processing industry create supply uncertainties and limit value addition, particularly as urbanization changes

FIGURE 1 Regional change in total aggregate R&T demand and supply, 2020–2050



Source: Rosegrant et al. (2024).

Note: CWANA = Central and West Asia and North Africa; ESA = East and Southern Africa; LAC = Latin America and the Caribbean; SEA = Southeast Asia and the Pacific, including East Asia; WCA = West and Central Africa; SA = South Asia; DVD = developed countries; DVG = developing countries; WLD = world.

consumer preferences for consumption of RT&B products. Unlike other regions, where processing stabilizes supply and expands markets, Africa's RT&B food systems remain underdeveloped. Strengthening and improving the efficiency of processing capacity and reducing postharvest losses could contribute to stabilizing supply, lowering import reliance, and creating local economic opportunities. Expanding the focus of foresight research beyond demand and production to include these critical intermediate elements of RT&B value chains can help inform targeted policy interventions, for example in RT&B seed systems, that can help build a more resilient and sustainable RT&B sector.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Evelyne Kihiu**, an Agricultural Economist in Social and Nutritional Sciences at the International Potato Center (CIP); **Guy Hareau,** a Principal Scientist in Social and Nutritional Sciences at CIP; **Sika Gbegbelegbe**, an Agricultural Economist at the International Institute of Tropical Agriculture (IITA); **Robert Andrade**, a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at the International Center for Tropical Agriculture (CIAT); **Athanasios Petsakos**, a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International; and **Arega Alene**, an Agricultural Economist (Principal Scientist) and Program Leader for Foresight, Impact Assessment, and Scaling at IITA.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Kihiu, E., G. Hareau, S. Gbegbelegbe, R. Andrade, A. Petsakos, and A. Alene. 2025. "What Do We Know About the Future of Roots, Tubers, and Bananas in Relation to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 33. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: MehmetO/Shutterstock

References

FAO (Food and Agriculture Organization of the United Nations). 2024. FAOSTAT: Food and Agricultural Data. Accessed April 24, 2024. https://www.fao.org/faostat

FAO and UNFCCC (United Nations Framework Convention on Climate Change). 2024. *Climate Technologies for Agrifood Systems Transformation: Placing Food Security, Climate Change and Poverty Reduction at the Forefront*. Rome. https://doi.org/10.4060/cd2877en

Gatto, M., A. Petsakos, and G. Hareau. 2020. "Sustainable Intensification of Rice-Based Systems with Potato in Eastern Indo-Gangetic Plains." *American Journal of Potato Research* 97: 162–174. https://doi.org/10.1007/s12230-020-09764-6

Nelson, G., J. Bogard, K. Lividini et al. 2018. "Income Growth and Climate Change Effects on Global Nutrition Security to Mid-Century." *Nature Sustainability* 1 (12): 773–781. https://doi.org/10.1038/s41893-018-0192-z

Palacios-Lopez, A., L. Christiaensen, and T. Kilic. 2017. "How Much of the Labor in African Agriculture Is Provided by Women?" *Food Policy* 67: 52–63. https://doi.org/10.1016/j.foodpol.2016.09.017

Pemsl, D.E., C. Staver, G. Hareau et al. 2022. "Prioritizing International Agricultural Research Investments: Lessons from a Global Multi-Crop Assessment." *Research Policy* 51 (4): 104473. https://doi.org/10.1016/j.respol.2022.104473

Petsakos, A., S.D. Prager, C.E. Gonzalez et al. 2019. "Understanding the Consequences of Changes in the Production Frontiers for Roots, Tubers and Bananas." *Global Food Security* 20: 180–188. https://doi.org/10.1016/j.gfs.2018.12.005

Robinson, S., S. Dunston, A. Mishra et al. 2024. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Documentation for Version 3.6*. IFPRI Modeling Systems. Washington, DC: IFPRI. https://hdl.handle.net/10568/148953

Rosegrant, M.W., T.B. Sulser, S. Dunston et al. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Rosegrant, M.W., T.B. Sulser, D. Mason-D'Croz et al. 2017. *Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio*. Project Report for USAID. Washington, DC: IFPRI. https://hdl.handle.net/10568/148186

Scott, G.J. 2021. "A Review of Root, Tuber and Banana Crops in Developing Countries: Past, Present and Future." *International Journal of Food Science and Technology* 56 (3): 1093–1114. https://doi.org/10.1111/ijfs.14778

Thiele, G., D. Dufour, P. Vernier et al. 2021. "A Review of Varietal Change in Roots, Tubers and Bananas: Consumer Preferences and Other Drivers of Adoption and Implications for Breeding." *International Journal of Food Science Technology* 56 (3): 1076-1092. https://doi.org/10.1111/ijfs.14684

Thiele, G., M. Friedmann, H. Campos, V. Polar, and J. Bentley, eds. 2022. *Root, Tuber and Banana Food System Innovations: Value Creation for Inclusive Outcomes*. Cham, Switzerland: Springer Nature. https://doi.org/10.1007/978-3-030-92022-7

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF WHEAT?

Gideon Kruseman (Kruseman Consultancy), Kai Sonder (CIMMYT), Diego Pequeno (CIMMYT), Matthew Reynolds (CIMMYT), and Aymen Frija (ICARDA)

Key messages

- Wheat has been and will remain a major component of diets globally. It accounts for an average of 18 percent of total energy intake and 19 percent of total protein intake globally. It is the primary staple food for 1.5 billion resource-constrained people in the Global South.
- Wheat represents 29 percent of the global cereals area and 14 percent of the global cropland area. It is an important crop in most agricultural areas of the world except the humid tropics and is less prominent in sub-Saharan Africa. Compared to rice and maize, it is more drought- and cold-tolerant.
- Wheat will continue to be an important source of protein in 2050, even under changing diets. In meat-based diets, wheat is often part of animal feed. In plant-based diets, wheat is a source of protein.
- Climate change offers both challenges and opportunities for wheat. Areas previously unsuitable for wheat production may have a comparative advantage under climate change. Similarly, some traditional wheat-growing areas may become less suitable for wheat production under climate change, especially due to heat stress. While Jägermeyr et al. (2021) indicate it can be beneficial for many existing wheat-growing areas, the impacts, for example, of increased frequency and intensity of heat waves, warmer night temperatures, and other weather anomalies are likely to counteract some of the benefits.
- Some of the poorer regions of the world are historically considered to be wheat-deficit areas and will increasingly depend on imports. This is a key factor in Africa, where there is less wheat production and wheat consumption is increasing with rising incomes.

RECENT TRENDS AND CHALLENGES

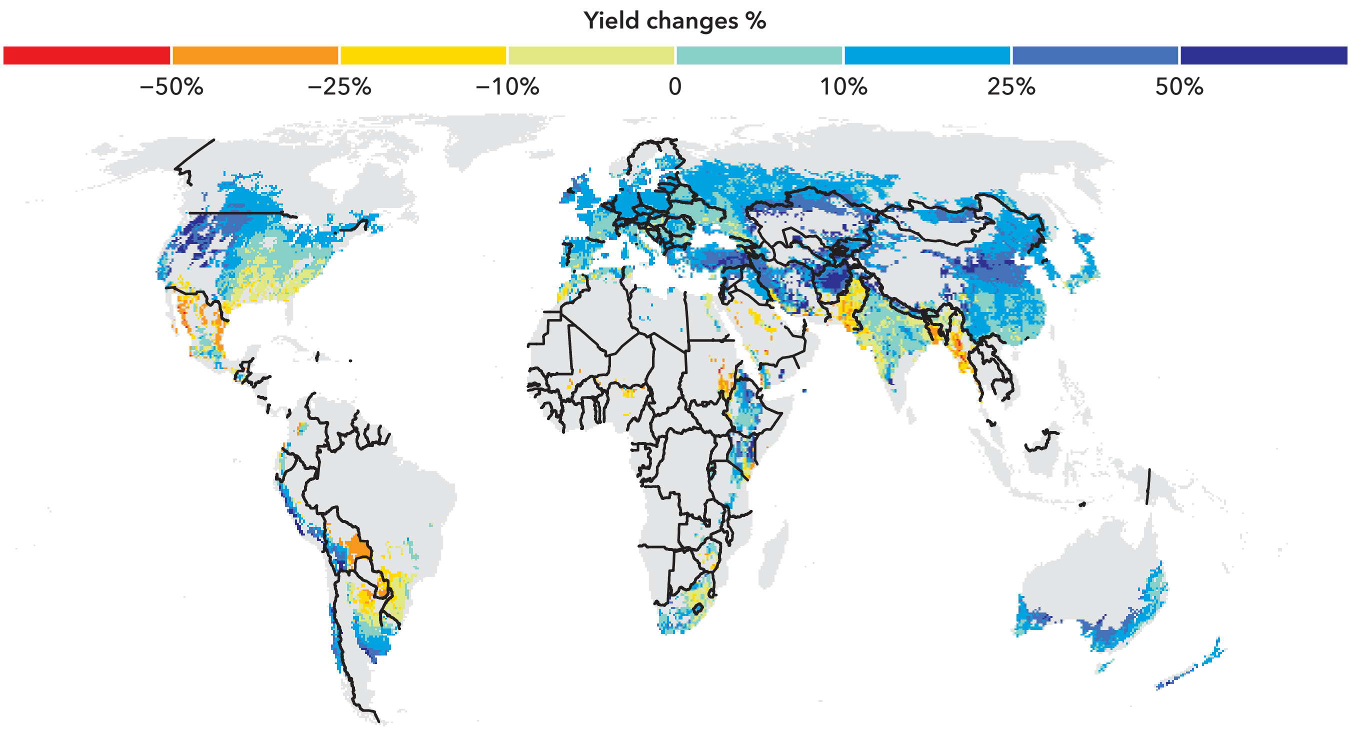
The growing human population and a changing environment have raised significant concern for global food security (Romanello et al. 2021). Economic development and urbanization induce changes in diets, leading to accelerated demand for some crops such as wheat in some geographies, while leading to stagnating demand in others. Economic development, urbanization, and related migration also lead to rural transformation (Kruseman et al. 2020), with impacts on crop and technology choices in wheat-based agrifood systems. Unexpected events, often called "black swan events (Bentley 2022; Mottaleb, Kruseman, and Snapp 2022; Noia Junio et al. 2022) and crises exacerbate these trends. Wheat is the most widely grown food crop in terms of area, representing 29.8 percent of the total cereal-growing area, with 779 metric tons (MT) produced globally in 2022 on 219 million hectares (ha); it is also among the fastest-growing crops in terms of cultivated area (especially in sub-Saharan Africa).

Climate change significantly impacts wheat production, particularly in low- and lower-middle income countries, where rising temperatures and disease pressures reduce yields and quality (Pequeno et al. 2021; Zhao et al. 2017; Asseng et al. 2019). Currently, wheat accounts for almost one-third of cultivated cereal land and about one-eighth of total cropland.

LATEST FORESIGHT RESEARCH

Foresight research on wheat and wheat-based systems often has a distinct focus. For example, a large body of work looks at the biophysical aspects of wheat production, especially in the context of climate change and climate change-induced stressors (Jägermeyr et al. 2021; Pequeno et al. 2021) (Figure 1). The analysis by Jägermeyr et al. may be overly optimistic being based on long-term averages, particularly for the more northerly latitudes, where extreme weather anomalies have already occurred in recent years and adversely affected wheat yields.

FIGURE 1 Projected global yield changes for wheat under RCP 8.5 for the end of the century in the absence of adaptation, technology change, and market adjustments



Source: Authors based on underlying data from Jägermeyr et al. (2021).

A second line of foresight research looks at the societal (social, economic, political, institutional, and policy) aspects of the future of wheat. In most cases, scenarios developed in other scientific domains are used as underlying assumptions. Few studies look at the interactions and feedback mechanisms between the biophysical and socioeconomic domains.

The traditional improvement rate of several important crops such as wheat seems inadequate to meet future demand (Ray et al. 2013) (see the case of Africa in Silva et al. 2023), reaching only 38 percent of the needed 60 percent for wheat by 2050. Technological breakthroughs in plant breeding such as speed breeding are expected to enhance wheat genetic gains (Li et al. 2018; Watson et al. 2018). Breeding strategies must continue to improve upon yield-advancing physiological traits, regardless of climate change impacts (Guarin et al. 2022; Frija et al. 2021). When including the second-order general equilibrium effects calculated with global economic models such as International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), Modular Applied GeNeral Equilibrium Tool (MAGNET), Model of Agricultural Production and its Impact on the Environment (MagPIE), or Global Biosphere Management Model (GLOBIOM), this discrepancy is overcome because both producers and consumers will respond to changed prices associated with new market equilibria (Chaudhary and Hertel 2024; Rosegrant et al. 2024; van Meijl et al. 2024).

Many studies overlook the role of management practices and varietal differences in adapting to climate change (Gbegbelegbe et al. 2017; Frija et al. 2021). Adapting wheat production to climate change involves implementing climate-smart agriculture (CSA) practices (Bhatt et al. 2016; Jat et al. 2019) and breeding climate-resilient varieties (Mondal et al. 2020). Compared to rice and maize, wheat is better adapted to frost and water deficit stress, both of which are expected to worsen with climate change.

To meet future demand under adverse conditions, such as declining groundwater in the Indo-Gangetic Plains, CSA solutions like subsurface drip fertigation in rice-wheat systems have shown promise, reducing nitrogen use by 20 percent and irrigation water by 50 percent without yield loss (Sidhu et al. 2019). Wheat also thrives in diverse climates, from high daytime temperatures in Sudan and Egypt to moderately warm, humid winters in Bangladesh and Brazil. Notably, Brazil is expanding wheat production in the Cerrado region, albeit with environmental impacts through drought-tolerant varieties, aiming for self-sufficiency (Noia Junio et al. 2024).

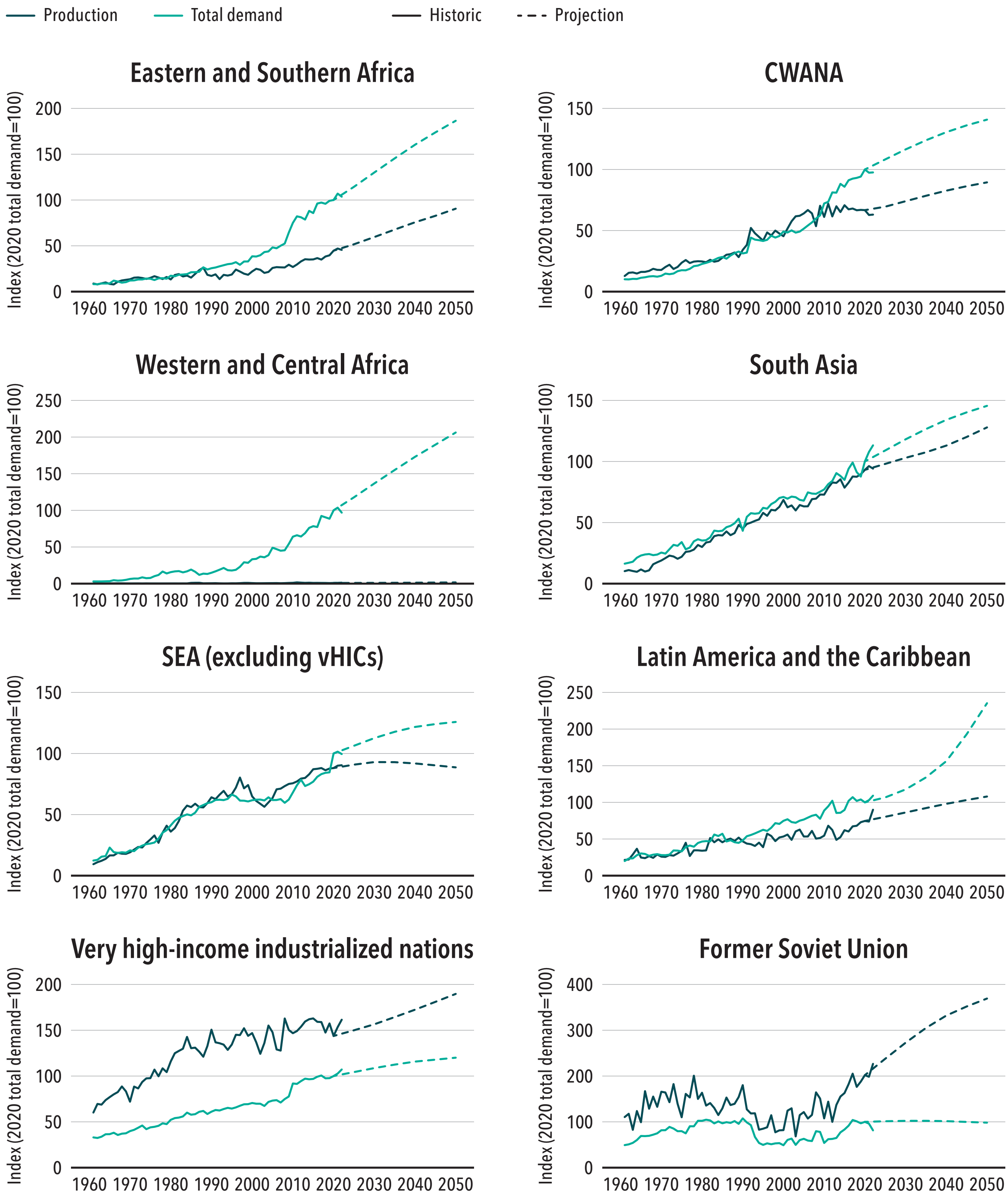
With limited progress on global greenhouse gas (GHG) emissions reductions, agriculture's role in mitigation is growing. Innovations such as biological nitrification inhibition in wheat (Subbarao et al. 2017; Leon et al. 2022) and nitrogen-efficient, stress-resilient varieties developed by CGIAR could significantly reduce GHG emissions. Additionally, wheat's comparative advantages may shift geographically. Silva et al. (2023) identify 86 million ha of potential new wheat-growing areas globally, including 25 million ha in sub-Saharan Africa suitable for rainfed cultivation without major irrigation. Yield gaps, often over 50 percent, can be addressed through improved rotations and agronomic practices like conservation agriculture. In Asia, production increases are expected to rely more on closing yield gaps than expanding cultivation areas.

These advancements underscore the need for integrated approaches combining technological innovation, CSA practices, and adaptive breeding to ensure wheat's resilience and productivity in a changing climate.

Wheat consumption is expected to grow in countries such as Bangladesh, India, Nepal, and Thailand by 2050 (Frija, Ouerghemmi, and Mottaleb 2021). Wheat is also expected to gain further importance as a major cereal in the diet of many sub-Saharan Africa countries by 2050, with increasing demand rates higher than those of other cereals (Frija, Ouerghemmi, and Mottaleb 2021). To meet the expected grain demand by mid-century, wheat production must also increase (Silva et al. 2023).

Dietary shifts from cereals toward animal proteins may reshape the global food system in the future (Kruseman et al. 2021a, 2021b). Dietary change has long been associated with changes in both the degree of urbanization and in disposable income, where the data indicate that wheat in most cases is a more desirable cereal than other coarse grains (Kruseman et al. 2021b). Although per capita consumption of global staple cereals is likely to decline in many countries, total demand will increase over the next several decades due to population growth (Rosegrant et al. 2024). Increased demand for quality and healthy food implies that the perception of wheat as a quality staple is on the rise in countries that are not traditionally wheat

FIGURE 2 Historical trends and projections in total demand for and production of wheat by region, 1961–2050



Source: Historic trends based on FAO (2024) food balance sheets. Projections based on IMPACT model results (Rosegrant et al. 2024).

Note: Index based on 2020 total demand per region = 100. An index is used to show the magnitude and direction of change rather than focusing on actual numbers. CWANA = Central and West Asia and North Africa. SEA = Southeast Asia. vHICs = very high-income countries.

consumers (Mottaleb et al. 2018a, 2018b, 2021; Frija, Ouerghemmi, and Mottaleb 2021). Higher incomes are associated with shifts from plant- to animal-based diets. In recent years in high-income countries, this trend started to reverse with the emergence of viable and more affordable plant-based alternatives. Some evidence suggests that gluten (a key protein in wheat) is likely to be an essential ingredient of affordable, high-quality, plant-based fish and meat alternatives (He et al. 2020; Zhang et al. 2021), in combination with a range of pulses. As animal-based food consumption is likely to be under pressure because of GHG emissions and other environmental concerns, wheat will continue to play a major role in the global human diet. Despite the perceived shift toward plant-based diets, considerable factors remain as barriers to a rapid dietary shift. For example, availability and accessibility as well as cultural, religious, social, economic, and legal considerations all influence consumers' food choices (Abe-Inge et al. 2023).

Figure 2 summarizes the effects of some of these issues by comparing historical trends to projections generated by the IMPACT model (Rosegrant et al. 2024). The eight panels show the production of wheat in seven main regions of the world as well as total demand, comprising food, feed, seed, and industrial uses. Some of the poorer regions of the world are historically wheat-deficit areas and will increasingly depend on imports. Projections do not take into account the effects of the Russia-Ukraine war on key supplies of food commodities (Mottaleb, Kruseman, and Snapp 2022; van Meijl et al. 2024).

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Research on wheat in relation to climate change has focused on the adaptation of wheat-based systems to new situations and stressors. While work has been done on technologies that offer some level of mitigation, such as biological nitrogen inhibition (for example, Leon et al. 2022), more foresight research is needed on the potential uptake of technologies that simultaneously offer adaptation to and mitigation of climate change. The spread of new diseases is a concern that could intensify with climate change, especially in tropical and subtropical regions (Pequeno et al. 2024), requiring additional research.

With climate change, the potential production areas for different crops, including wheat, will shift. In recent years wheat production in North Africa has become increasingly difficult due to climate change-related stressors. More research is needed to identify areas with an increasing comparative advantage to grow wheat. Foresight research is also needed to guide best agronomic, varietal, and other practices for expected wheat expansion areas. Analysis needs to consider not just carbon dioxide (CO_2) and changing rainfall patterns, as was done in Jägermeyr et al. (2021), but also scenarios that take into account: the negative impact on yields of warmer night temperatures (which influence yield variance more than day temperatures do, and which are increasing faster than day temperatures); heatwaves, which are expected to be more extreme and frequent; delayed rains and less even distribution of precipitation; and floods and untimely frosts. Increased CO_2 does not mitigate any of the above and heavier rain is only useful if timely, and on soils with good infiltration rates.

Awareness is growing that animal-based diets have a strong impact on the environment. Dietary change is generally slow, but a movement toward more plant-based diets is likely. Foresight research is needed on dietary change in relation to plant-based meat products and the implications for wheat, as wheat is likely to be an important component of such a diet.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Gideon Kruseman**, Founder of Kruseman Foresight and Metrics Consultancy; **Kai Sonder**, Head of the Geographic Information System Unit in the Sustainable Agrifood Systems Program at the International Maize and Wheat Improvement Center (CIMMYT); **Diego Pequeno**, a Scientist and Wheat Crop Modeler in the Sustainable Agrifood Systems Program at CIMMYT; **Matthew Reynolds**, Head of the Wheat Physiology Group at CIMMYT; and **Aymen Frija**, a Senior Scientist and Agricultural Economist in the Social, Economic, and Policy Research Team at the International Center for Agricultural Research in the Dry Areas (ICARDA).

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Kruseman, G., K. Sonder, D. Pequeno, M. Reynolds, and A. Frija. 2025. "What Do We Know About the Future of Wheat?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 34. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: ESB Professional/Shutterstock

References

Abe-Inge, V., R. Aidoo, M.M. de la Fuente, and E.M. Kwofie. 2023. "Plant-Based Dietary Shift: Current Trends, Barriers, and Carriers." *Trends in Food Science & Technology*. https://doi.org/10.1016/j.tifs.2023.104292

Asseng, S., P. Martre, A. Maiorano, et al. 2019. "Climate Change Impact and Adaptation for Wheat Protein." *Global Change Biology* 25: 155–173. https://doi.org/10.1111/GCB.14481

Bentley, A. 2022. "Broken Bread—Avert Global Wheat Crisis Caused by Invasion of Ukraine." *Nature* 603: 551–551. https://doi.org/10.1038/d41586-022-00789-x

Bhatt, R., S.S. Kukal, M.A. Busari, S. Arora, and M. Yadav. 2016. "Sustainability Issues on Rice–Wheat Cropping System." *International Soil and Water Conservation Research* 4: 64–74. https://doi.org/10.1016/j.iswcr.2015.12.001

FAO (Food and Agriculture Organization of the United Nations). 2024. FAOSTAT Crops and Livestock Products. Accessed October 2024. https://www.fao.org/faostat/en/#data/QCL

Frija, A., H. Ouerghemmi, and K.A. Mottaleb. 2021. *Dietary Change in Asia, Sub-Saharan Africa, and North Africa: Historical Changes and Future Food Consumptions Perspectives*. Policy Brief. Cairo: International Center for Agricultural Research in the Dry Areas (ICARDA). https://hdl.handle.net/20.500.11766/66832

Frija, A., W. Tadesse, Z. Bishaw, et al. 2021. *The Future of Wheat Research and Production in Sub-Saharan Africa*. Technical Brief. Beirut: ICARDA. https://hdl.handle.net/20.500.11766/66804

Gbegbelegbe, S., D. Cammarano, S. Asseng, et al. 2017. "Baseline Simulation for Global Wheat Production With CIMMYT Mega-Environment Specific Cultivars." *Field Crops Research* 202: 122–135. https://doi.org/10.1016/J.FCR.2016.06.010

Guarin, J.R., P. Martre, F. Ewert, et al. 2022. "Evidence for Increasing Global Wheat Yield Potential." *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/ACA77C

He, J., N.M. Evans, H. Liu, and S. Shao. 2020. "A Review of Research on Plant-Based Meat Alternatives: Driving Forces, History, Manufacturing, and Consumer Attitudes." *Comprehensive. Reviews in Food Science and Food Safety* 19: 2639–2656. https://doi.org/10.1111/1541-4337.12610

Jägermeyr, J., C. Müller, A.C. Ruane, et al. 2021. "Climate Impacts on Global Agriculture Emerge Earlier in New Generation of Climate and Crop Models." *Nature Food* 2 (11): 873–885. https://doi.org/10.1038/s43016-021-00400-y

Jat, H.S., A. Datta, M. Choudhary, et al. 2019. "Climate Smart Agriculture Practices Improve Soil Organic Carbon Pools, Biological Properties and Crop Productivity in Cereal-Based Systems of North-West India." *Catena* 181: 104059. https://doi.org/10.1016/j.catena.2019.05.005

Kruseman, G., K.A. Mottaleb, K. Tesfaye, et al. 2020. "Rural Transformation and the Future of Cereal-Based Agri-Food Systems." *Global Food Security* 26: 100441. https://doi.org/10.1016/j.gfs.2020.100441

Kruseman, G., A. Dermawan, M. Diagne, et al. 2021a. "Foresight for Income and Employment: What Can We Learn for Agricultural Research for Development." *SocArZiv Papers*. https://doi.org/10.31235/OSF.IO/783RW

Kruseman, G., K.A. Mottaleb, S. Gbegbelegbe, A. Frija, S. Bairagi, and M. Springmann. 2021b. "Effects of Dietary Change—Synthesis Across the Case Studies." Integrated Development Program Discussion Paper No. 3. Texcoco, Mexico: International Maize and Wheat Improvement Center (CIMMYT). https://repository.cimmyt.org/handle/10883/21821

Leon, A., G.V. Subbarao, M. Kishii, N. Matsumoto, and G. Kruseman. 2022. "An Ex Ante Life Cycle Assessment of Wheat With High Biological Nitrification Inhibition Capacity." *Environmental Science and Pollution Research* 29: 7153–7169. https://doi.org/10.1007/s11356-021-16132-2

Li, H., A. Rasheed, L.T. Hickey, and Z. He. 2018. "Fast-Forwarding Genetic Gain." *Trends in Plant Science*. https://doi.org/10.1016/j.tplants.2018.01.007

Mondal, S., S. Dutta, L. Crespo-Herrera, J. Huerta-Espino, H.J. Braun, and R.P. Singh. 2020. "Fifty Years of Semi-Dwarf Spring Wheat Breeding at CIMMYT: Grain Yield Progress in Optimum, Drought and Heat Stress Environments." *Field Crops Research* 250: 107757. https://doi.org/10.1016/j.fcr.2020.107757

Mottaleb, K.A., F.A. Fatah, G. Kruseman, and O. Erenstein. 2021. "Projecting Food Demand in 2030: Can Uganda Attain the Zero Hunger Goal?" *Sustainable Production and Consumption* 28: 1140–1163. https://doi.org/10.1016/J.SPC.2021.07.027

Mottaleb, K.A., G. Kruseman, and S. Snapp. 2022. "Potential Impacts of Ukraine-Russia Armed Conflict on Global Wheat Food Security: A Quantitative Exploration." *Global Food Security* 35: 100659. https://doi.org/10.1016/j.gfs.2022.100659

Mottaleb, K.A., G. Kruseman, A. Frija, K. Sonder, and S. Lopez-Ridaura. 2023. "Projecting Wheat Demand in China and India for 2030 and 2050: Implications for Food Security." *Frontiers in Nutrition* 9. https://doi.org/10.3389/FNUT.2022.1077443

Mottaleb, K.A., D.B. Rahut, G. Kruseman, and O. Erenstein. 2018a. "Evolving Food Consumption Patterns of Rural and Urban Households in Developing Countries: A Bangladesh Case." *British Food Journal* 120: 392–408. https://doi.org/10.1108/BFJ-12-2016-0620

Mottaleb, K.A., D.B. Rahut, G. Kruseman, and O. Erenstein. 2018b. "Changing Food Consumption of Households in Developing Countries: A Bangladesh Case". Journal of International Food and Agribusiness Marketing 30 (2): 156–174. https://doi.org/10.1080/08974438.2017.1402727

Nóia Júnior, R. de S., F. Ewert, H. Webber, P. Martre, T.W. Hertel, M.K. van Ittersum, S. Asseng. 2022. "Needed Global Wheat Stock and Crop Management in Response to the War in Ukraine." *Global Food Security* 35: 100662. https://doi.org/10.1016/j.gfs.2022.100662

Nóia Júnior, R. de S., M. Nardinom, E.F. Elli, D. Pequeno, C. Fraisse, S. Asseng. 2024. "Achieving Self Sufficiency in Wheat in Brazil." *Environmental Research Letters* 19 (3): 031003. https://doi.org/10.1088/1748-9326/ad26b8

Pequeno, D.N.L., T.B. Ferreira, J.M.C. Fernandes, et al. 2024. "Production Vulnerability to Wheat Blast Disease Under Climate Change." *Nature Climate Change* 14: 178–183. https://doi.org/10.1038/s41558-023-01902-2

Pequeno, D.N.L., I.M. Hernández-Ochoa, M. Reynolds, et al. 2021. "Climate Impact and Adaptation to Heat and Drought Stress of Regional and Global Wheat Production." *Environmental Research Letters* 16 (5): 054070. https://doi.org/10.1088/1748-9326/ABD970

Ray, D.K., N.D. Mueller, P.C. West, J.A. Foley. 2013. "Yield Trends Are Insufficient to Double Global Crop Production by 2050." *PLoS One* 8: e66428. https://doi.org/10.1371/journal.pone.0066428

Romanello, M., A. McGushin, C. Di Napoli, et al. 2021. "The 2021 Report of the *Lancet* Countdown on Health and Climate Change: Code Red for a Healthy Future." *Lancet* 398: 1619–1662. https://doi.org/10.1016/S0140-6736(21)01787-6

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security Under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Sidhu, H.S., M.L. Jat, Y. Singh, et al. 2019. "Sub-Surface Drip Fertigation With Conservation Agriculture in a Rice-Wheat System: A Breakthrough for Addressing Water and Nitrogen Use Efficiency." *Agricultural Water Management* 216: 273–283. https://doi.org/10.1016/j.agwat.2019.02.019

Silva, J.V., M. Jaleta, K. Tesfaye, et al. 2023. "Pathways to Wheat Self-Sufficiency in Africa." *Global Food Security* 37: 100684. https://doi.org/10.1016/J.GFS.2023.100684

Subbarao, G.V., J. Arango, K. Masahiro, et al. 2017. "Genetic Mitigation Strategies to Tackle Agricultural GHG Emissions: The Case for Biological Nitrification Inhibition Technology." *Plant Science* 262: 165–168. https://doi.org/10.1016/j.plantsci.2017.05.004

Van Meijl, H., H. Bartelings, S. van Berkum, H.D. Cui, Z.S. Kristkova, and W.J. van Zeist. 2024. "The Russia-Ukraine War Decreases Food Affordability But Could Reduce Global Greenhouse Gas Emissions." *Communications Earth & Environment* 5 (1): 59. https://doi.org/10.1038/s43247-024-01208-x

Watson, A., S. Ghosh, M.J. Williams, et al. 2018. "Speed Breeding Is a Powerful Tool to Accelerate Crop Research and Breeding." *Nature. Plants* 4: 23–29. https://doi.org/10.1038/s41477-017-0083-8

Zhang, T., W. Dou, X. Zhang, et al. 2021. "The Development History and Recent Updates on Soy Protein-Based Meat Alternatives." *Trends in Food Science and Technology* 109: 702–710. https://doi.org/10.1016/j.tifs.2021.01.060

Zhao, C., B. Liu, S. Piao, et al. 2017. "Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates." *PNAS* 114 (35): 9326–9331. https://doi.org/10.1073/PNAS.1701762114

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FORESIGHT DATA AND ANALYTICAL TOOLS?

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF MEASURING FOOD SYSTEMS?

Jessica Fanzo (Columbia University), Bianca Carducci (Columbia University), and Michael Puma (Columbia University and NASA)

Key messages

- Many food systems-related databases, tools, and dashboards are available, but to ensure these tools are useful for decision-makers, they must be harmonized and their sophistication increased to capture trade-offs and synergies.
- The Food Systems Countdown Initiative holds great potential to address this need, but its success will depend on several factors, such as filling national and subnational data gaps, ensuring countries formalize their commitments, translating global ambitions into national contexts, and integrating sectoral policies and programs.
- A new generation of food systems indicators must capture multifaceted interactions, trade-offs, and synergies by integrating observations, models, and complex system analyses with clear metadata for appropriate use.

RECENT TRENDS AND CHALLENGES

To better characterize food systems, a descriptive analysis of a comprehensive set of indicators is an essential step, including diet, nutrition, livelihood, and environmental outcomes, as well as potential food system determinants. It is challenging to comprehend food systems fully because of their myriad components, actors, processes, interactions, inherent uncertainties, and the limits of what is knowable and predictable within such complex systems. However, over the last 20 years, the ecosystem of food systems data and data tools has evolved into an intricate and multifaceted landscape characterized by a wide range of resources and platforms. Some platforms include searchable databases, dashboards, and country and regional platforms.

To provide a few examples, the Food Systems Dashboard aggregates data from over 40 sources and presents approximately 300 indicators spanning various components of food systems. This comprehensive tool enables users to describe, diagnose, and decide on actions related to food systems at both national and subnational levels (Fanzo et al. 2020). The World Bank's Global Food and Nutrition Security dashboard focuses more on food crisis severity. Complementing these tools are specialized diet-related resources, such as the Global Diet Quality Project for standardized food group consumption data collection and the Food Compass, which rates the healthfulness of foods around the world. The Food Prices for Nutrition project has developed metrics for analyzing food price and diet cost data. The Food and Agriculture Organization of the United Nations (FAO) has a number of data platforms, the best-known of which is its flagship database, FAOSTAT. This database provides free access to a significant range of food and agriculture statistics for over 245 countries and territories, covering all FAO regional groupings from 1961 to the present. IFPRI also has several databases and related analytical tools, including the IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model, which combines climate, crop, and economic models to analyze future scenarios for agricultural production and food security, and the Food Security Portal, which provides country-level information on food security indicators.

This diverse ecosystem of data sources and analytical tools collectively has the potential to empower researchers, policymakers, and practitioners to gain deep insights into the multifaceted nature of food systems, facilitating evidence-based decision-making and policy formulation. However, data standardization and harmonization across these diverse tools (Zhou et al. 2022) and increased participatory approaches for users of data tools are critical for food system transformation (Béné et al. 2024).

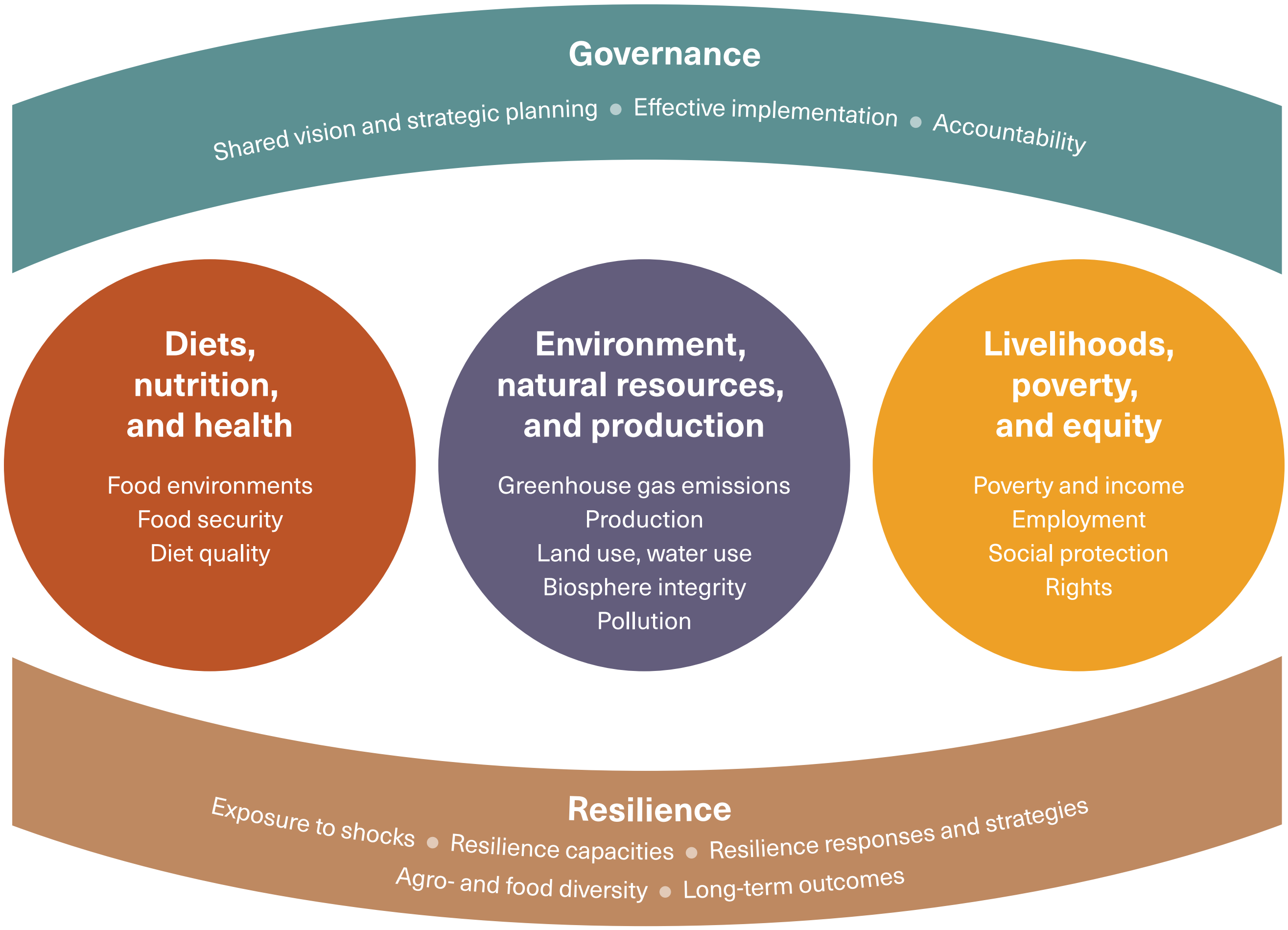
LATEST FORESIGHT RESEARCH

Foresight can take many forms, including learning from the past and present to inform our understanding of the future. Careful selection, compilation, and analysis of key indicators is essential not just for understanding food systems today, but also as a precondition for rigorous analysis of possible future pathways and projections for food systems transformation. For example, IFPRI's IMPACT model can generate projections to inform decisions about future food systems.

The Food Systems Countdown Initiative (FSCI) is an interdisciplinary collaboration of researchers that emerged from the 2021 United Nations Food Systems Summit. Over a two-year process, the collaboration developed a comprehensive, independent, science-based framework to monitor food systems that includes five themes: (1) diets, nutrition, and health; (2) environment, natural resources, and production; (3) livelihoods, poverty, and equity; (4) governance; and (5) resilience (Fanzo et al. 2021) (Figure 1). The FSCI then used a rigorous, multi-stakeholder process to select 50 indicators to monitor change across these five themes. The 50 indicators provide a comprehensive yet concise picture of food systems (Schneider et al. 2022). While the FSCI does not include foresight data, there is potential to consider projections of a portion of these 50 indicators in the future.

Using this framework, the current baseline analysis of the FSCI indicators reveals the complex challenges in global food systems: no country, region, or income group exhibits desirable status across all indicators. These baseline data also highlight significant gaps (as discussed above) that need to be filled in order to guide action in service of food system transformation to meet the Sustainable Development Goals, and ensure that food systems contribute positively to the many global goals linked to them (Schneider et al. 2023). The FSCI will undertake this research and action agenda in the coming years as well provide regularly updated assessments that track

FIGURE 1 The five thematic areas of the FSCI



Source: Fanzo et al. (2021).

progress from this baseline forward, including the addition of new indicators or the refinement of the current set of indicators as food systems science progresses.

In addition, monitoring the performance of food systems across countries requires setting clear numerical targets for each indicator. Target setting will allow decision-makers to use the framework as a starting point to: consider what changes in indicators are required at different scales; compare with neighboring countries; and forge coalitions to drive change. The choice of the specific numerical target values is typically: taken from the 2030 Sustainable Development Goal Agenda and other international agreements; drawn from the scientific literature; or calculated based on top-performing countries (van Vuuren et al. 2022). However, little consensus exists on which science-based methods for performing such assessments are best across a large set of indicators, hence bringing the risk of cherry picking and arbitrary target setting among the 50 indicators and potentially compromising the robustness, usefulness, and credibility of such assessments (Gebara et al. 2024). To mitigate such challenges, the FSCI aims to develop a standardized method that recognizes the interplay between global and regional targets, incorporating both achievable and aspirational targets across scales.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Significant progress has been made in ensuring that food system-related data are available, but gaps remain, including data on links across supply chains (storage, transport, processing), food environments, livelihoods, and consumer behaviors. Data availability varies across geographic areas and income groups and data are often available only in highly aggregated forms. It is particularly challenging to disaggregate data by geographic location at the subnational level. In addition to gaps in data availability, poor quality data (for example, sometimes only modeled estimates) and other data-related challenges can make monitoring food systems and assessing and implementing effective policy and intervention strategies more challenging. The frequency of data collection is also limited, with very little real-time data available across food systems components. Lastly, the temporal and spatial interconnectedness of food system data makes exploring the relationships among food systems inputs, processes, outputs, and outcomes a challenging endeavor (Marshall et al. 2021). These data limitations and complexities underscore the need for improved research approaches.

Given these data challenges and system complexities, we must explore opportunities that allow researchers to capture the dynamic nature of food systems, including their feedback loops, trade-offs, and synergies (Nayak and Waterson 2019). Current metrics often fail to reflect the complex interactions within these systems, potentially leading to oversimplified assessments and interventions (Allen et al. 2019). To tackle this challenge, we call for a new generation of indicators built by combining observations, models, and complex system analyses. For instance, a systemic risk indicator could integrate real-time supply chain data, climate stress patterns, and economic volatility to provide early warning signals, while a predictive health indicator might combine dietary data with local food environments and machine learning to identify intervention points before health crises emerge.

Developing these next-generation indicators requires leveraging advanced models — including artificial intelligence, agent-based models, econometrics, simulation models, and complex systems science — to innovate how we understand and measure food systems. While these models incorporate novel computational approaches, they must be grounded in a historical understanding of how food systems have evolved. As Brooks and Place (2019) note, while future transformations may differ from past ones, historical patterns remain relevant for constructing plausible scenarios and testing assumptions about future changes. Such modeling approaches depend on integrating diverse datasets, such as satellite imagery, climate data, economic indicators, health surveys, and logistics networks. Platforms like Dojo (Dojo Modeling Platform 2024) support this integration by serving as versatile platforms that allow researchers to unify diverse data sources and sophisticated models. By analyzing how these factors interact within such platforms, we can gain deeper insights into system resilience, efficiency, and vulnerability while remaining cognizant of how past policy decisions around productivity, trade, and environment have shaped food systems. Critically, these indicators should include metadata to explicitly highlight guardrails for their appropriate use. For instance, Dojo enables users to add detailed metadata to models and datasets, which promotes reproducibility and ensures results are applied appropriately (Dojo Modeling Platform 2024). This comprehensive approach not only enhances our understanding of food systems' complexities but also provides clear guidance on the indicators' applications and limitations.

These advancements are directly applicable to the FSCI. By incorporating advanced indicators and methodologies, the FSCI can more accurately monitor progress and identify areas needing attention. This integration presents an opportunity to address critical questions, such as how to effectively measure system resilience or assess the impact of policy interventions across different sectors.

However, significant gaps remain in the availability and accessibility of high-quality, granular data necessary for these advanced models. Questions about standardizing data formats, ensuring interoperability, and protecting data privacy require urgent attention. Opportunities for further foresight research include developing interoperable platforms for data sharing, creating standardized protocols for metadata annotation, and exploring the use of emerging technologies like machine learning and blockchain to enhance data security and traceability.

The set of 50 FSCI indicators is meant to be examined holistically to better understand synergies and trade-offs across different domains of food systems. In an upcoming paper, the FSCI authors assess interactions across the indicators and find that certain governance and resilience indicators have the greatest number of connections to other indicators across all food system themes, thus highlighting key leverage points for action (this may have been due to their generality) (Schneider et al. 2025). Whether those relationships between indicators were synergistic or antagonistic, what is certain is that the interactions between indicators are context-dependent and strongly influenced by policy measures taken at local or national scales.

While these advances in data integration and modeling show promise, the political context presents additional measurement challenges that are difficult to capture. Foresight analyses must become more sophisticated to analyze potential patterns of policy change and how politics and policies, especially in a competitive international environment, trigger deviations from the norm that lead to unpredictable trends. This shifting political landscape may mean that the indicators we have on hand are insufficient, and we need new metrics (along with participatory stakeholder consultation and engagement to review foresight outcomes) to measure future food systems change. This approach to measurement may also mean that we need to incorporate historical insights into scenarios of the future. These scenarios should include assumptions of what "was" and what "is" to support what "if" type scenarios for unexpected policy shocks.

By tackling these issues and fostering interdisciplinary collaboration, we can create a more robust framework that supports more effective interventions for food system transformation.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Jessica Fanzo**, Professor of Climate and Food and Director of the Food for Humanity Initiative in the Columbia Climate School at Columbia University; **Bianca Carducci**, a Postdoctoral Scientist in the Columbia Climate School at Columbia University; and **Michael Puma**, Professor of Climate in the Columbia Climate School and Unit Director of the Center for Climate Systems Research at Columbia University and the NASA Goddard Institute for Space Studies.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Fanzo, J., B. Carducci, and M. Puma. 2025. "What Do We Know About the Future of Measuring Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 35. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Ryan Brown/UN Women

References

Allen, T., P. Prosperi, B. Cogill, M. Padilla, and I. Peri. 2019 "A Delphi Approach to Develop Sustainable Food System Metrics." *Social Indicators Research* 141: 1307–1339. https://doi.org/10.1007/s11205-018-1865-8

Béné, C., C.K. Chege, B. Even et al. 2024. "Why Building Participatory Dashboards Is Key for Sustainable Food System Transformation." *Frontiers in Sustainable Food Systems* 8 : 1405670. https://doi.org/10.3389/fsufs.2024.1405670

Brooks, K., and F. Place. 2019. "Global Food Systems: Can Foresight Learn from Hindsight?" *Global Food Security* 20: 66–71. https://doi.org/10.1016/j.gfs.2018.12.004

Dojo Modeling Platform. Accessed Oct. 17, 2024. https://www.dojo-modeling.com/

Fanzo, J., L.Haddad, R. McLaren, et al. 2020. "The Food Systems Dashboard Is a New Tool to Inform Better Food Policy." *Nature Food* 1: 243–246. https://doi.org/10.1038/s43016-020-0077-y

Fanzo, J., L. Haddad, K.R. Schneider et al. 2021. "Viewpoint: Rigorous Monitoring Is Necessary to Guide Food System Transformation in the Countdown to the 2030 Global Goals." *Food Policy* 104: 102163. https://doi.org/10.1016/j.foodpol.2021.102163

Gebara, C.H., C. Thammaraksa, M. Hauschild, and A. Laurent. 2024. "Selecting Indicators for Measuring Progress Towards Sustainable Development Goals at the Global, National and Corporate Levels." *Sustainable Production and Consumption* 44: 151–165. https://doi.org/10.1016/j.spc.2023.12.004

Marshall, Q., A.L. Bellows, R. McLaren, A.D. Jones, and J. Fanzo. 2021. "You Say You Want a Data Revolution? Taking on Food Systems Accountability." *Agriculture* 11 (5): 422. https://doi.org/10.3390/agriculture11050422

Nayak, R., and P. Waterson. 2019 "Global Food Safety as a Complex Adaptive System: Key Concepts and Future Prospects." *Trends in Food Science and Technology* 91: 409–425. https://doi.org/10.1016/j.tifs.2019.07.040

Schneider, K.R., J. Fanzo, L. Haddad et al. 2023. "The State of Food Systems Worldwide in the Countdown to 2030." *Nature Food* 4: 1090–1110. https://doi.org/10.1038/s43016-023-00885-9

Schneider, K.R., R. Remans, T.H. Bekele et al. 2025. "Governance and Resilience as Entry Points for Transforming Food Systems in the Countdown to 2030." *Nature Food*. https://doi.org/10.1038/s43016-024-01109-4

van Vuuren, D.P., C. Zimm, S. Busch et al. 2022. "Defining a Sustainable Development Target Space for 2030 and 2050." *One Earth* 5: 142–156. https://doi.org/10.1016/j.oneear.2022.01.003

Zhou, B., S. Liang, K.M. Monahan et al. 2022. "Food and Nutrition Systems Dashboards: A Systematic Review." *Advances in Nutrition* 13: 748–757. https://doi.org/10.1093/advances/nmac022

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

CGIAR
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

What do we know about THE FUTURE OF FOOD DEMAND, PRODUCTION, AND FOOD SECURITY BASED ON IMPACT MODEL PROJECTIONS?

Nicola Cenacchi (IFPRI), Timothy B. Sulser (IFPRI), and Abhijeet Mishra (IFPRI)

Key messages

- Global food demand is projected to increase as incomes rise, and diets will continue shifting toward more nutrient-dense foods, especially in low- and middle-income countries (LMICs).
- IMPACT model projections indicate that global production for all agricultural commodities will increase by over 40 percent between 2020 and 2050, driven by innovation and productivity growth, but resource constraints and climate change pose challenges. As with demand, production is projected to grow fastest in LMICs.
- In the coming decades, food demand is projected to outpace production in most LMIC regions. As a result, most of these regions, with the exception of Latin America and the Caribbean (LAC), are expected to increase their reliance on imports.
- Increases in production and trade are expected to enhance food availability, but most LMIC regions are not on track to achieve Sustainable Development Goal 2.1 on ending hunger by 2030.
- Strengthening model integration and incorporating socioeconomic disaggregation will enhance IMPACT's ability to provide more comprehensive insights for decision-making to address these challenges.

RECENT TRENDS AND CHALLENGES

As global population and incomes continue to rise, demand for food, water, and other essential resources increases, placing significant pressure on agricultural systems and natural ecosystems. Rising temperatures, shifting precipitation patterns, and more frequent extreme weather events will also affect food production and global supply chains, with different magnitudes of effects across regions and latitudes. Making the food security picture even more complex, geopolitical dynamics, shifts in trade policies, and related government interventions will influence access to markets, input costs, and the stability of the food supply.

Given these complex and interconnected challenges and uncertainty, scenario analysis using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) provides a crucial tool for assessing the potential scale and severity of future food system challenges and opportunities to address them. IMPACT is a system of models in which water, land use, crop, and value chain models are all linked to a core partial equilibrium multimarket economic model of global production, trade, demand, and prices for agricultural commodities. The modeling system also integrates projections of future changes in technology (drawing on the expertise of CGIAR scientists and other experts around the world) as well as in climate, population, and gross domestic product (Robinson et al. 2015; Eyring et al. 2016; K.C. et al. 2024).

By simulating different futures under alternative socioeconomic, environmental, and policy conditions, the model helps researchers, policymakers, and stakeholders: identify vulnerabilities; evaluate adaptation strategies by weighing their synergies and trade-offs; and develop informed, evidence-based policies to enhance resilience and guide the sustainable transition of global food systems.

The results presented here (and in the other chapters in this volume) are based on IMPACT release v3.4 (Rosegrant et al. 2024). They show the model projections for agriculture demand, production, net trade, and food security under a business-as-usual scenario characterized by middle-of-the-road population and income growth (SSP2) taken from the Shared Socioeconomic Pathways (SSP) database (Riahi et al. 2017) and a radiative forcing coded in the Representative Concentration Pathway 7.0 (RCP 7.0) downscaled using the IPSL-CM6A-LR global circulation model from climate scenarios produced by the Coupled Model Intercomparison Project–Phase 6 (CMIP6) (Eyring et al. 2016).

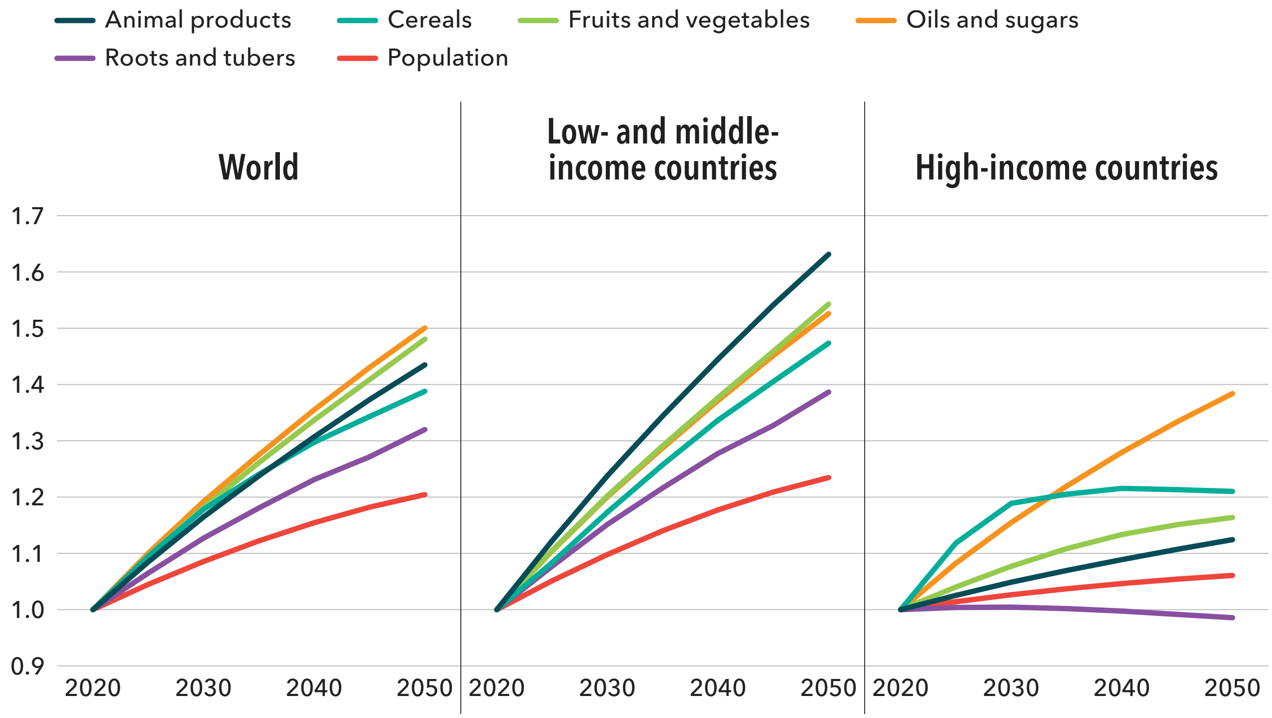
Baseline projections like these provide a starting point for analysis of the possible alternative policy and investment scenarios noted above and also underlie some of the findings in the other chapters of this volume. While we touch on growing demand, trade, nutrition, climate, and agricultural investments below, more details can be found in the corresponding chapters on animal-source foods, trade, diets and nutrition, and innovation. Similarly, dedicated chapters on LMIC regions add nuance and clarification to the regional results illustrated here.

LATEST FORESIGHT RESEARCH

Based on IMPACT projections, global demand for food commodities is expected to grow faster than population between 2020 and 2050, with a more rapid increase in LMICs compared to HICs (Figure 1). Incomes are projected to grow at about 3 percent per year, and — in accordance with Bennet's law — diets shift toward nutrient-dense foods, including more fruits and vegetables, processed foods, and animal-source foods. Cereals as a share of total average diet are projected to decrease by 4 percentage points globally by 2050, and by 5 percentage points across LMICs, due to slower demand growth. Demand for animal products is projected to grow by over 60 percent in LMIC regions,[1] a growth rate five times faster than in the rest of the world. Meat production is projected to double in East and Southern Africa (ESA), West and Central Africa (WCA), and South Asia (SA) by 2050; however, per capita consumption levels in LMICs will remain less than one-half of those in high-income countries (HICs). In HICs, demand for cereals is saturated by 2050, but not for oils and sugar, highlighting concerns about health impacts.

1 The names and acronyms used here for LMIC regions follow the CGIAR classification (https://www.cgiar.org/research/cgiar-regions/).

FIGURE 1 **Population growth and demand growth (by food group) between 2020 and 2050, world and aggregated LMICs and HICs**



Source: Extended results from Rosegrant et al. (2024).

Note: Indexed values, 2020 = 1. LMICs = low- and middle-income countries; HICs = high-income countries.

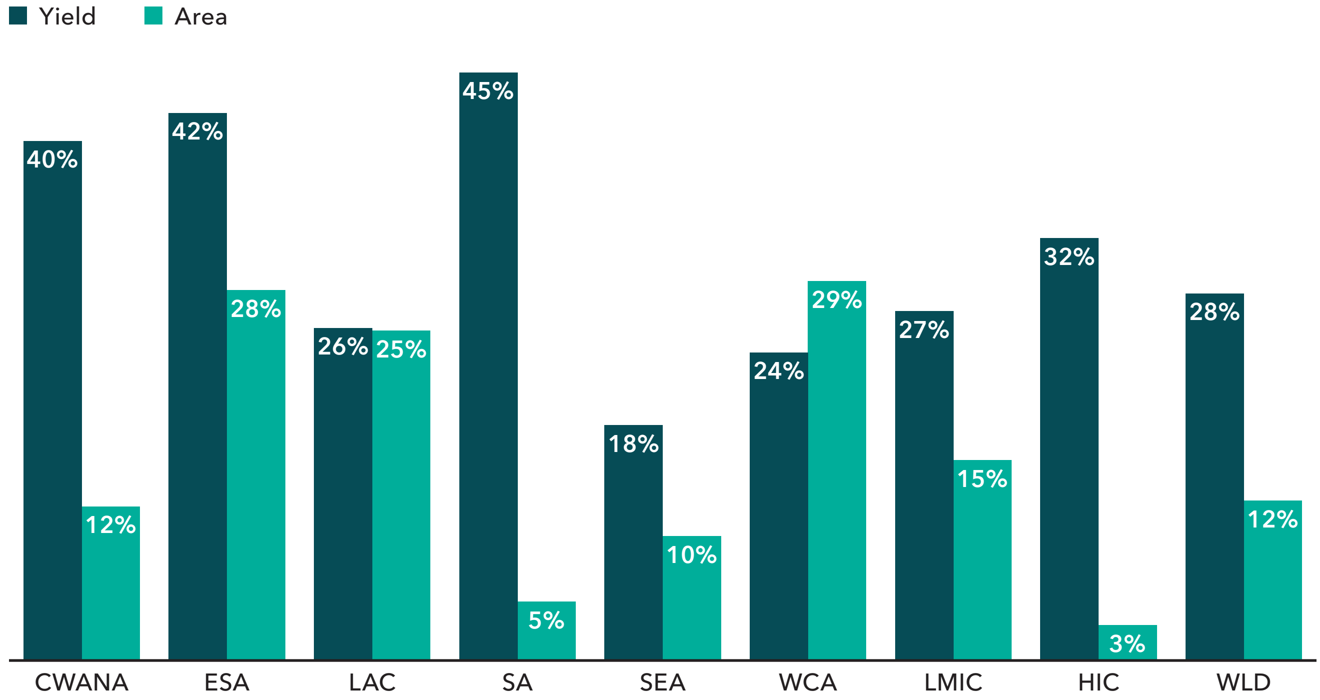
On average, demand for fruits and vegetables and oils and sugars will also grow by close to 50 percent, globally as well as across LMIC regions. In particular, the growing demand for processed foods is revealed by the increase in production of oil crops: by 2050, production is expected to grow by more than 80 percent in WCA and by 70 percent in Southeast Asia and the Pacific (SEA). Production of fruits and vegetables is projected to double in SA and ESA, while WCA and Central and West Asia and North Africa (CWANA) are projected to see increases of over 70 percent by 2050.

Baseline projections indicate that aggregate global food production will grow by about 44 percent over 2020 levels by 2050 to keep up with demand. Production and demand are projected to grow more rapidly in LMICs, particularly in Africa, than in HICs. By 2050, the baseline scenario shows crop production over 80 percent greater in ESA, 60 percent greater in WCA, and more than 50 percent higher in LAC and CWANA. In comparison, crop production in HICs is expected to grow by about 30 percent on average between 2020 and 2050.

In most regions, productivity growth is expected to be the primary driver of increased agricultural production, driven by investments in R&D, efficiency gains, and mechanization (Figure 2). However, when accounting for water constraints and the projected rise in weather variability and extreme events—particularly affecting crop production in equatorial regions (Heikonen et al. 2025) — the agriculture sector is expected to require an additional 170 million hectares of cropland globally to meet demand by 2050. Notably, 95 percent of this cropland expansion is projected to take place in LMICs, especially in ESA, LAC, and WCA.

Despite the increase in production, demand for food commodities is estimated to be larger and grow faster than production across LMIC regions. As a result, all regions except LAC will rely increasingly on imports, and LMICs as a group will be a net importer for all major food groups (Figure 3) (see additional details in the trade chapter). A greater volume of trade is essential to respond to geographic shifts in production and demand, while also adapting to the impacts of shifting weather patterns as well as demographic and income changes. Global trade

FIGURE 2 **Percentage change in yields and harvested area between 2020 and 2050, by world, LMIC region, and aggregated LMICs and HICs**



Source: Extended results from Rosegrant et al. (2024).

Note: CWANA = Central and West Asia and North Africa; ESA = East and Southern Africa; LAC = Latin America and the Caribbean; SA = South Asia; SEA = Southeast Asia; WCA = West and Central Africa; LMIC = low- and middle-income countries; HIC = high-income countries; WLD = world.

volumes are projected to more than double by 2050, but subject to considerable uncertainty, depending on changes in trade policies.

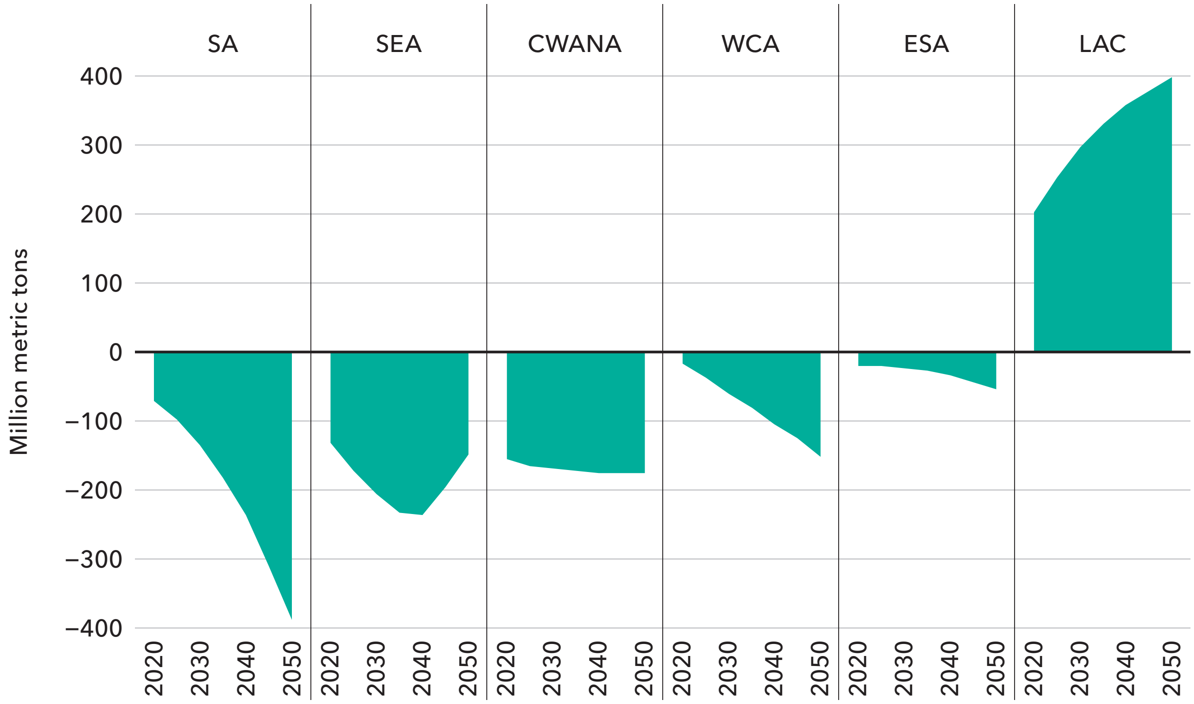
Larger trade volumes, along with greater production, are projected to increase food availability and raise the average per capita calorie availability across LMICs by 265 kilocalories (kcal) between 2020 and 2050, an increase of 10 percent. Globally, average dietary energy consumption is projected to increase by about 8 percent, to nearly 3,000 kcal per capita per day. As a result, the global population at risk of hunger is projected to decline by over 200 million (over 30 percent from 2020 levels). A decrease is projected across all regions except CWANA, with the largest improvements in SA, where over 130 million fewer people will be at risk by 2050 (Figure 4). The share of population at risk also declines for the group of LMICs, but not fast enough to reach the 5 percent threshold in 2030 and achieve SDG 2.1.

Despite progress, a business-as-usual trajectory under moderate climate change is projected to leave almost 450 million people at risk of hunger by 2050, with about one-half of that total equally distributed between ESA and SA. The challenge will be to find affordable and more efficient and equitable ways of increasing access to food worldwide.

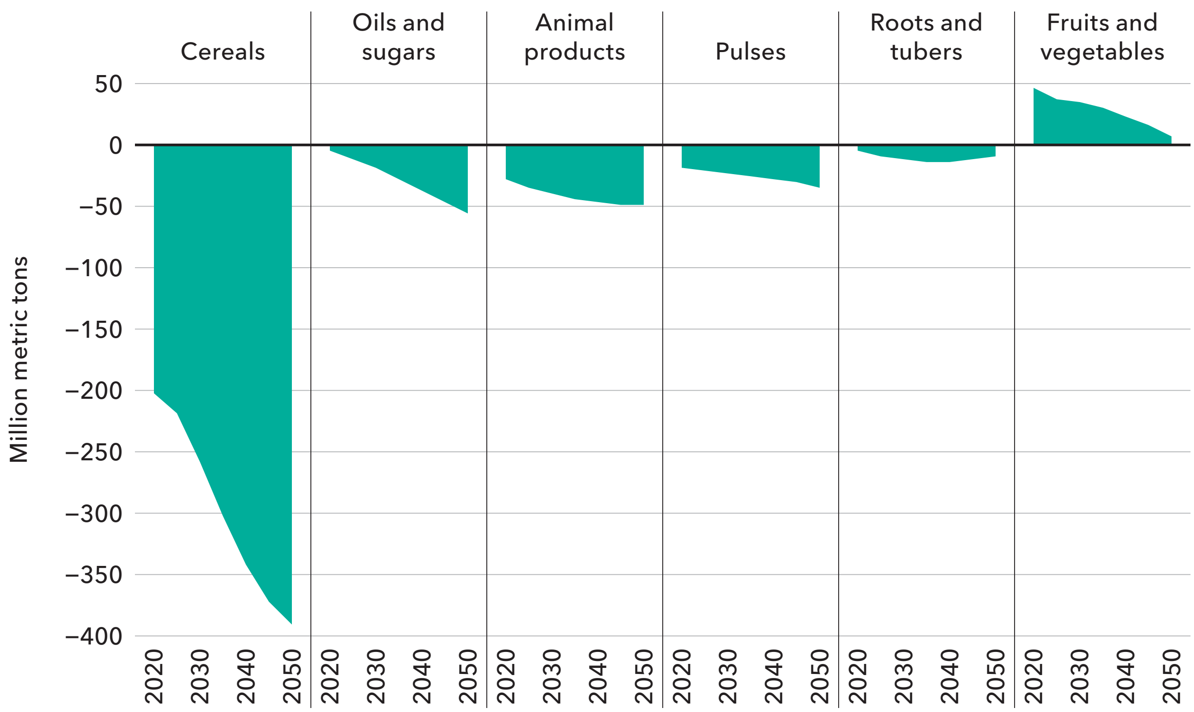
At the same time, improving the nutritional content of diets will be essential to counteract current trends in obesity as well as micronutrient deficiency (Costlow et al. 2025; Beal et al. 2017). While our projections suggest a decline in micronutrient deficiency, the availability of different nutrients is expected to be influenced by changing dietary preferences, fluctuating prices and incomes, and the rising concentrations of atmospheric carbon dioxide (Beach et al. 2019) (see the chapter on diets and nutrition). Healthier diets are also likely to be less “tradable,” as they require greater consumption of foods that may be more expensive, perishable, and harder to transport or store. Therefore, agricultural investments focused on boosting local productivity are going to be critical. Additional agricultural investments in infrastructure and R&D have the potential to speed up the progress (Sulser et al. 2021).

FIGURE 3 Net trade between 2020 and 2050

A Net trade - LMIC regions - all commodities

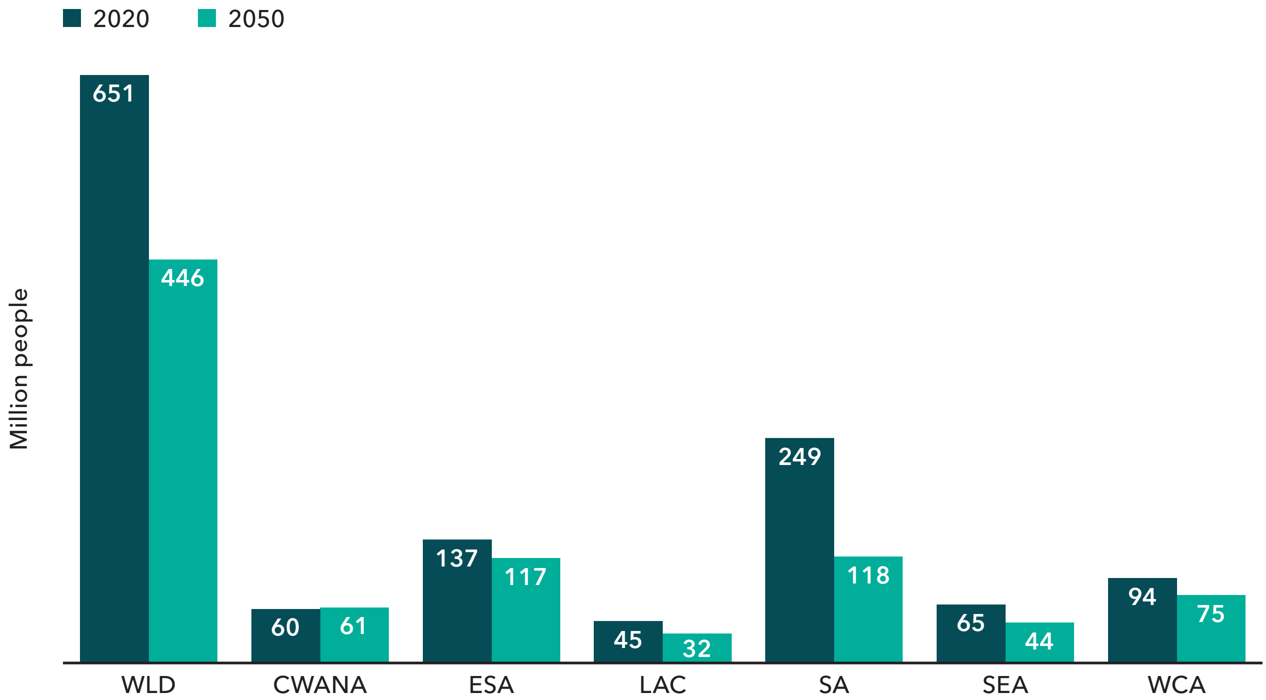


B Net trade - LMICs - by food group



Source: Extended results from Rosegrant et al. (2024).

FIGURE 4 Population at risk of hunger, by world and LMIC region, in 2020 and 2050



Source: Extended results from Rosegrant et al. (2024).

Note: WLD = world; CWANA = Central and West Asia and North Africa; ESA = East and Southern Africa; LAC = Latin America and the Caribbean; SA = South Asia; SEA = Southeast Asia; WCA = West and Central Africa.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

The IMPACT modeling system links climate, water, and crop models to support the integrated study of future changes in population, income, diets, technology, natural resources, and climate, allowing for in-depth analysis of a variety of critical issues of interest to policymakers. IMPACT has been adapted over time to augment its capacity to address different issues of interest, such as water, climate change, and biofuels, among others. We highlight here a few themes currently in focus for the modeling framework, though many other topics are under development. Links between IMPACT and the global dynamic computable general equilibrium (CGE) model (GLOBE) further enhance analyses by allowing researchers to explore how investments or shocks in the agriculture sector may influence broader economic outcomes at national and regional levels and how that feeds back on incomes, an important driver in IMPACT. The interlinkage between these two modeling frameworks (partial equilibrium and general equilibrium, respectively) can be increased in a number of ways. For example, labor markets and other factors of production (such as inputs like fertilizer) are heavily influenced by the broader economy, as modeled by GLOBE, and are crucial for agriculture sector dynamics, as modeled by IMPACT.

The rising demand for protein highlights the need for a deeper understanding of livestock and fish production, as well as an exploration of future demand dynamics. Direct climate effects on animal-source foods are relatively understudied compared to crops, and developing a globally consistent knowledge base for the effects of climate change on animal productivity is crucial. Advancing this area will require both enhancements to the IMPACT modeling framework and stronger linkages with other analytical approaches, particularly for assessing herd dynamics, economic implications, and nutritional outcomes under different management strategies.

The recent link with a novel land-use model has expanded IMPACT's capacity to evaluate how the global food system and shifting weather patterns influence the distribution of cropland and natural habitats. While this allows exploration of questions around agricultural expansion and encroachment on specific natural habitats, full feedback between the land use model and IMPACT is still under development.

Relatedly, increasing efforts are being directed toward disentangling the impacts of weather variability and extremes alongside long-term climate trends. Further work is envisioned to disaggregate results by income class, gender, and rural and urban populations, as well as to conduct more granular subnational analyses. These refinements will not only improve our ability to explore alternative futures but will also strengthen the evidence base for policymaking, fostering more informed dialogues about productive, sustainable, and resilient solutions.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

The authors of this chapter are **Nicola Cenacchi**, a Senior Research Analyst in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); **Timothy B. Sulser**, a Senior Scientist in the Foresight and Policy Modeling Unit at IFPRI; and **Abhijeet Mishra**, an Associate Research Fellow in the Foresight and Policy Modeling Unit at IFPRI.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Cenacchi, N., T.B. Sulser, and A. Mishra. "What Do We Know About the Future of Food Demand, Production, and Food Security, Based on IMPACT Model Projections?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 36. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: Sahana M S/Shutterstock

References

Beach, R.H., T.B. Sulser, A. Crimmins, et al. 2019. "Combining the Effects of Increased Atmospheric Carbon Dioxide on Protein, Iron, and Zinc Availability and Projected Climate Change on Global Diets: A Modelling Study." *Lancet Planetary Health* 3 (7): e307–e317. https://doi.org/10.1016/S2542-5196(19)30094-4

Beal, T., E. Massiot, J.E. Arsenault, M.R. Smith, and R.J. Hijmans. 2017. "Global Trends in Dietary Micronutrient Supplies and Estimated Prevalence of Inadequate Intakes." *PLoS ONE* 12 (4): e0175554. https://doi.org/10.1371/journal.pone.0175554

Costlow, L., A. Herforth, T.B. Sulser, N. Cenacchi, and W.A. Masters. 2025. "Global Analysis Reveals Persistent Shortfalls and Regional Differences in Availability of Foods Needed for Health." *Global Food Security* 44:100825. https://doi.org/10.1016/j.gfs.2024.100825

Eyring, V., S. Bony, G.A. Meehl, C.A. Senior, B. Stevens, R.J. Stouffer, and K.E. Taylor. 2016. "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization." *Geoscientific Model Development* 9 (5): 1937–1958. https://doi.org/10.5194/gmd-9-1937-2016

Heikonen, S., M. Heino, M. Jalava, S. Siebert, D. Viviroli, and M. Kummu. 2025. "Climate Change Threatens Crop Diversity at Low Latitudes." *Nature Food* 6: 331–342. https://doi.org/10.1038/s43016-025-01135-w

K.C., S., M. Dhaka, M. Potancokova, et al. 2024. "Updating the Shared Socioeconomic Pathways (SSPs) Global Population and Human Capital Projections." WP-24-003. IIASA Working Paper. International Institute for Applied Systems Analysis, Laxenburg, Austria. https://pure.iiasa.ac.at/id/eprint/19487/

Riahi, K., D.P. van Vuuren, E. Kriegler, et al. 2017. "The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview." *Global Environmental Change* 42:153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Robinson, S., D. Mason-D'Croz, S. Islam, T.B. Sulser, R.D. Robertson, T. Zhu, A. Gueneau, G. Pitois, and M.W. Rosegrant. 2015. "The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3." IFPRI Discussion Paper 1483. IFPRI, Washington, DC. https://hdl.handle.net/10568/150391

Rosegrant, M.W., T.B. Sulser, S. Dunston, A. Mishra, N. Cenacchi, Y. Gebretsadik, R. Robertson, T. Thomas, and K. Wiebe. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41:100755. https://doi.org/10.1016/j.gfs.2024.100755

Sulser, T.B., K. Wiebe, S. Dunston, et al. . 2021. *Climate Change and Hunger: Estimating Costs of Adaptation in the Agrifood System.* Food Policy Report. Washington DC. https://doi.org/10.2499/9780896294165

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

What do we know about THE FUTURE OF FORESIGHT MODELING RELATED TO FOOD SYSTEMS?

Keith Wiebe (IFPRI), Aline Mosnier (FABLE, SDSN), Daniel Mason-D'Croz (Cornell University), Athanasios Petsakos (Bioversity International), Johannes Svensson (BC3, IDDRI), and Monika Zurek (University of Oxford)

Key messages

- "Foresight modeling" is thinking about the future using a simplified representation of reality to inform choices we make today.
- Quantitative foresight modeling is increasingly used to inform decision-making related to food systems by analytically exploring alternative possible futures in a world that is becoming more complex and uncertain.
- Foresight modeling is improving in coverage and resolution, but various technical and institutional challenges remain.
- Artificial intelligence can help gather and synthesize information to improve foresight modeling, but it cannot replace the role of human expertise and foresight in testing assumptions and helping to shape the future.
- To be most effective, quantitative foresight modeling needs to be better linked with qualitative foresight approaches and complemented by engagement with decision-makers in an ongoing and systematic process.

RECENT TRENDS AND CHALLENGES

Food systems are inherently complex, involving biophysical and socioeconomic processes and interactions among the choices made by more than 8 billion people every day. It is impossible to measure and analyze all aspects of food systems, but it is possible to know quite a lot about some aspects and critical to understand their key features and how they are changing. As shown in this book, foresight modeling can help us do that.

Foresight modeling may sound like a mysterious and complicated process, but if you have ever asked a question starting with the words "What if…", you have used foresight. And if you have ever formed an opinion or drawn a conclusion based on incomplete information (which is what we all do, most of the time), you have used a model. Simply put, foresight is thinking about the future to inform choices we make today. And modeling is using a simplified representation of an object or a process to better understand it.

In this sense, we all use mental models implicitly, and all foresight involves modeling in some way. Farmers have used informal foresight models since the dawn of agriculture — including each time they make a decision about what, where, and when to plant a crop that will be harvested weeks or months later. Their models are based on past experience as well as assumptions about weather and market conditions in the future.

Foresight modeling can be simple or complex, subconscious or deliberate, implicit or explicit, and qualitative or quantitative, depending on the question at hand. Deciding whether to take an umbrella when you leave the house in the morning is a relatively simple foresight modeling exercise, based on looking out the window or at the weather forecast on your mobile phone. The weather forecast on your phone, on the other hand, is the result of very complex and sophisticated modeling. Similarly, the future of food systems involves the interaction of complex biological and physical processes (including weather) as well as social and economic processes (including the choices we make about what we eat and how we produce it). Understanding the future of food systems thus requires complex foresight modeling (Wiebe et al. 2018).

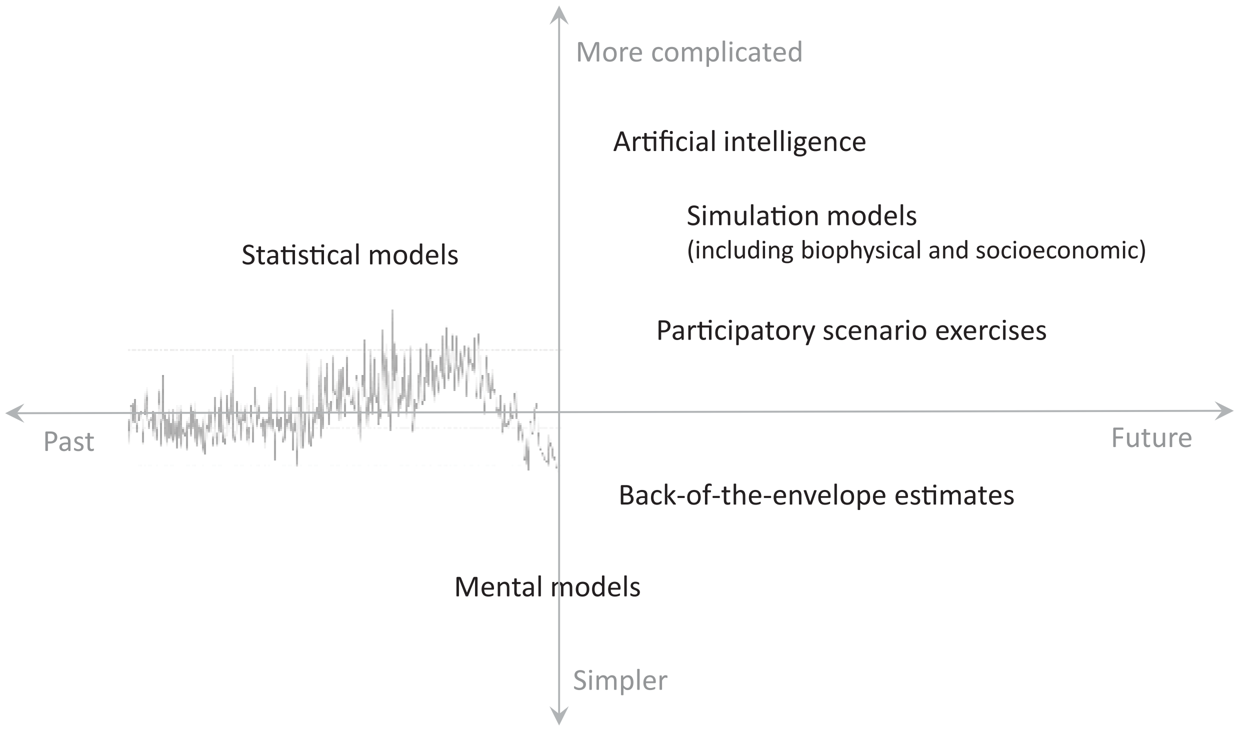
In recent years, food systems have become larger and more complicated in some ways (including the growing volume of production and complexity of global value chains), even while becoming simpler in other ways (including the increasing scale of production and focus on fewer major commodities in many areas). Over the same period, more formal foresight models have been developed to better understand food systems and how they may change in the future. These models vary in approach, complexity, and time horizon (Figure 1). Qualitative models may be based on structured dialogue with stakeholders about alternative future scenarios, usually resulting in a set of "storylines" about how various scenarios may unfold. Quantitative models include both statistical models that analyze historical data and simulation models that draw on historical patterns and explore how they might change in the future. These simulation models include specialized models, focused on specific biophysical and socioeconomic aspects of food systems, and are sometimes linked in integrated modeling frameworks. Foresight exercises often draw on both qualitative and quantitative models to bring together their complementary strengths.

Quantitative models are based on explicit assumptions about the model's components and how they interact with each other. This is sometimes seen as a weakness of these models, but it is actually their strength, because it makes those elements transparent and allows the assumptions to be tested — and changed if desired. (If someone does not make explicit assumptions about some things, it does not mean those things are not important. It just means that person has made *implicit* assumptions — for example, that those things do not change, or that they are not relevant. In fact, that person is using an implicit model, possibly without realizing it.)

These simplifying assumptions mean, as statistician George Box (1976) once wrote, that all models are "wrong" in that they do not capture reality completely or perfectly. (Box may have been writing about statistical models, but the same is true, by definition, for all models.) But as Box also noted, some models are still useful — specifically if they capture the features of an object or system that are essential for considering a particular question and omit features that are not relevant for that question.

No single model can capture all aspects of food systems, and indeed some aspects may not be captured by any model. But different models can be linked in various ways to capture multiple aspects of food systems. This chapter focuses primarily on economic simulation models linked

FIGURE 1 Foresight models include a wide variety of approaches and time horizons



Source: Authors' construction.

to other types of models that together capture some of the main features of food systems, including changes in population, income, technology, climate, land and water use, crop growth, diets, and health. By bringing together expertise about these different components of food systems, such modeling systems can help test assumptions and hypotheses about how food systems work, how they may change over time, and how the choices we make today can help direct those changes toward desirable outcomes in the future.

LATEST FORSIGHT RESEARCH

The past several decades have seen rapid growth in the development and use of biophysical and socioeconomic models to analyze various aspects of food systems. Many of these modeling systems have been further refined over the past decade through collaboration initiated as part of the Agricultural Model Intercomparison and Improvement Project (AgMIP). Among the global economic models involved in this collaboration are the AIM model developed by the National Institute for Environmental Studies (Japan), the CAPRI model developed by the Joint Research Centre of the European Commission, the ENVISAGE model developed originally at the World Bank, the GLOBIOM model developed by the International Institute for Applied Systems Analysis (IIASA), the IMPACT model developed by the International Food Policy Research Institute (IFPRI), the MAGNET model developed by Wageningen University & Research, and the MAgPIE model developed by the Potsdam Institute for Climate Impact Research. Other models used to analyze aspects of food systems include the EPPA model developed by the Massachusetts Institute of Technology and the GTAP model developed by Purdue University.

While these modeling systems share a general aim in exploring how food systems are changing, they also differ in important ways, depending on the specific purpose for which they were designed. Some focus on agriculture and food, while others incorporate other sectors of the economy. Some focus on global and regional scales, while others offer more detail at the national or even subnational level. Some offer greater detail on commodity production, trade, and diets, while others provide deeper analysis of land, water, energy, employment, income, or other indicators.

These models typically incorporate possible future changes in population, climate, and other factors as inputs from other modeling efforts, which enter these economic modeling systems as assumptions. These assumptions help define scenarios that may also reflect broader storylines about alternative possible futures (for example, a future characterized by slower population growth, increased investment in sustainable technologies, or more fragmented trade relations). These assumptions are then tested and their impacts compared in the context of dynamic economic relationships among production, trade, and consumption of different food and other commodities in different regions and over time.

While research in this area has expanded rapidly over the past decade, a few examples illustrate how these modeling systems can be used to explore key features of food systems. Using 10 global economic models, Valin et al. (2014) found that socioeconomic factors will have a bigger effect on global food demand than climate change in 2050. Nelson et al. (2014) analyzed results from 9 global economic models, 2 climate models, and 5 crop models to examine impacts of climate change on crop yields, area, production, prices, trade, and consumption. Wiebe et al. (2015) conducted a similar study with additional scenarios, finding that yield impacts increase at high emissions levels and vary with changes in population, income, and technology, but are reduced in all cases by endogenous changes in prices and other variables.

Further exploring interactions within food systems, Hasegawa et al. (2018) examined trade-offs among different policy goals, finding that climate mitigation policies need to be carefully implemented to avoid adversely affecting global hunger, particularly in sub-Saharan Africa and South Asia. Van Zeist et al. (2020) compared projections of future yields from five global economic models, finding that significant potential for further yield growth remains even in 2050 in some regions, particularly sub-Saharan Africa. Van Dijk et al. (2021) analyzed 57 studies projecting future global food demand and risk of hunger and found that most projected an increase in demand of 45–56 percent between 2010 and 2050. Rosegrant et al. (2024) used the IMPACT model to analyze how climate change will affect food security in different regions in 2035 and 2050 under multiple socioeconomic and climate scenarios. Most recently, 10 global economic models, as well as multiple input–output and optimization models, have been used to explore the impacts of dietary change on planetary boundaries and other food systems metrics, including livelihoods and incomes — and how policies and investments can help shape those outcomes — as part of the EAT-Lancet 2.0 Commission report (Rockström et al. forthcoming) and related background studies.

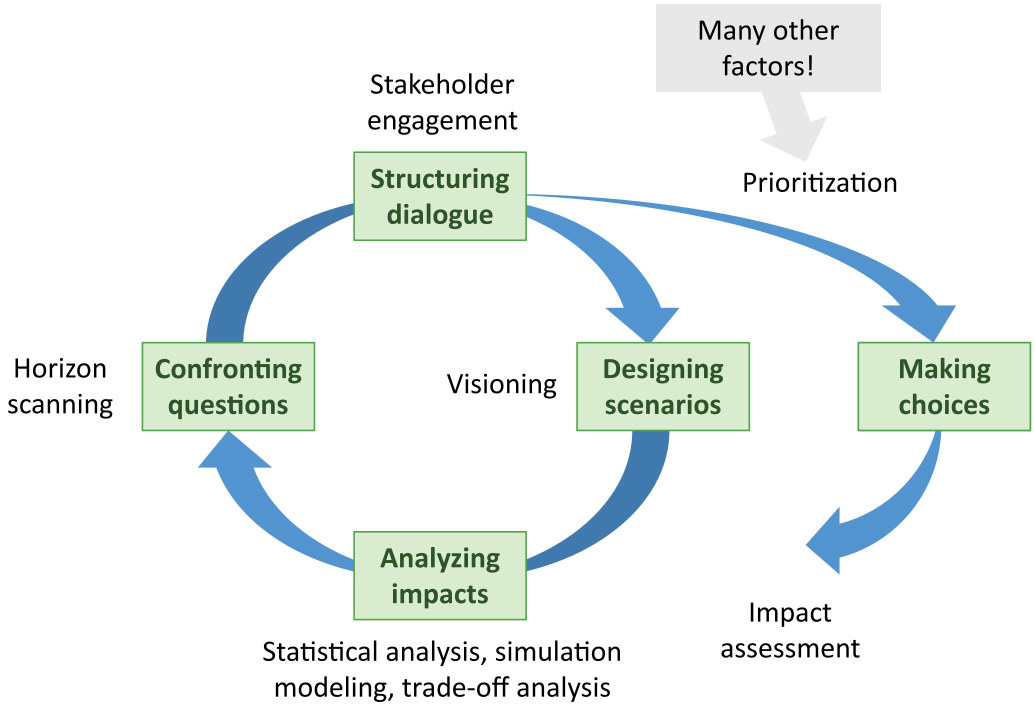
Foresight modeling studies like these have been used to inform policy and investment decisions by national governments, aid agencies, multilateral development banks, and private foundations, as well as intergovernmental processes like the Intergovernmental Panel on Climate Change. In addition to the global and regional models and studies noted above, country-level models such as IFPRI's RIAPA model are playing an increasingly important role in informing national governments (particularly in low- and middle-income countries) about impacts and policy options related to short- and medium-term shocks such as COVID-19 (Pauw et al. 2021) and the Russia-Ukraine conflict (Arndt et al. 2022). Many of these models include details at subnational levels, but they are most often used to explore interactions and challenges at larger scales.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Foresight models have evolved from an initial focus on commodities and production to capture more food systems features related to livelihoods, incomes, diets, health, natural resource use, the environment, and climate. Further attention to socioeconomic differences in access to resources and opportunities, biophysical differences in resource conditions, and spatial differences in both of these dimensions can help better target both the results provided by foresight modeling and the policy and investment choices made by decision-makers.

Different models are needed to address different questions, but end-users may find it difficult to make an informed choice about which models to use. Moreover, it can be challenging to find a model that can provide results for countries with small economies or territories (Mosnier et al. 2023). The FABLE Consortium, the Deep Decarbonization Pathways initiative, and the Foresight4Food (F4F) initiative are now developing a simple, collaboratively produced, and publicly accessible tool to help end-users identify the models that are

FIGURE 2 **Foresight modeling is part of a larger process to inform decision-making**



Source: Adapted by the authors from Wiebe et al. (2018)

best suited for their purposes. Three criteria guide this selection. First, can the model represent the actions the users want to test and the outcomes they want to observe before and after the implementation of these actions? Second, can the model produce results at the geographic scale required? And third, what is needed to access the model and how easy is it to adapt it? The tool is built upon a detailed database that includes different types of simulation models (not only economic models) that are relevant for food systems foresight. The database is currently being expanded by including more models, by capturing recent developments of models already included, and by adding more criteria to improve the tool's capacity to guide the choice of models.

Looking beyond existing models, artificial intelligence (AI) offers considerable potential but also risks in relation to foresight modeling of food systems. In planning for the future, as in understanding the past, we want to be informed by the best available evidence. Collecting data has historically been a challenge, but today we live in a world saturated by data, to the point that processing and interpreting that data is as much of a challenge as gathering it. While quantitative foresight models offer a tool to process such complex information, this complexity can also make these models difficult to use. AI approaches increase our capacity to collect and synthesize information from a wide spectrum of sources, which could help improve the representation of complex systems in quantitative foresight models, increase the speed at which these models can be updated and validated, identify previously overlooked relationships, and inform the development of a broader range of relevant scenarios. Machine-reading and learning approaches, for example, can speed up the process of reviewing previous research to find key coefficients and relationships to parameterize model behavior (Brandtner and Mates 2021; Ködding et al. 2023). AI approaches could also help summarize and simplify the results of quantitative foresight models, making it easier to communicate them to a broader audience, including decision-makers and other stakeholders.

Despite these opportunities to improve foresight modeling, AI approaches are unlikely to replace human expertise entirely. First, the systems we are interested in are complex and ultimately chaotic, and increased data will not be able to fully eradicate uncertainty (Geurts et al. 2022; van der Sluijs 2005). If not applied carefully, AI can contribute to overconfidence in our knowledge of complex systems, increasing the risk of unintended consequences (Mason-D'Croz et al. under review; Suckling et al. 2021; De Zwart 2015). Second, AI applications are not perfect, and as they are often black boxes, they can introduce errors and biases in opaque ways (Chen 2023; Vicente and Matute 2023). As a result, human expertise will be critical in responsible AI use to assess the quality of data used by AI as well as the design of AI applications. And finally, while AI may help improve our ability to understand past trends and forecast future ones, ultimately foresight goes beyond trying to predict the future; it is about helping shape and define the future. Defining the future is not just about preparing for what will come, but also deciding which futures we want to achieve or avoid. That requires answering fundamental questions about what we care about most, which AI cannot do for us.

While foresight modeling tools continue to be improved, experience has shown that they are most useful as part of an iterative process that also includes qualitative foresight approaches to engage with decision-makers and other stakeholders, while recognizing that results from foresight exercises are themselves part of a larger set of factors that influence decision-making (Figure 2). This linkage improves effectiveness in multiple ways, including before and during the modeling stage by informing the framing of the scenarios and the modeling assumptions, and afterward by ensuring that the results are accessible and useful for decision-makers.

As noted at the beginning of this chapter, we all use models implicitly, whether we realize it or not. But understanding food systems and exploring options to improve them in the future requires more formal foresight modeling. The goal is not for everyone to become quantitative foresight modelers, and certainly not for all decisions to be made by such models. It is important, however, to help decision-makers *think* more like modelers — that is, to identify the key features of food systems that are important for particular decision-making contexts, to be explicit about the assumptions that are made about those features in a complex and uncertain world, and to be willing to test — and if necessary, change — those assumptions to better understand the likely future impacts of choices we make today.

This chapter was supported by the CGIAR Research Initiative on Foresight and the CGIAR Science Program on Policy Innovations. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

This chapter was developed jointly with the Foresight4Food Initiative, which is hosted by the Food Systems Transformation Group of the Environmental Change Institute at the University of Oxford.

The authors of this chapter are **Keith Wiebe**, a Senior Research Fellow in the Foresight and Policy Modeling Unit at the International Food Policy Research Institute (IFPRI); **Aline Mosnier**, Scientific Director of the Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Pathways Consortium and the Sustainable Development Solutions Network (SDSN); **Daniel Mason-D'Croz**, a Senior Research Associate in the Department of Global Development at Cornell University and a PhD Candidate with the Agricultural Economics and Rural Policy Group at Wageningen University & Research; **Athanasios Petsakos**, a Scientist in the Performance, Innovation and Strategic Analysis for Impact Program at Bioversity International; **Johannes Svensson**, a Technical Manager of Research on Terrestrial Ecosystems and the Governance of Land Use Transitions at the Basque Center for Climate Change (BC3), and an associated researcher at the Institut du Développement Durable et des Relations Internationales (IDDRI); and **Monika Zurek**, a titular Associate Professor and Lead of the Food System Transformation Group at the Environmental Change Institute at the University of Oxford.

Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

Citation: Wiebe, K., A. Mosnier, D. Mason-D'Croz, A. Petsakos, J. Svensson, and M. Zurek. 2025. "What Do We Know About the Future of Foresight Modeling Related to Food Systems?" In *What Do We Know About the Future of Food Systems?*, eds. K. Wiebe and E. Gotor, Chapter 37. Washington, DC: IFPRI. https://hdl.handle.net/10568/175019

Photo credit: ABCDstock/Shutterstock

References

Arndt, C., X. Diao, P. Dorosh, K. Pauw, and J. Thurlow. 2022. *Russia-Ukraine War and the Global Crisis: Impacts on Poverty and Food Security in Developing Countries*. Global Crisis Country Brief 20. Washington, DC: IFPRI. https://doi.org/10.2499/p15738coll2.136382

Box, G.E.P. 1976. "Science and Statistics." *Journal of the American Statistical Association* 71 (356): 791–799. https://doi.org/10.1080/01621459.1976.10480949

Brandtner, P., and M. Mates. 2021. "Artificial Intelligence in Strategic Foresight: Current Practices and Future Application Potentials." Paper presented at the *Proceedings of the 2021 12th International Conference on E-business, Management and Economics*, Beijing, China, July 17–19. https://doi.org/10.1145/3481127.3481177

Chen, Z. 2023. "Ethics and Discrimination in Artificial Intelligence-Enabled Recruitment Practices." *Humanities and Social Sciences Communications* 10: 567. https://doi.org/10.1057/s41599-023-02079-x

De Zwart, F. 2015. "Unintended But Not Unanticipated Consequences." *Theory and Society* 44: 283–297. https://doi.org/10.1007/s11186-015-9247-6

Geurts, A., R. Gutknecht, P. Warnke, A. Goetheer, E. Schirrmeister, B. Bakker, and S. Meissner. 2022. "New Perspectives for Data-Supported Foresight: The Hybrid AI-Expert Approach." *Futures & Foresight Science* 4 (1): e99. https://doi.org/10.1002/ffo2.99

Hasegawa, T., S. Fujimori, P. Havlík, et al. 2018. "Risk of Increased Food Insecurity Under Stringent Global Climate Change Mitigation Policy." *Nature Climate Change* 8: 699–703. https://doi.org/10.1038/s41558-018-0230-x

Ködding, P., C. Koldewey, and R. Dumitrescu. 2023. "Scenario-Based Foresight in the Age of Digital Technologies and AI." In *New Digital Work: Digital Sovereignty at the Workplace*, eds. A. Shajek and E.A. Hartmann, 51–67. https://doi.org/10.1007/978-3-031-26490-0_4

Mason-D'Croz, D., C. Kugler, R. Remans, et al. Under review. "Upping the 'Ante': Rigorous Anticipatory Governance Needed for Responsible Food System Transformation." *Nature Food*.

Mosnier, A., V. Javalera-Rincon, S.K. Jones, et al. 2023. "A Decentralized Approach to Model National and Global Food and Land Use Systems." *Environmental Research Letters* 18: 045001. https://doi.org/10.1088/1748-9326/acc044

Nelson, G.C., H. Valin, R.D. Sands, et al. 2014. "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks." *PNAS* 111 (9): 3274–3279. https://doi.org/10.1073/pnas.1222465110

Pauw, K., J. Smart, and J. Thurlow. 2021. "The Short-Run Economic Costs of COVID-19 in Developing Countries in 2020: A Synthesis of Results from a Multi-Country Modeling Exercise." IFPRI Project Note June 2021. Washington, DC: IFPRI. https://doi.org/10.2499/p15738coll2.134430

Rockström, J., et al. Forthcoming. "EAT-Lancet Commission on Healthy, Sustainable, and Just Food Systems." *Lancet*.

Rosegrant, M.W., T.B. Sulser, S. Dunston, et al. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." *Global Food Security* 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Suckling, J., C. Hoolohan, I. Soutar, and A. Druckman. 2021. "Unintended Consequences: Unknowable and Unavoidable, or Knowable and Unforgivable?" *Frontiers in Climate* 3: 737929. https://doi.org/10.3389/fclim.2021.737929

Valin, H., R.D. Sands, D. van der Mensbrugghe, et al. 2014. "The Future of Food Demand: Understanding Differences in Global Economic Models." *Agricultural Economics* 45 (1): 51–67. https://doi.org/10.1111/agec.12089

van der Sluijs, J.P. 2005. "Uncertainty as a Monster in the Science–Policy Interface: Four Coping Strategies." *Water Science and Technology* 52 (6): 87–92. https://doi.org/10.2166/wst.2005.0155

van Dijk, M., T. Morley, M.L. Rau, and Y. Saghai. 2021. "A Meta-Analysis of Projected Global Food Demand and Population at Risk of Hunger for the Period 2010–2050." *Nature Food* 2 (7): 494–501. https://doi.org/10.1038/s43016-021-00322-9

van Zeist, W.-J., E. Stehfest, J.C. Doelman, et al. 2020. "Are Scenario Projections Overly Optimistic about Future Yield Progress?" *Global Environmental Change* 64: 102120. https://doi.org/10.1016/j.gloenvcha.2020.102120

Vicente, L., and H. Matute. 2023. "Humans Inherit Artificial Intelligence Biases." *Scientific Reports* 13: 15737. https://doi.org/10.1038/s41598-023-42384-8

Wiebe, K., H. Lotze-Campen, R. Sands, et al. 2015. "Climate Change Impacts on Agriculture in 2050 under a Range of Plausible Socioeconomic and Emissions Scenarios." *Environmental Research Letters* 10: 085010. https://doi.org/10.1088/1748-9326/10/8/085010

Wiebe, K., M. Zurek, S. Lord, et al. 2018. "Scenario Development and Foresight Analysis: Exploring Options to Inform Choices." *Annual Review of Environment and Resources* 43: 545–570. https://doi.org/10.1146/annurev-environ-102017-030109

Hyperlinks to models mentioned in the text (all links accessed June 2025):

AIM: https://www-iam.nies.go.jp/aim/

CAPRI: https://www.capri-model.org/

ENVISAGE: https://www.gtap.agecon.purdue.edu/models/envisage.aspx

EPPA: https://globalchange.mit.edu/research/research-tools/eppa

GLOBIOM: https://iiasa.ac.at/models-tools-data/globiom

GTAP: https://www.gtap.agecon.purdue.edu/models/current.asp

IMPACT: https://www.ifpri.org/project/ifpri-impact-model/

MAGNET: https://www.magnet-model.eu/

MAgPIE: https://www.pik-potsdam.de/en/institute/departments/activities/land-use-modelling/magpie

RIAPA: https://www.ifpri.org/project/riapa-model/

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

A world free of hunger and malnutrition

IFPRI is a CGIAR Research Center

1201 Eye St, NW, Washington, DC 20005 USA | T. +1-202-862-5600 | F. +1-202-862-5606 | Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

Handle: https://hdl.handle.net/10568/175019

INTERNATIONAL
FOOD POLICY
RESEARCH
INSTITUTE

IFPRI

IFPRI is a CGIAR Research Center

1201 Eye Street, NW
Washington, DC 20005 USA

T. +1-202-862-5600
F. +1-202-862-5606
Email: ifpri@cgiar.org

www.ifpri.org | www.ifpri.info