



ENDING HUNGER IN ASIA AND THE PACIFIC BY 2030

AN ASSESSMENT OF INVESTMENT
REQUIREMENTS IN AGRICULTURE

OCTOBER 2019



INTERNATIONAL
FOOD POLICY
RESEARCH
INSTITUTE



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On the cover: A woman farmer harvesting rice crops from the field in Bhutan (photo by Eric Sales/ADB).

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Foreword

Despite economic progress achieved in the past decades, hunger still exists. The number of people experiencing hunger has increased all over the world—from 804 million in 2016 to 821 million in 2017. During the same period, the incidence of hunger in Asia and the Pacific has increased by 1 million. Global food production is facing formidable challenges, threatening the attainment of the global Sustainable Development Goal (SDG) of ending hunger and malnutrition by 2030 (SDG 2). The agricultural systems in the developing member countries (DMCs) of the Asian Development Bank (ADB) are already under stress due to changes in rainfall patterns, shortages of irrigation water, extreme weather events, global warming exceeding the survival threshold of traditional crops, and loss of agricultural land to other uses. Increasing investments in agriculture are required not only to protect but increase the current level of production to feed the growing population in DMCs. At this juncture, it is important to know how much and where within the agriculture sector we should invest to achieve food security.

Against this background, ADB in partnership with the International Food Policy Research Institute (IFPRI) conducted a study to quantify the investment needs and identify the priority areas within the agriculture sector using a holistic approach. This report presents the analysis and recommendations of the study to end hunger and malnutrition in DMCs by 2030. These recommendations are formulated based on a review of recent trends in food security, gross domestic product, population growth, agricultural supply, demand, and trade in the region, as well as quantitative assessments of potential impacts of various climate change and investment scenarios.

The recommendations presented in this report aim to guide the upscaling of investment in priority areas in DMCs to eliminate hunger and malnutrition. They will also help clarify the most effective investments in agri-logistics and infrastructure to strengthen agricultural supply chains. By identifying the amount of annual agricultural investment required to achieve SDG 2 in DMCs, this report aims to provide a basis to forge partnerships among stakeholders to mobilize this investment.

This report is the output of a close collaboration between ADB and IFPRI. It melds ADB's knowledge and experience in agriculture and the natural resources sector with IFPRI's globally recognized expertise in agriculture and food policy and investment analysis. This report is aligned with ADB's Strategy 2030, adopted with the aim of making Asia and the Pacific food-secure, prosperous, inclusive, and sustainable. This publication also responds to ADB's operational priority of promoting rural development and food security.

We are confident that this report will become a key resource for policymakers of developing member countries of ADB in undertaking evidence-based actions to promote sustainable agriculture.



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Abbreviations

ADB	Asian Development Bank
ANR	agriculture and natural resources sector
CGE	computable general equilibrium
CGIAR	Consultative Group for International Agricultural Research
COMP	a comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios
COMP2	a comprehensive investment scenario that combines the Hi+NARS+EFF, IRREXP-WUE, and RMM/PHL scenarios
DMC	developing member country
ha	hectare
GDP	gross domestic product
FAO	Food and Agriculture Organization of the United Nations
HadGEM	Hadley Centre Global Environmental Model (scenario)
Hi-IARCs	increased investment in IARCs
Hi+NARS	intensified NARS research
Hi+NARS+EFF	investment in advanced technologies for higher research efficiency to Hi+NARS
IARC	international agricultural research center
ICT	information and communication technology
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IRREXP	investment in irrigation expansion and development
IRREXP-WUE	irrigation investment scenario involving 10% expansion in irrigated area with systems modernization and water-use efficiency improvements
km ³	cubic kilometers
mt	metric ton
NARS	national agricultural research system
NoCC	no climate change (scenario)
OECD	Organisation for Economic Co-operation and Development
PCC	Panel on Climate Change
PHL	postharvest loss
PPP	purchasing power parity
PRC	People's Republic of China
R&D	research and development
RMM	increased infrastructure investment that reduces marketing margins, jointly with PHL
SP2	Shared Socioeconomic Pathway 2
WUE	water-use efficiency

Executive Summary

This study reviews recent trends in food security; gross domestic product (GDP); population growth; and agricultural supply, demand, and trade in Asia and the Pacific. It then applies quantitative modeling to assess the projected impacts of climate change and alternative agricultural investments on agricultural area, yield, and production; food prices, demand and trade; household income; and key food and nutrition security indicators in Asia and the Pacific to 2030.

The International Model for Policy Analysis of Agricultural Commodities and Trade of the International Food Policy Research Institute is used to explore alternative scenarios, impacts, and policy and investment responses at global, regional, and country scales. The International Model for Policy Analysis of Agricultural Commodities and Trade modeling system also analyzes the socioeconomic and climate pathways with different assumptions about policy, agricultural research and development (R&D), and investments to understand the possible impacts on food security and other agricultural outcomes and assess the investment costs required for climate change adaptation and reducing hunger. Three types of investments are analyzed, including investment in agricultural R&D, investment in irrigation infrastructure, water use efficiency (WUE), and investment in rural infrastructure.

The population in developing member countries (DMCs) of the Asian Development Bank (ADB) in Asia and the Pacific is projected to reach 4.3 billion in 2030 with a total GDP of purchasing power parity (PPP) \$61 trillion, for a per capita GDP of PPP \$14,000 per capita, more than double the per capita GDP in 2015. Population is projected to rise by 9% from 2015 to 2030, with South Asia accounting for two-thirds of the population increase. For the ADB DMCs excluding the People's Republic of China, population is projected to increase by 16% between 2015 and 2030 and GDP per capita is projected to increase by 73%. Rapid urbanization is projected to continue, with the proportion of the population in urban areas increasing from 48% to 55% from 2014 to 2030. The combination of income growth and urbanization will not only increase food demand but will induce diversification of demand and production away from cereals, roots tubers into meat, oils, and fruits and vegetables. Cereal production in Asia and the Pacific is projected to increase by 11%, meat production by 26%, production of fruits and vegetables by 28%, oilseeds by 44%, pulses by 16%, and roots and tubers by 8% from 2015 to 2030.

Although the negative effects of climate change on agriculture will become much higher after 2030, detrimental impacts are already being experienced. In future, the climate shock will reduce yields and production more significantly, which will then induce price increases that will partially offset fall in production as farmers respond to higher prices and reduce GDP as well. Food consumption by the poor will fall due to higher prices. In this climate change scenario, the number of hungry people in Asia and the Pacific in 2030 will be 38 million people more than in a no climate change scenario. Under the climate change scenario, the number of undernourished people will decline from 507 million in 2015 to 362 million in 2030, and the number of malnourished children from 93 million to 76 million, showing very slow progress.

Increased investment in agricultural R&D, irrigation, and rural infrastructure are projected to achieve success in reducing hunger. Increased investment in agricultural R&D, including investment in advanced breeding technologies, achieves major reductions in hunger and child malnutrition in Asia and the Pacific. Working through productivity, price, and income effects, this scenario improves food consumption and reduces the number of hungry people by an additional 84 million in 2030 compared to the climate change scenario. This projected large reduction achieves a near-halving of hunger from 2015 to 2030. In addition, these investments generate economy-wide economic benefits. Because Asia and the Pacific has such a large agricultural sector within the global economy, these increases in production result in a projected decline in world prices of 7% for crops and 6% for meats compared to the climate change reference scenario. Economy-wide impacts also increase total GDP by 1.3%. While this may seem small, it amounts to PPP \$725 billion annually based on the 2015 GDP in Asia and the Pacific, far higher than the investments that generate this income.

Increased investment in expanding irrigated area and in improving, and modernizing irrigation systems to enhance WUE has substantial, but smaller, impacts on hunger compared to the agricultural R&D scenario. Irrigation affects only crops, and a more limited area of crops than agricultural R&D, which also applies to livestock. The biggest impact of increased irrigation investment is to increase area harvested, but it also boosts crop yields. Under this scenario, the number of hungry people is projected to decline by 28 million compared to the 2030 climate scenario. This scenario also has the significant benefit of reducing agricultural water use by a projected 7%.

Investments in rural infrastructure targeting value chain effectiveness have powerful impacts, generating both lower marketing margins and reduced PHL. By simultaneously increasing prices for producers and cutting costs to consumers, and reducing food losses in the value chain, this scenario generates substantial reductions in hunger in Asia and the Pacific. Reduced marketing margins result in a projected drop in the number of hungry people of 16 million in 2030 relative to the reference scenario, while reductions in PHL are projected to have larger impacts, cutting the number of hungry people by 67 million compared to the reference scenario, driven by reduced commodity prices and the resulting higher food consumption.

Increased investments in agricultural productivity growth, irrigation and WUE, and rural infrastructure are highly effective in improving agricultural production, reducing prices, and raising incomes. The result is large reductions in hunger, and somewhat smaller reductions in child malnutrition. Agricultural R&D and rural infrastructure have particularly large impacts on reducing hunger. Combining these investments in a more comprehensive scenario can effectively end hunger in DMCs of ADB. The total annual investments in agricultural R&D, irrigation expansion, improvement of WUE, and reduction of PHL and marketing margins in these countries in the reference scenario are \$41.7 billion, and the additional investments under the comprehensive scenario required are \$36.9 billion to reduce the number of food insecure people in DMCs below the 5% of total population threshold indicated by the Food and Agriculture Organization, International Fund for Agricultural Development, and World Food Programme (2015) for eliminating hunger by 2030. Moving Central and West Asia and Southeast Asia below the hunger threshold by 2030 and further improving the overall results, will require policies that must reach out directly to the poor by supporting investments in human capital. Investments in health, nutrition, clean water and sanitation, and education are crucial and essential to address hunger and childhood malnutrition. Moreover, even with rapid economic growth in Asia and the Pacific, some of the poor will be reached slowly, if at all, and many of them will remain vulnerable to economic reversals. These groups can be reached through income transfers, or through safety nets that will alleviate their nutritional needs and socioeconomic conditions during short-term shocks.

Chapter 1

INTRODUCTION

Geographic location, rising population, unequal income distribution, evolving institutions, and inadequate or poor policies compounded by changes in climate conditions are some major threats to food security affecting developing countries. Despite huge progress in recent decades in much of the Asia and the Pacific, an estimated 490 million people still experience hunger and are undernourished in 2017, over half of the estimated 821 million undernourished people in the same year.¹

The agriculture sector serves a variety of functions. Agricultural development can deliver numerous economic, social, and environmental co-benefits. However, perhaps the most fundamental purpose of the agriculture sector is to ensure food security. The eradication of hunger should also be a primary aim of climate action in the agriculture sector, and thus a primary target toward which countries and the international community should work. Reports from the Asian Development Bank (ADB) midterm review of the long-term strategic framework and Operational Plan for Agriculture and Natural Resources, 2015–2020 focused on investigating the importance of the agriculture and natural resources sector (ANR) as a key driver of inclusive growth and promotion of food security in Asia and the Pacific. Given the importance of this sector, there is a need to assess the investments required in ANR to achieve food security in the region. The need for investments also varies across agriculture subsectors within a country. Against this backdrop, ADB is conducting an analysis of the total investment required in the agriculture sector to achieve food security in Asia and the Pacific by 2030.

In relation to ADB's technical assistance umbrella project on Investment Assessment and Application of High-Level Technology for Food Security in Asia and Pacific, the International Food Policy Research Institute (IFPRI) completed a research study on Investment Requirements to Achieve Food Security in Asia and the Pacific by 2030 with direction and guidance from the Sustainable Development and Climate Change Department, ADB. This regional research study, carried out over 2 years, includes country case studies in the People's Republic of China (PRC) and Indonesia.

¹ Food and Agriculture Organization of the United Nations (FAO). 2018. *State of Food and Agriculture in Asia and the Pacific Region, including Future Prospects and Emerging Issues*. Paper prepared for the 34th Session of the FAO Regional Conference for Asia and the Pacific. Nadi, Fiji. 9–13 April. <http://www.fao.org/3/mw252en/mw252en.pdf>; FAO et al. 2018. *The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition*. Rome: FAO. <http://www.fao.org/3/I9553EN/I9553en.pdf>.

1.2. Objectives

This research study conducted an analysis to (i) estimate the total investments required in the ANR sector in ADB regions by taking into account the changing climate and ongoing economic and demographic transitions to produce adequate food to meet the demand in the region by 2030 and for Indonesia to 2045; (ii) prioritize areas for investment in Indonesia and the PRC, including the potential for investment in advanced technologies; and (iii) suggest actions to be taken by governments and other stakeholders to mobilize new investments in the prioritized areas.

1.3. Study Regions and Countries

This research study was implemented in the five ADB-member regions: Central and West Asia, East Asia, the Pacific, South Asia, and Southeast Asia. Analyses are limited to the ADB developing member countries and regions in the same geographic location in Table 1.1.

Table 1.1: Regions and Developing Members under the Asian Development Bank

Region	Members
Central and West Asia	Afghanistan, Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Pakistan, Tajikistan, Turkmenistan, and Uzbekistan
East Asia	Hong Kong, China; Mongolia; People's Republic of China; Republic of Korea; and Taipei, China
Pacific	Cook Islands, Fiji, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, and Vanuatu
South Asia	Bangladesh, Bhutan, India, Maldives, Nepal, and Sri Lanka
Southeast Asia	Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam

Source: Asian Development Bank.

Because of the geographic size and influence on agricultural trade, detailed country case studies were implemented in Indonesia and the PRC. These country studies will supplement the main report with country-specific analysis.

1.4. Country Case Studies

1.4.1. People's Republic of China

The country case study for the PRC focuses on information and communication technology (ICT) used in the agriculture sector. The major goal of this study is to have a better understanding of the potential uses of ICT in agriculture and provide guidelines for its investment in the PRC. Because of the in-depth analysis carried out in this case study, the PRC report is presented as a companion technical report.

1.4.2. Indonesia

This country case study carried out an assessment of agricultural investments and policies including a modeling approach that links the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) with an Indonesian computable general equilibrium (CGE) model, to capture both the agriculture sector and economywide impacts of agricultural investments, as well as examine the institutional structure to address food security issues in Indonesia. It encompassed a comprehensive evaluation of investments in the agriculture sector including subsector analysis from public and private sectors, the policy responses to external and internal changes, and current developments addressing food security in Indonesia. To assist in the planning processes, projections of key indicators under different scenarios, including the number and percentage of hungry people and number and percentage of malnourished children were estimated and analyzed. The study also carried out projections of water demand by irrigation and other sectors and an assessment of the impact of investments in irrigation on food security outcomes. Complex issues of food security involve food availability, food accessibility, food price stability, and vulnerability and malnutrition. The Indonesia study reviewed policy issues related to these food security issues as well as development priorities such as rural investment, trends in adoption of advanced technologies including precision agriculture, ICT, and policy obstacles to investments, and developed policy recommendations to promote agricultural investments in Indonesia. The Indonesia case study is presented as a companion report to this technical report.

1.5. Impact and Outcome Statement

The outputs of this research study will help ADB and the national governments of Asia and the Pacific to prioritize their agricultural investments and policies (and selected social investments) as they try to achieve their goals of long-term sustainable economic development, climate adaptation, and ending hunger in Asia and the Pacific. It will extend technical support and inform the national governments on the impacts of alternative agricultural policies and investments. The vision is that the strong and influential partnerships between the national agricultural agencies and ADB will encourage the implementation of the planned activities and help achieve policy impact through the direct linkage of scientists with policymakers. The project results are also expected to influence the national economic development plans and guide investment strategies for the agriculture sector in the region.

Chapter 2

DETERMINANTS AND TRENDS IN FOOD SECURITY IN ASIA AND THE PACIFIC

2.1. Defining Food Security

In 1996, at the World Food Summit, the Food and Agriculture Organization of the United Nations² stated, “Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life.” The World Health Organization (WHO) adds to this definition the following aspects of food security:

- Availability: Sufficient quantities of appropriate food are available from domestic production, commercial imports or food assistance on a consistent base.
- Access: Adequate income or other resources are available to access appropriate food through home production, buying, exchange, gifts, borrowing or food aid.
- Utilization: Food is properly used through appropriate food processing and storage practices, adequate knowledge and application of nutrition and child care practices, and adequate health and sanitation services.
- Stability: Adequate food must be obtainable at all times so that access and availability of food is not curtailed by acute or recurring emergencies (sudden crises or seasonal shortages).³

This report addresses the prospects for food security and nutrition security under alternative investment scenarios. The first step in assessing these prospects is measuring food security and nutrition security. In this report, food security utilizes the FAO measure, defined as undernourishment, which is “the proportion of the population whose dietary energy consumption is less than a pre-determined threshold.”⁴ The threshold utilized by FAO and in this report is the “daily minimum dietary energy requirements, over a period of one year.”⁵

For malnutrition, this report utilizes childhood malnutrition, defined in terms of stunting. For stunting, this report uses the commonly used measure: “...the percent of children under [5] years, whose height-for-age z-score is less than -2 standard deviations below the median of a global reference population of children who are well-nourished and received key recommended caring practices.”⁶

² FAO. 1996. *Declaration on World Food Security*. World Food Summit. Rome.

³ World Health Organization.

⁴ FAO. 2008. *An Introduction to the Basic Concepts of Food Security*. Rome, Italy. <http://www.fao.org/3/al936e/al936e00.pdf>.

⁵ FAO. 2019. SDG Indicator 2.1.1—Prevalence of Undernourishment. International Rice Commission Newsletter Vol. 48. Rome, Italy. <http://www.fao.org/sustainable-development-goals/indicators/211/en/>.

⁶ L. C. Smith and L. Haddad. 2015. Reducing Child Undernutrition: Past Drivers and Priorities for the Post-MDG Era. *World Development*. 68, pp. 180–204.

Food availability is usually interpreted to mean aggregate national supplies, while food access is related to the capacity of households to purchase food, considering household income. But, as Warr notes, food availability also has a price dimension.⁷ The combination of physical availability and price of food is a function of productivity growth, international trade, food distribution, and direct support for food consumption of those with inadequate income.⁸

Warr (footnote 8) assessed the determinants of food security in 2000–2010, using the FAO undernourishment indicator as the dependent variable and gross domestic product (GDP) growth per capita in agriculture, industry, and services, and the price of food as explanatory variables. The price variable is important, because undernourishment depends on the price of food, in addition to GDP, which represents purchasing power. Undernourished people spend a higher proportion of income on food than the national average, so their consumption of food is more sensitive to the level of food prices. Lower food prices mean lower levels of undernourishment. The results also show that agricultural growth causes a larger reduction in undernourishment than industrial and service sector growth (footnote 8).

Expansion of agricultural output in turn is driven by investment in agricultural research and development and infrastructure. “Food insecurity can be reduced most effectively by raising agricultural productivity through investments in infrastructure and research, supplemented by food safety nets to assist those unable to benefit from market-based economic development.”⁹

Indeed, productivity growth is a critical driver of agricultural supply increase and maintenance of lower food prices. There is extensive literature focused on understanding the determinants of the gains in productivity in the agriculture sector.¹⁰ These studies show that public and private research and development (R&D) investments have played a crucial role in realizing productivity growth.¹¹ In developing countries, R&D on agriculture has been mainly undertaken by public institutions such as government laboratories and universities, as well as nonprofit institutions such as the Consultative Group for International Agricultural Research

⁷ P. G. Warr. 2014. Food Insecurity and Its Determinants. *Australian Journal of Agricultural and Resource Economics*. 58 (4). pp. 519–537. <https://ssrn.com/abstract=2512996> or <http://dx.doi.org/10.1111/1467-8489.12073>.

⁸ P. G. Warr. 2014. Food Insecurity and Its Determinants. *Australian Journal of Agricultural and Resource Economics*. 58 (4). pp. 519–537. <https://ssrn.com/abstract=2512996> or <http://dx.doi.org/10.1111/1467-8489.12073>.

⁹ P. G. Warr. 2014. Food Insecurity and Its Determinants. *Australian Journal of Agricultural and Resource Economics*. 58 (4). pp. 519–537. <https://ssrn.com/abstract=2512996> or <http://dx.doi.org/10.1111/1467-8489.12073>.

¹⁰ J. M. Alston et al. 2000. A Meta-analysis of Rates of Return to Agricultural R&D: Ex pede Herculem? *IFPRI Research Report 113*. Washington, DC: International Food Policy Research Institute. <http://www.ifpri.org/sites/default/files/publications/rr113.pdf>; J. M. Alston et al. 2010. U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending. *Natural Resource Management and Policy* 34. 504; and R. Evenson. 2001. Economic Impacts of Agricultural Research and Extension. In: B. Gardner and G. Rausser (eds.) *Handbook of Agricultural Economics*. Amsterdam: Elsevier Science.

¹¹ M. W. Rosegrant, S. Tokgoz, and P. Bhandary. 2013. The Future of the Global Food Economy: Scenarios for Supply, Demand, and Prices. In C. B. Barrett, ed. *Food Security and Sociopolitical Stability*. pp. 35–63. Oxford University Press.

(CGIAR). However, private sector research has been increasing rapidly, particularly in relatively fast-growing countries such as Brazil and India. Evenson and Gollin showed that the productivity growth associated with modern crop varieties had important consequences.¹² They found that increased food production driven by R&D on agriculture reduced food prices globally, boosting food consumption, improving health, and reducing poverty in developing countries.

In addition to the contributions of R&D to the growth of agriculture and to improved food security, irrigation and rural roads and other infrastructure play important roles. Irrigation increases crop yields while improving the impact of other inputs such as fertilizer and expanding the feasible land area. When rural infrastructure is weak, inefficiencies in markets and transportation increase the cost of inputs to farmers and reduce the price of outputs, reducing profitability and limiting the incentives to adopt technologies and utilize inputs. Remote rural areas that are hardly reached by infrastructure may have no market access. Electrification is especially important in the value chain, since it is beneficial to cold chain development and the development of agribusiness, and also provides farmers with a more reliable and cheaper source of power.

Investments in agricultural productivity growth also contribute to reductions in hunger and malnutrition. It is estimated that “an additional investment of \$8 billion per year globally would reduce the number of underweight children by 10 million and of hungry people by 201 million by 2050 and raise the income of many of the world’s poorest people.”¹³ Agricultural growth by itself is not enough to end hunger. Complementing broad-based agricultural and economic growth, targeted agricultural programs and social safety nets can play a major role in reducing hunger and malnutrition.¹⁴

A cross-country econometric analysis using data from 116 developing countries collected from 1970 to 2012 further elaborated on these pathways for food security in the context of child malnutrition, as measured by stunting.¹⁵ The study found that the key drivers of reductions in stunting have been the quantity and quality of food available through growth in income and production or access to imports, together with “safe water access, sanitation, women’s education, and gender equality” (footnote 15). Income growth and governance have had important supporting roles. The differences in historical performance across the Asia and Pacific region in achieving reductions in undernourishment and child stunting, as described in the following section, are largely attributable to differential outcomes for these key determinants.

¹² R. E. Evenson and D. Gollin. 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*. 300 (5620). pp. 758–762.

¹³ J. F. Hoddinott, M. W. Rosegrant, and M. Torero. 2013. Hunger and Malnutrition. In B. Lomborg, ed. *Global Problems, Smart Solutions: Costs and Benefits*. New York, NY, USA: Cambridge University Press. Chapter 6. <http://www.fao.org/nr/water/aquastat/investment/index.stm>.

¹⁴ M. T. Ruel and H. Alderman. 2013. Nutrition-Sensitive Interventions and Programmes: How Can They Help to Accelerate Progress in Improving Maternal and Child Nutrition? *The Lancet: The Maternal and Child Nutrition Study Group*. 382 (9891). pp. 536–551. [https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(13\)60843-0/fulltext](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(13)60843-0/fulltext).

¹⁵ L. C. Smith and L. Haddad. 2015. Reducing Child Undernutrition: Past Drivers and Priorities for the Post-MDG Era. *World Development*. 68. pp. 180–204.

2.2. Trends in Hunger and Malnutrition in Asia and the Pacific

The trend in the number of people who experience hunger in Asia and the Pacific from 1990 to 2017 using estimates from the Food and Agriculture Organization Corporate Statistical Database is presented in Table 2.1. East Asia and Southeast Asia have dramatically improved, halving the number of hungry people from 1990 to 2017. FAO noted that these developments may be attributed to enhancement of the agriculture sector such as adoption of improved and high-yielding varieties of major cereals (rice, wheat, maize), investments in irrigation, and increased fertilizer application, to name a few.¹⁶ Moreover, better livestock breeds contribute to higher production of meat, milk, eggs, and other livestock products. Expansion of crop, livestock, and fisheries production in East and Southeast Asia resulted in the availability and accessibility of food as well as opportunities for higher income in the rural areas, and thereby reducing the number of people who experience hunger in these regions. Higher household incomes due to agricultural growth and broader economic growth have contributed to improved diet quantity and quality (footnote 16).

Table 2.1: Undernourishment in Asia, by ADB Region

Region	1990–1992	2000–2002	2005–2007	2010–2012	2014	2016	2017
Number of undernourished (million)							
Central and West Asia	38.22	46.00	43.70	43.80	42.40	43.70	43.90
East Asia	295.40	221.70	217.60	174.70	142.60	139.50	139.60
Pacific	1.50	1.70	1.80	2.00	2.30	2.60	2.80
South Asia	262.58	237.20	283.80	237.50	251.00	238.60	237.70
Southeast Asia	137.50	117.60	103.20	72.50	60.60	63.60	63.70
Total	735.20	624.20	650.10	530.50	498.90	488.00	487.70
Prevalence of undernourishment (%)							
Central and West Asia	20.88	21.62	18.84	17.26	16.97	16.87	16.65
East Asia	23.20	16.00	15.20	11.80	8.73	8.51	8.54
Pacific	5.20	5.33	5.29	5.39	5.79	6.60	7.00
South Asia	22.67	19.07	22.28	18.18	17.30	16.45	16.49
Southeast Asia	30.60	22.30	18.30	12.10	9.70	9.90	9.80
ADB DMCs	23.77	18.35	18.39	14.43	12.48	12.11	12.10

ADB = Asian Development Bank, DMC = developing member country.

Source: FAOSTAT database, recomputed by the authors according to ADB regions.

¹⁶ FAO. 2018. *State of Food and Agriculture in Asia and the Pacific Region, including Future Prospects and Emerging Issues*. Paper presented at the 34th Session for the FAO Regional Conference for Asia and the Pacific. Nadi, Fiji. 9–13 April. <http://www.fao.org/3/mw252en/mw252en.pdf>.

South Asia and Central and West Asia achieved small reductions in the prevalence of hunger but increases in the number of hungry people because of population growth. In the Pacific, both the prevalence and the number of people who experience hunger increased. The weak recognition of women and their needs; unavailability, inferior quality, or inaccessibility of health care services; insufficient accessibility and availability of food; and poor hygienic household environments contribute to food insecurity in the Pacific region.¹⁷ The relatively slow growth in per capita food consumption in South Asia is a large part of the explanation of the slow progress in reducing undernourishment in that region (footnote 16). Poor levels of sanitation and gender inequality have also contributed to this slow progress in addressing undernourishment and childhood stunting (footnote 15).

Table 2.2 shows that the prevalence of stunted children under 5 years old in Asia declined from 48% in 1990 to 24% in 2017, resulting in a halving of the number of malnourished children. East Asia had a remarkable performance, cutting the number of stunted children from 50 million in 1990 to 5 million in 2017. South Asia and Southeast Asia both had substantial progress in almost halving the number and prevalence of stunted children below 5 years old in a span of over a decade (Table 2.2). However, South Asia remains home to 49 million stunted children, 60% of the total number for Asia and Pacific. In addition to the relatively slow growth in overall food availability, diets that are deficient in micronutrients, calories, protein, vitamins, and minerals hamper fetal and child growth and development. Furthermore, the inadequate nutrient diet of mothers leads to undernutrition and therefore to a greater probability of low birth weight which is a contributory factor in child stunting.¹⁸ The numbers of stunted children in Central and West Asia and the Pacific have been virtually unchanged since 1990. Low availability and poor access to nutritious food contribute to the stunted growth of children. Availability of food is impacted by climate change that influence agriculture and food prices, and this may be the case for the Pacific. The continuing conflicts in Central and West Asia are a likely cause of hindering access and availability of food (footnote 18).

¹⁷ R. Shrimpton, N. V. Mbuya, and A. M. Provo. 2016. The Double Burden of Malnutrition in East Asia and the Pacific: Evidence and Lessons for a Multisectoral Response. *Health, Nutrition, and Population Discussion Paper*. World Bank. December. <https://openknowledge.worldbank.org/bitstream/handle/10986/26102/112852-WP-DoubleBurdenofMalnutritioninEAP-PUBLIC.pdf?sequence=1&isAllowed=y>.

¹⁸ FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, and WHO. 2018. *The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition*. Rome: FAO. <http://www.fao.org/3/I9553EN/i9553en.pdf>.

Table 2.2: Trends in Stunting of Children Under 5 Years in Asia, by ADB Region, 1990–2017

Regions	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
Number affected (million)												
Central and West Asia	11.1	10.9	10.1	10.2	10.6	10.7	11.0	10.7	10.4	9.8	10.1	10.4
East Asia	50.1	29.6	17.1	11.5	8.1	7.6	7.1	6.6	6.2	5.7	5.3	4.8
Pacific	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
South Asia	94.8	88.1	81.0	72.4	63.6	61.7	59.1	57.1	55.2	53.6	51.3	49.2
Southeast Asia	26.6	24.2	21.0	19.2	17.2	16.9	16.6	16.3	16.0	15.6	15.3	14.9
Total	183.0	153.2	129.6	113.8	100.0	97.4	94.3	91.2	88.3	85.2	82.5	79.8
Prevalence (%)												
Central and West Asia	40.5	40.8	39.0	37.7	36.7	36.3	37.8	36.5	35.4	33.9	32.9	31.6
East Asia	35.7	26.6	19.2	13.4	9.2	8.5	7.9	7.3	6.7	6.2	5.7	5.3
Pacific	36.0	36.4	36.8	37.2	37.5	37.6	37.7	37.8	37.8	37.9	38	38.1
South Asia	61.7	56.1	50.6	44.9	39.4	38.2	36.9	35.9	35.0	34.3	33.3	32.6
Southeast Asia	46.9	42.6	38.4	34.4	30.6	29.9	29.1	28.4	27.7	27	26.4	25.7
ADB DMCs	48.3	43.4	39.2	34.4	29.8	28.8	28.0	27.0	26.1	25.3	24.5	23.9

ADB = Asian Development Bank, DMC = developing member country.

Sources: UNICEF, WHO, and World Bank 2018, recomputed by the authors according to ADB regions.

Chapter 3

SCENARIOS FOR FOOD SECURITY IN ASIA AND THE PACIFIC TO 2030

3.1. Overview

This chapter focuses on the availability and access to food to address food security. The regions and countries representing each region used in this analysis are presented in Table 1.1.

3.2. Trends in Agriculture and the Economy: 2000–2015

3.2.1. Population and Income

The population for the aggregated ADB member countries grew at a lesser rate compared with non-ADB developing member countries (DMCs) and the rest of the world and the world aggregate (including ADB DMCs), due mainly to the low population growth obtained in the PRC, which accounts for nearly all of the East Asian countries. Other ADB regions, however, recorded higher growth rates for both population and income than in non-ADB DMCs and the world from 2000 to 2015.

On average, the population of ADB DMCs in 2015 increased by 18% from 2000 figures, at an annual rate of 1.10%. The annual rate was highest for Pacific at 2.11%, followed by the Central and West Asia at 1.96%, while the PRC grew the least with an annual rate of 0.57% (Table 3.1 and Figure 3.1). South Asia accounted for one-half of the growth in total population from 2000 and 2015.

Table 3.1: Population Growth, 2000–2015

Region	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
	(million)					(%)
Central and West Asia	230	254	279	308	34	1.96
East Asia	1,362	1,403	1,443	1,482	9	0.57
Pacific	8	9	10	12	37	2.11
South Asia	1,228	1,334	1,431	1,521	24	1.43
Southeast Asia	524	561	596	633	21	1.26
ADB DMCs	3,346	3,554	3,752	3,948	18	1.10

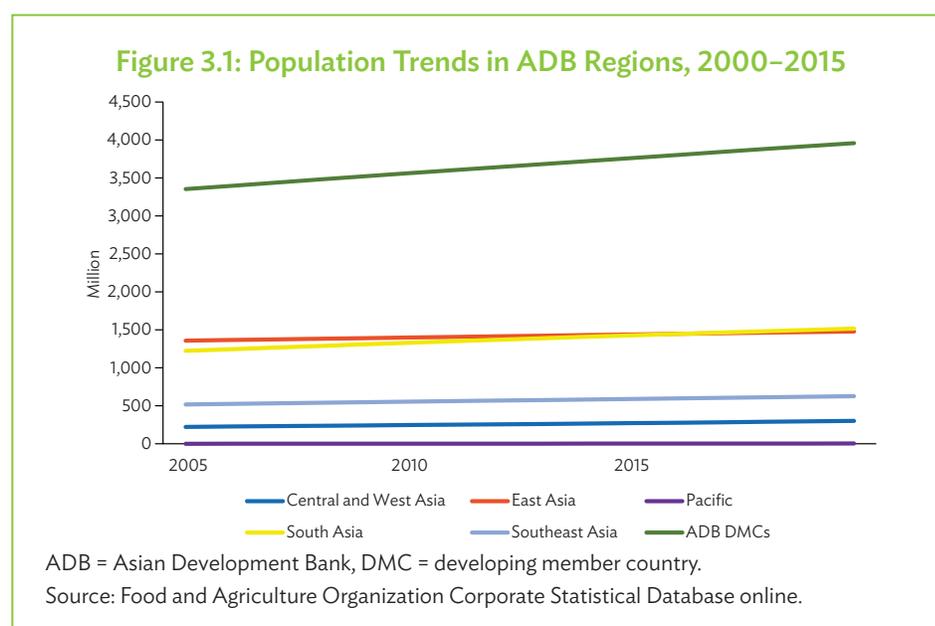
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Table 3.1 continued

Region	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
	(million)				(%)	
Non-ADB DMCs	2,799	2,988	3,206	3,435	23	1.39
World	6,145	6,542	6,958	7,383	20	1.23

ADB = Asian Development Bank, DMC = developing member country.

Source: Food and Agriculture Organization Corporate Statistical Database online.



Annual income (GDP and purchasing power parity [PPP]) also grew faster in all ADB regions compared with non-ADB DMCs and with the world averages: 7.89% for ADB DMCs, 2.88% for non-ADB DMC and 4.23% average for the world (Table 3.2a and Figure 3.2a). Trends were similar for per capita GDP, except for the Pacific, which had lower per capita growth than the world's average, mainly due to the high population growth in the region (Table 3.2b and Figure 3.2b).

Table 3.2a: Gross Domestic Product Growth, 2000–2015

Region	Year				Change 2000– 2015	Annual Growth Rate
	2000	2005	2010	2015		
GDP (constant 2005 international \$ billion, PPP)						(%)
Central and West Asia	708	1,004	1,347	1,706	141	6.20
East Asia	5,343	8,095	13,210	18,789	252	9.19
Pacific	18	20	25	30	70	4.26
South Asia	2,659	3,641	5,420	7,560	184	7.52
Southeast Asia	2,711	3,495	4,590	5,925	119	5.53

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Table 3.2a continued

Region	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
ADB DMCs	11,439	16,255	24,592	33,994	197	7.89
Non-ADB DMCs	42,950	49,375	57,042	64,111	49	2.88
World	54,389	65,630	81,634	98,104	80	4.23

ADB = Asian Development Bank, DMC = developing member country, GDP = gross domestic product, PPP = purchasing power parity.

Note: Values were deflated to constant 2005 to be consistent with IMPACT GDP values.

Source: World Bank-World Development Indicators online.

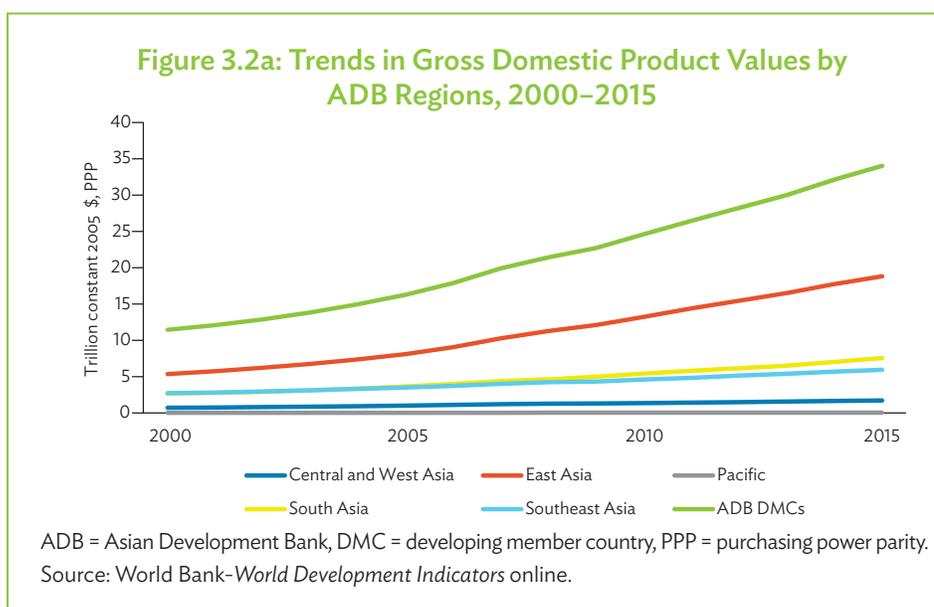
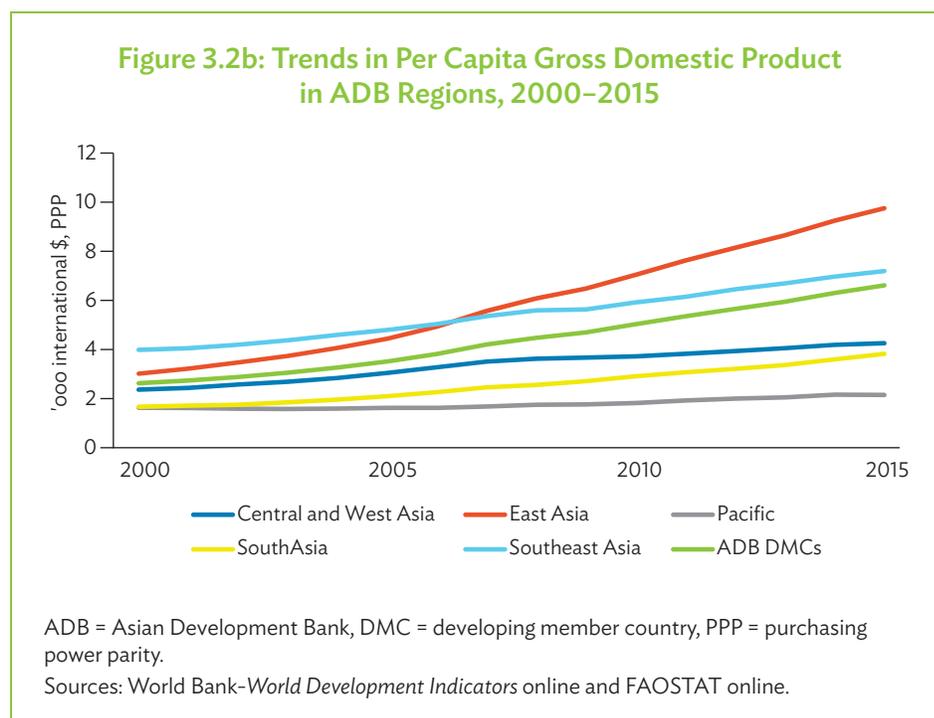


Table 3.2b: Per Capita Gross Domestic Product Growth, 2000–2015

Regions	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
GDP per capita (constant 2005 international \$, PPP)						(%)
Central and West Asia	2,366	3,045	3,719	4,256	80	4.16
East Asia	3,018	4,439	7,043	9,753	223	8.58
Pacific	1,626	1,624	1,816	2,147	32	2.24
South Asia	1,666	2,100	2,913	3,824	130	6.01
Southeast Asia	3,982	4,795	5,922	7,196	81	4.21
ADB DMCs	2,625	3,512	5,032	6,610	152	6.70
Non-ADB DMCs	11,830	12,738	13,718	14,390	22	1.48
World	6,808	7,717	9,025	10,221	50	2.96

ADB = Asian Development Bank, DMC = developing member country, GDP = gross domestic product, PPP = purchasing power parity.

Sources: World Bank-World Development Indicators online and FAOSTAT online.



3.3.2. Demand, Supply, and Food Prices

Demand for Food Commodities

As populations rise and per capita incomes improve in ADB DMCs, demand for food commodities increases—especially for food crops and meat products. Due to urbanization and income growth, demand growth for fruits, vegetables, oil crops, and meat products has escalated compared to cereals,¹⁹ starchy roots, and sugar, showing the movement to more diversified diets, away from staple foods and toward higher valued foods.

Demand for fruits has grown annually by 5.36% in ADB DMCs, vegetables by 3.75% and oil crops by 4.19%. Preferences for meat products over cereals were seen as high demand growth rates for all meat products with a 3.55% rate, with the highest rate of growth being for poultry meat at 4.67% per year. Demand for pork continued to grow rapidly at 3.34% per year. The rapid growth of meat consumption contrasts with lower rates for rice at 1.43% per year and wheat products at 1.70% per year (Tables 3.3a–3.3b, and Figures 3.3–3.5b).

¹⁹ Note that the demand of maize as feed is included here. Increased demand for meat products increases the derived demand for maize as livestock feeds.

Table 3.3a: Growth of Food Demand in ADB Developing Member Countries, 2000–2015

Region	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
	(million metric ton)				(%)	
Meat Products	80	92	113	131	64	3.55
Beef	12	13	15	17	41	2.49
Mutton and goat meat	5	6	7	7	55	2.92
Pork	43	50	60	69	61	3.34
Poultry meat	19	22	29	36	88	4.67
Cereals	802	834	951	1,079	35	2.23
Maize	175	199	253	328	88	4.63
Rice	341	353	389	412	21	1.43
Wheat	247	244	272	304	23	1.70
Fruits	159	205	271	340	114	5.36
Vegetables	487	573	713	857	76	3.75
Oil crops	151	191	239	277	83	4.19
Pulses	22	25	31	37	67	3.44
Starchy Roots	272	286	306	358	31	1.91
Sugar	56	63	71	85	52	2.57

ADB = Asian Development Bank.

Note: Includes demand for feed, seed, and waste.

Source: FAOSTAT online.

Table 3.3b: Growth of Per Capita Demand for Agricultural Commodities in ADB Developing Member Countries, 2005–2015

Region	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
	(kg/capita)				(%)	
Meat Products	24	26	30	33	39	1.56
Bovine meat	3	4	4	4	19	0.52
Mutton and goat meat	1	2	2	2	32	0.95
Pig meat	13	14	16	18	36	1.36
Poultry meat	6	6	8	9	59	2.66
Cereals	239	234	253	273	14	0.27
Maize	52	56	67	83	59	2.62

continued on next page

Table 3.3b continued

Region	Year				Change 2000- 2015	Annual Growth Rate
	2000	2005	2010	2015		
	(kg/capita)				(%)	
Rice	102	99	104	104	3	(0.52)
Wheat	74	69	72	77	5	(0.25)
Fruits	47	58	72	86	81	3.34
Vegetables	145	161	190	217	49	1.76
Oil crops	45	54	63	70	55	2.19
Pulses	7	7	8	9	41	1.46
Starchy Roots	81	80	81	90	11	(0.05)
Sugar	17	18	19	21	29	0.60

() = negative, ADB = Asian Development Bank, kg = kilogram.

Source: FAOSTAT online.

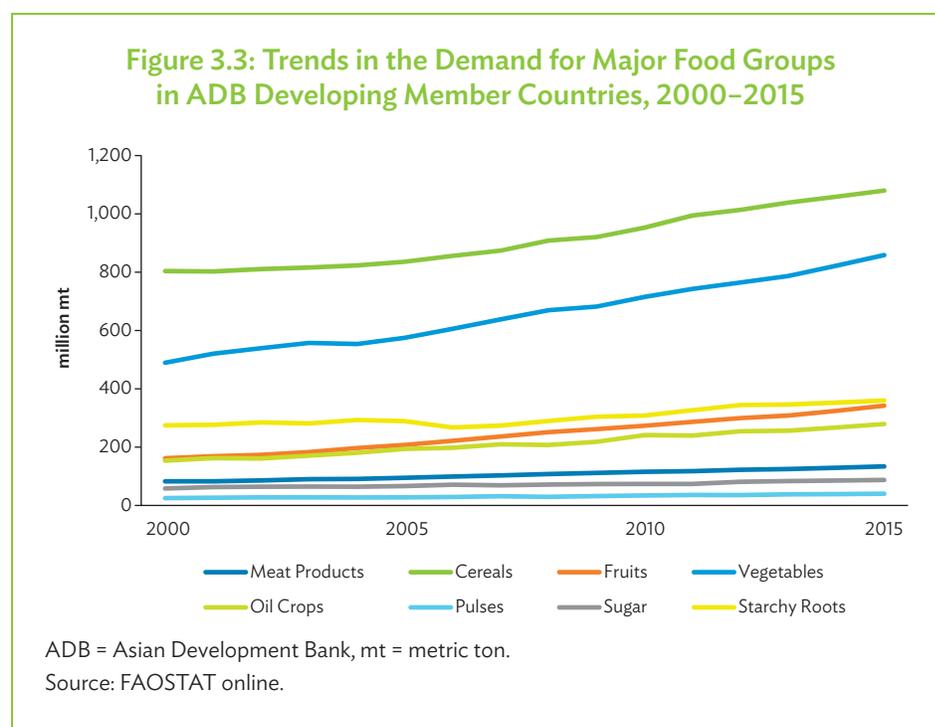
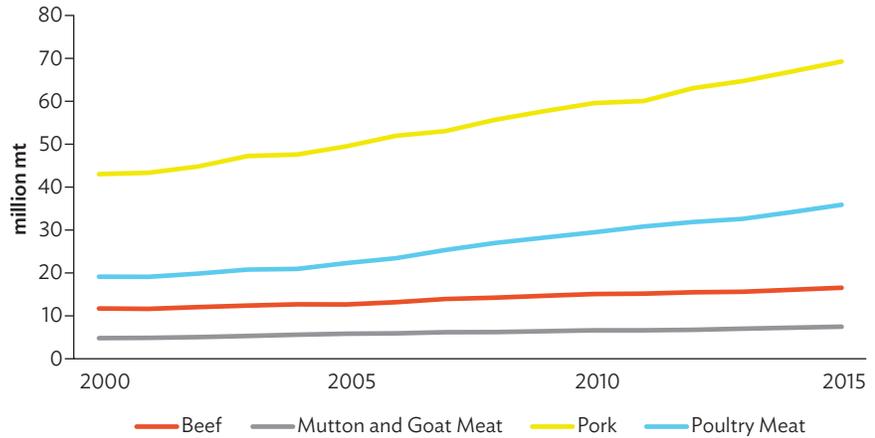


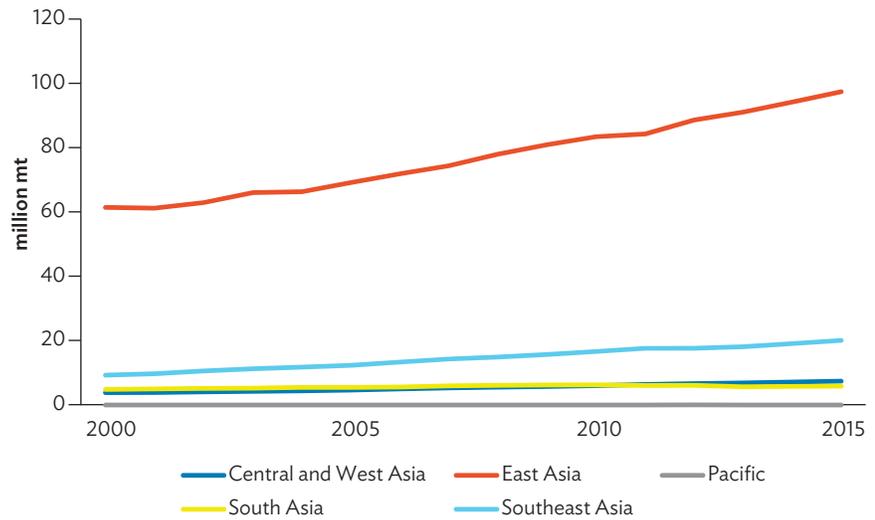
Figure 3.4a: Trends in the Demand for Meat Products in ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank, mt = metric ton.

Source: FAOSTAT online.

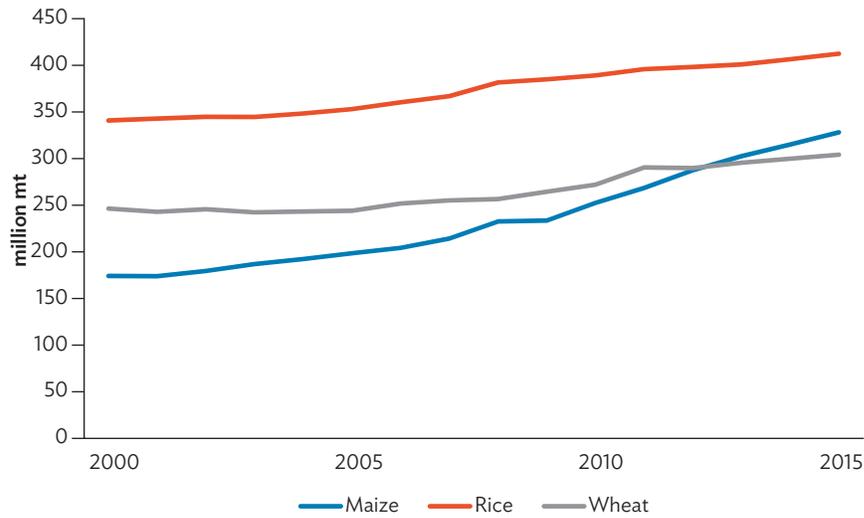
Figure 3.4b: Trends in Demand for Meat Products by ADB Regions, 2000–2015



ADB = Asian Development Bank, mt = metric ton.

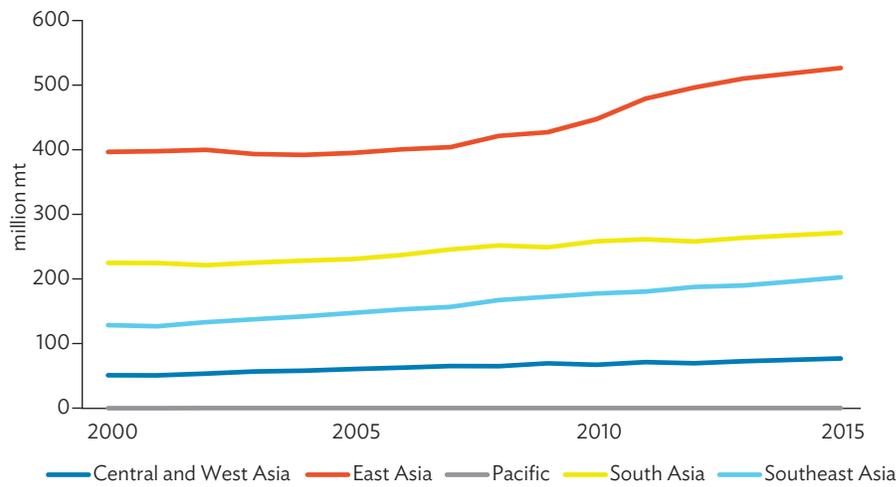
Source: FAOSTAT online.

Figure 3.5a: Trends in Demand for Cereal in ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.

Figure 3.5b: Trends in Demand for Cereal by ADB Regions, 2000–2015



ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.

Demand per capita clearly shows the changing preference for fruits, vegetables, oil crops, and meat products, particularly poultry meat, over cereals. While per capita demand for fruits has grown annually by 3.34% and poultry meat by 2.66%, per capita demand rates for cereals have declined: -0.52% annually for rice and -0.25% annually for wheat (Table 3.3b).

Production of Food Commodities

Trends in food production in ADB DMCs show that growth rates do not always expand rapidly enough with demand. Fruit and vegetable production has grown at pace with the rise in demand, while the production of meat, sugar, pulses, and oil crops lagged behind the increase in demand. On the other hand, the production of cereals has outpaced the growth of demand for the region as a whole (Table 3.4 and Figures 3.6–3.8b).

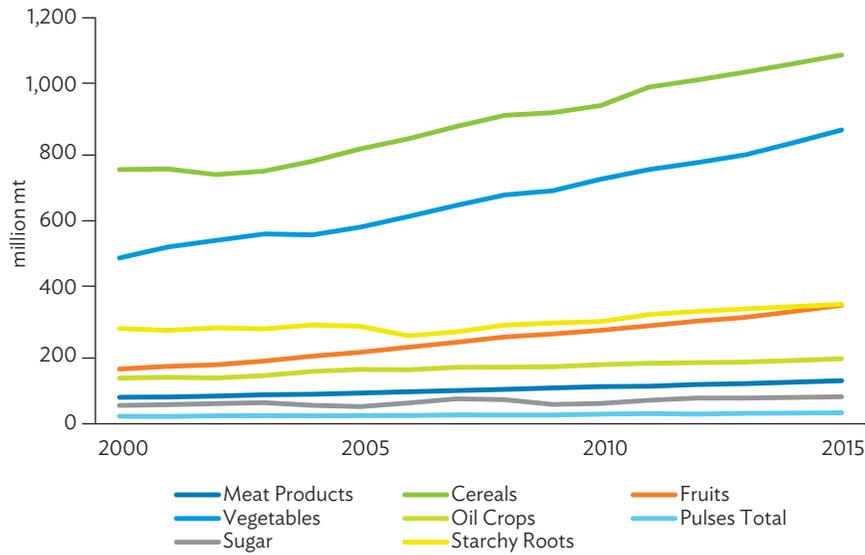
Table 3.4: Trends in Production of Food Commodities in ADB Developing Member Countries, 2000–2015

Region	Year				Change 2000– 2015	Annual Growth Rate
	2000	2005	2010	2015		
	(million metric ton)				(%)	
Meat Products	78	91	110	127	62	3.40
Beef	11	12	15	16	44	2.69
Mutton and goat meat	5	6	7	7	50	2.71
Pork	43	49	59	67	58	3.15
Poultry meat	19	22	28	34	85	4.44
Cereals	751	813	941	1,090	45	2.89
Maize	144	189	245	321	123	5.62
Rice	353	371	412	454	29	2.06
Wheat	219	218	248	285	30	2.38
Fruits	162	212	277	350	116	5.38
Vegetables	490	581	723	868	77	3.78
Oil crops	135	161	175	193	42	2.43
Pulses	23	24	29	33	44	2.63
Starchy Roots	282	289	302	353	25	1.67
Sugar	54	51	60	80	47	2.47

ADB = Asian Development Bank.

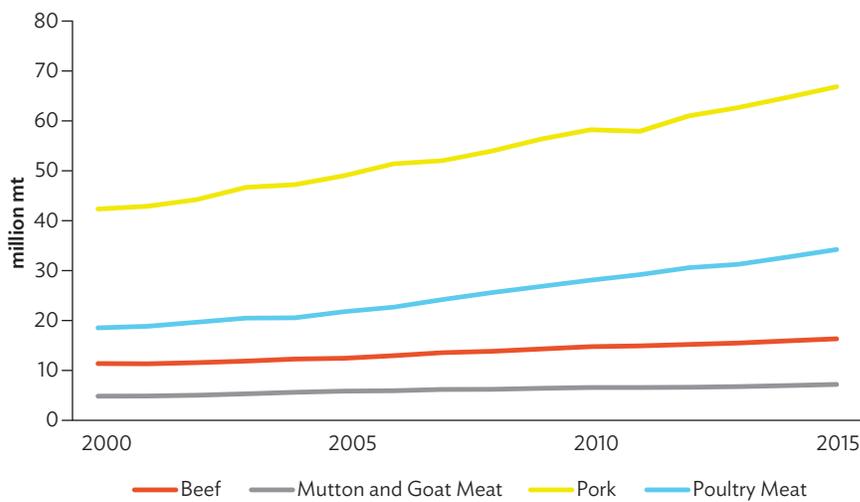
Source: FAOSTAT online.

Figure 3.6: Trends in the Production of Major Food Groups in ADB Developing Member Countries, 2000–2015



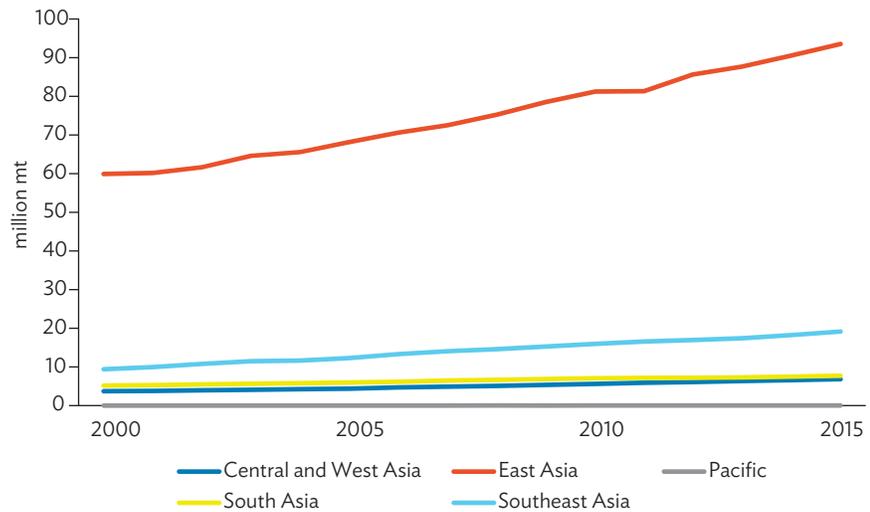
ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.

Figure 3.7a: Trends in the Production of Meat Products in ADB Developing Member Countries, 2000–2015



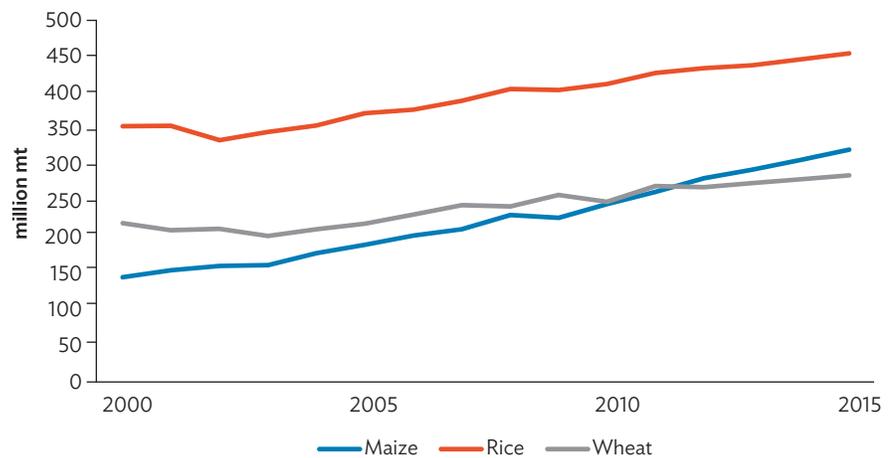
ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.

Figure 3.7b: Trends in the Production of Meat Products, by ADB Regions, 2000–2015

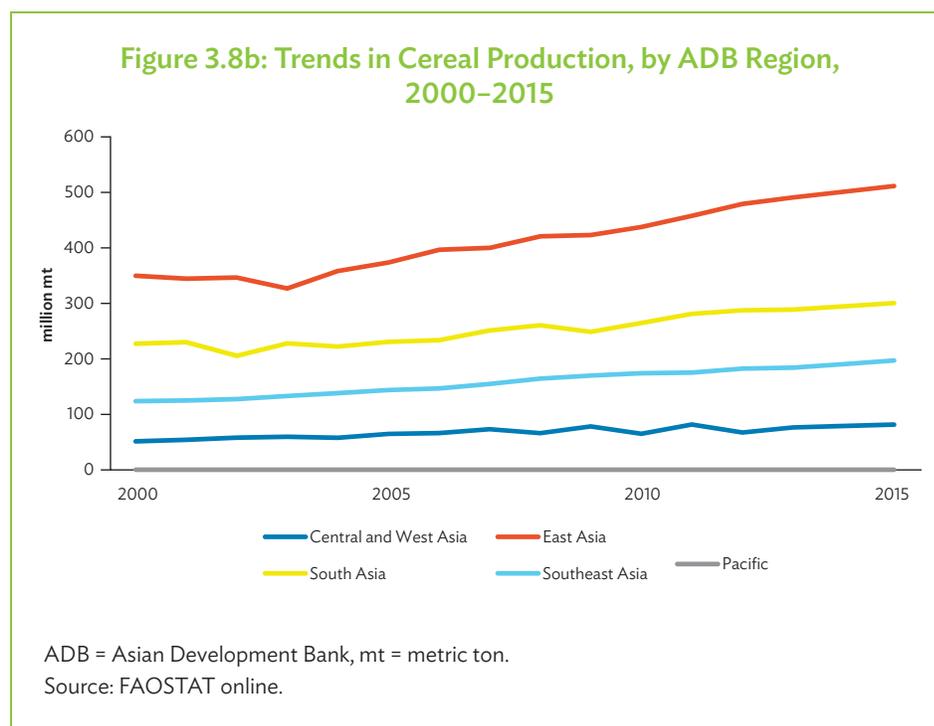


ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.

Figure 3.8a: Trends in Cereal Production in ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.



The production of cereals has grown at an annual rate of 2.28%, maize at 5.62%, rice at 2.06%, and wheat 2.38%—all outpacing demand growth rates for the respective commodities in the ADB DMCs. Maize production more than doubled between 2000 and 2015. The production growth rates of meat products, on the other hand, were slower than demand with an annual growth rate of 3.40% as compared with demand’s 3.55%. The growth rates in the production of poultry meat (4.44%), pork (3.15%), and mutton and goat meat (2.71%), have been lower than corresponding demand growth rates.

World Prices of Food Commodities

The ADB DMCs are large enough to have a significant influence on the prices of food commodities at the global level. The interplay between demand and production in the region influences the historical trends in the world prices of food commodities.

With the exception of sugar, all real-world food commodity prices reviewed and presented in this study have increasing growth trends in 2000–2015, although the prices of cereals, fruits and vegetables, and oil products have declined in recent years (Table 3.5 and Figures 3.9a–3.9c)—reflecting the differences in the growth rates of production, which are higher than demand in recent years. Nevertheless, cereal prices in 2015 remain above the prices that prevailed from 2000 to 2007, prior to the price spikes that began in 2008. The prices of meat products continue to have upward trends, thus reflecting the continued rapid growth of demand.

Table 3.5: Real World Prices of Major Food Commodities, 2000–2015

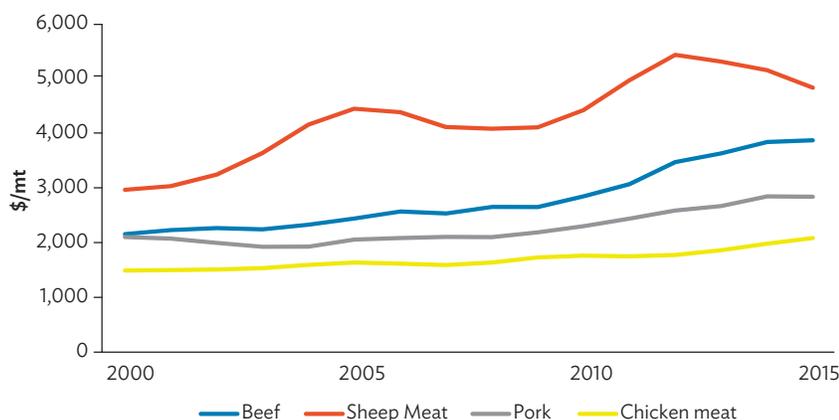
Regions	Year				Change 2000–2015	Annual Growth Rate
	2000	2005	2010	2015		
	(constant 2005 \$/metric ton)				(%)	
Meat Products						
Beef	2,170	2,617	3,076	3,763	73	4.41
Sheep meat	2,941	4,438	4,877	4,441	51	3.06
Pork	2,098	2,224	2,452	2,652	26	2.86
Chicken meat	1,472	1,629	1,737	2,151	46	2.28
Cereals						
Maize	99	99	171	144	45	5.74
Rice	227	286	449	328	44	5.99
Wheat, US SRW	111	136	211	176	58	4.83
Wheat, US HRW	128	152	205	174	36	4.37
Fruits, Oilseeds, Oils						
Banana	476	603	797	814	71	4.09
Groundnut	948	888	1,178	1,062	12	3.12
Soybean	238	275	413	332	40	5.13
Groundnut oil	802	1,060	1,288	1,137	42	4.18
Soybean oil	380	545	922	644	70	5.70
Coconut oil	506	617	1,031	944	87	7.00
Sugar	480	469	727	465	(3)	0.32

(-) = negative, HRW = hard red winter, SRW = soft red winter, US = United States.

Note: Values were deflated to constant 2005 to be consistent with the IMPACT GDP values.

Source: World Bank-World Development Indicators online.

Figure 3.9a: Trends in Real World Prices of Meat Products, 2000–2015

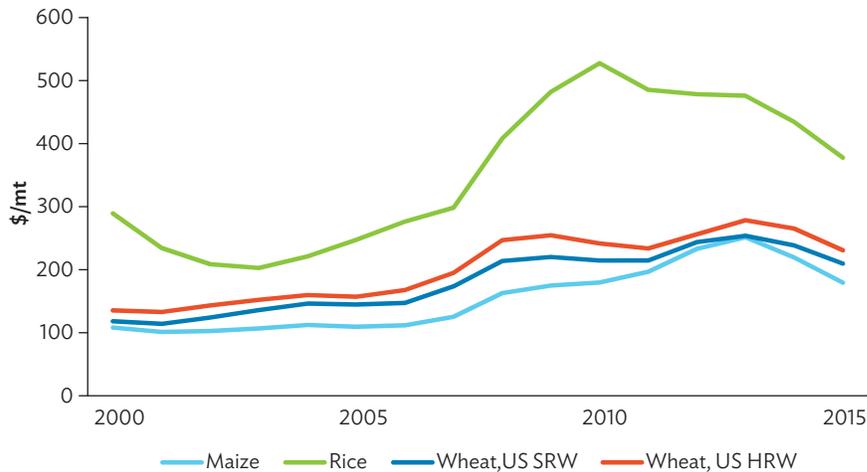


mt = metric ton.

Note: Values were deflated to constant 2005 to be consistent with the IMPACT GDP values.

Source: World Bank-World Development Indicators online.

Figure 3.9b: Trends in Real World Prices of Cereals, 2000–2015

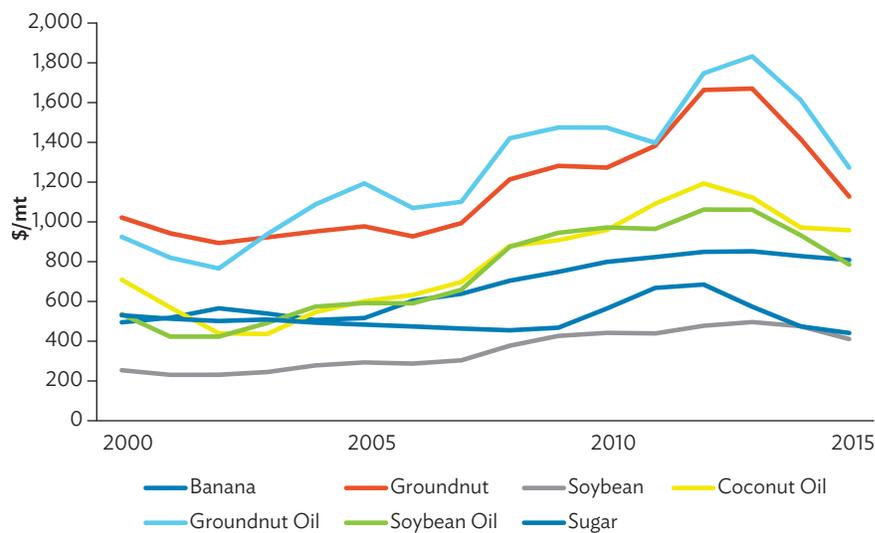


mt = metric ton.

Note: Values were deflated to constant 2005 to be consistent with the IMPACT GDP values.

Source: World Bank-World Development Indicators online.

Figure 3.9c: Trends in Real World Prices of Fruits, Oil Crops and Oils, and Sugar, 2000–2015



HRW = hard red winter, mt = metric ton, SRW = soft red winter, US = United States.

Note: Values were deflated to constant 2005 to be consistent with the IMPACT GDP values.

Source: World Bank-World Development Indicators online.

3.3. Historical Trends in Food Availability and Access

The historical trends and growth rates in demand, domestic production, and net trade of food commodities are shown in Table 3.6a for Asia DMCs, and in Tables 3.6b–3.6c for regional trends. These also show the behavior of the region's trade with the rest of the world. Asia is traditionally a net importer of meat products, maize, wheat, oil crops, and sugar while being a traditional exporter of rice, fruits, and vegetables. However, the food trade in Asia reverted in 2000–2015 from being a net exporter to a net importer of starchy roots, and tubers and pulses.

Table 3.6a: Trends in the Demand, Production, and Net Trade of Food Commodities in ADB Developing Member Countries, 2000–2015

Food Group	2000			2015			Demand		Production	
	Demand	Production	Net Trade	Demand	Production	Net Trade	Change 2000– 2015	Annual Growth	Change 2000– 2015	Annual Growth
	('000 metric ton)								(%)	
Meat Products	79,855	78,441	(1,414)	131,265	127,455	(3,809)	64	3.55	62	3.40
Beef	11,721	11,344	(378)	16,524	16,363	(161)	41	2.49	44	2.69
Mutton and goat meat	4,816	4,761	(55)	7,475	7,129	(346)	55	2.92	50	2.71
Pork	43,016	42,567	(450)	69,265	67,269	(1,996)	61	3.34	58	3.15
Poultry meat	19,125	18,566	(559)	35,883	34,387	(1,496)	88	4.67	85	4.44
Cereals	801,793	751,443	(50,350)	1,078,621	1,089,896	11,274	35	2.23	45	2.89
Maize	174,513	144,126	(30,387)	328,256	320,804	(7,452)	88	4.63	123	5.62
Rice	340,915	353,233	12,318	412,458	454,200	41,742	21	1.43	29	2.06
Wheat	246,672	218,973	(27,699)	304,390	285,129	(19,262)	23	1.70	30	2.38
Fruits	159,128	162,190	3,062	339,998	350,471	10,473	114	5.36	116	5.38
Vegetables	487,314	490,480	3,166	857,121	868,390	11,269	76	3.75	77	3.78
Oil crops	151,123	135,305	(15,818)	277,297	192,597	(84,700)	83	4.19	42	2.43
Pulses	22,496	22,703	206	37,493	32,622	(4,870)	67	3.44	44	2.63
Starchy Roots	272,155	281,962	9,807	357,567	353,201	(4,366)	31	1.91	25	1.67
Sugar	55,686	54,400	(1,286)	84,910	79,964	(4,946)	52	2.57	47	2.47

(-) = negative, ADB = Asian Development Bank.

Note: Net trade values are results of the region's trade with the rest of the world and do not include intraregional trade between and among countries in the region.

Source: World Bank and USDA.

Table 3.6b: Historical Trends of the Demand and Supply of Cereals, by ADB Region, 2000–2015

Region	2000			2015			Demand		Production	
	Demand	Production	Trade	Demand	Production	Trade	Change 2000–2015	Annual Growth	Change 2000–2015	Annual Growth
	('000 metric ton)						(%)			
Central and West Asia	51,226	51,176	(50)	77,261	81,371	4,110	51	2.77	59	2.81
East Asia	396,731	349,375	(47,356)	526,551	511,078	(15,473)	33	2.19	46	3.08
Pacific	351	136	(215)	472	180	(291)	34	2.00	32	2.47
South Asia	224,860	227,114	2,254	271,593	300,373	28,780	21	1.47	32	2.35
Southeast Asia	128,626	123,642	(4,984)	202,745	196,893	(5,852)	58	3.32	59	3.36
ADB DMCs	801,793	751,443	(50,350)	1,078,621	1,089,896	11,274	35	2.23	45	2.89

() = negative, ADB = Asian Development Bank, DMC = developing member country.

Source: Authors' calculations from demand and production tables.

Table 3.6c: Historical Trends of Demand and Supply of Meat Products, by ADB Region, 2000–2015

Region	2000			2015			Demand		Production	
	Demand	Production	Trade	Demand	Production	Trade	Change 2000–2015	Annual Growth	Change 2000–2015	Annual Growth
	('000 metric ton)						(%)			
Central and West Asia	3,948	3,786	(162)	7,529	6,902	(627)	91	4.72	82	4.32
East Asia	61,490	59,902	(1,588)	97,435	93,499	(3,936)	58	3.32	56	3.16
Pacific	96	65	(31)	127	85	(42)	33	1.93	32	1.79
South Asia	4,936	5,231	295	5,984	7,769	1,785	21	1.31	49	2.74
Southeast Asia	9,385	9,458	73	20,189	19,200	(989)	115	5.27	103	4.73
ADB DMCs	79,855	78,441	(1,414)	131,265	127,455	(3,809)	64	3.55	62	3.40

() = negative, ADB = Asian Development Bank, DMC = developing member country.

Source: Authors' calculations from demand and production tables.

Net imports as percentage of demand in 2000 was highest for maize (17%) followed by wheat (11%) and oil crops (10%). In 2015, maize net import share of demand was reduced to 2%, wheat to 6%, while oil crops share escalated to 31%. Net imports of oil crops, mainly soybeans for animal feed, increased dramatically, and net imports of meat doubled.

Net export's share of production has also changed over the years. Share of net export rose—rice at 3% in 2000 to 9% in 2015; fruits at 2% in 2000 to 3% in 2015, and vegetable from 0.65% in 2000 to 1.30% in 2015.

As shown in Tables 3.6b–3.6c, East Asia (primarily the PRC) has significantly increased net imports of cereals and meats while South Asia has boosted exports of these commodities. The other regions showed relatively little change in net trade.

3.4. Food Security Indicators

In addition to demand and supply (production and net trade) balance as indicators of food availability and access, daily calorie consumption, number of malnourished children, and the number of people at risk of hunger (included in the United Nations' State of Food Insecurity) were analyzed in this study with the application of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model's estimates based on the data and procedure of the Food and Agriculture Organization of the United Nations (FAO). Results of the analysis are presented in Table 3.7 for 2015 and serve as base values for comparison with alternative investment scenarios and security pathways for the region in 2030.

Table 3.7: Base Value of Food Security Indicators, by ADB Region, 2015

Region	Calorie Consumption (Kcal/capita/day)	Malnourished Children (million)	Number of Hungry People
Central and West Asia	2,492	11.2	58.0
East Asia	3,214	4.2	89.0
Pacific	2,482	0.4	0.7
South Asia	2,432	64.2	139.0
Southeast Asia	2,601	13.2	75.0
ADB DMCs	2,750	93.1	362.0

ADB = Asian Development Bank, DMC = developing member country, Kcal = kilocalorie.

Source: IMPACT simulation results.

In 2015, the region's demand, production, and trade balances and world prices of commodities revealed that the region's daily kilocalorie consumption was estimated at 2,748 kilocalories per capita with about 93.1 million malnourished children and 470.6 million people at risk of hunger.

Calorie consumption was highest for East Asia with 3,214 kilocalories per capita, and lowest for South Asia with 2,430 kilocalories. South Asia also has the most number of malnourished children at 64 million and the people at risk of hunger at 139 million.

3.5. Investment Opportunities for Food Security to 2030

This section explores the sources of past commodity production growth and presents preliminary projections for agriculture and food security to 2030—including a baseline projection with and without climate change to assess the impact of climate change—and a scenario with reduced investments in the agriculture sector.

3.5.1. Determinants of Food Demand and Supply to 2030

Food Demand to 2030

In the next 15 years, population in the ADB regions is projected to expand at lower rates than in the last 15 years for all regions but with the biggest decline coming from the PRC, which is projected to have reduction rates of 3% (Tables 3.8a–3.8b). The population of the entire region is projected to escalate by 9%, with an annual growth of 0.7%. Projected GDP however, will grow at a high rate of 5.87% per year, and per capita GDP rate of 5.26% (Tables 3.9a–3.9b). Thus, total food demand in the region will continue to rise at almost the same rate as in the past 15 years.

Table 3.8a: Projected Population, by ADB Region

Region	Year				Change 2015– 2030	Annual Growth Rate
	2015	2020	2025	2030		
	(million)				(%)	
Central and West Asia	308	332	357	380	23	1.43
East Asia	1,482	1,440	1,447	1,443	(3)	0.09
Pacific	12	13	14	15	26	1.45
South Asia	1,521	1,617	1,703	1,780	17	1.04
Southeast Asia	633	653	678	699	10	0.76
ADB DMCs	3,956	4,055	4,197	4,316	9	0.69

(-) = negative, ADB = Asian Development Bank, DMC = developing member country.

Source: FAOSTAT online.

Table 3.8b: Projections of Population, by ADB Region, 2015–2030

Region	Year		Historical Change 2000–2015	Projected Population in 2030	Projected Change 2015–2030
	2000	2015			
	(million)		(%)	(million)	(%)
Central and West Asia	230	308	34	380	23
East Asia	1,362	1,482	9	1,443	(3)
Pacific	8	12	37	15	26
South Asia	1,228	1,521	24	1,780	17
Southeast Asia	524	633	21	699	10
ADB DMCs	3,352	3,956	18	4,316	9

(-) = negative, ADB = Asian Development Bank, DMC = developing member country.

Source: FAOSTAT online.

Table 3.9a: Projections of Gross Domestic Product, by ADB Region, 2015–2030

Region	Year		Historical Change 2015– 2030	Projected GDP in 2030	Projected Change 2015– 2030	Annual Growth Rate (%)
	2000	2015				
			(%)		(%)	
GDP (constant 2005 international \$ billion, PPP)						
Central and West Asia	544	1,312	141	2,268	73	3.72
East Asia	4,110	14,453	252	38,074	163	6.67
Pacific	14	25	81	83	234	8.38
South Asia	2,045	5,816	184	13,399	130	5.72
Southeast Asia	2,086	4,558	119	7,703	69	3.56
ADB DMCs	8,799	26,149	197	61,527	135	5.87

ADB = Asian Development Bank, DMC = developing member country, GDP = gross domestic product, PPP = purchasing power parity.

Source: International Model for Policy Analysis of Agricultural Commodities and Trade's GDP projections based on Organisation for Economic Co-operation and Development's forecasts.

Table 3.9b: Projections of Gross Domestic Product Per Capita, by ADB Region, 2015–2030

Regions	Year		Historical	Projected	Projected	Annual Growth Rate (%)
	2000	2015	Change 2015–2030 (%)	GDP in 2030	Change 2015–2030 (%)	
GDP (constant 2005 international \$, PPP) per capita						
Central and West Asia	2,366	4,256	80	5,975	40	2.29
East Asia	3,018	9,753	223	26,392	171	6.86
Pacific	1,626	2,147	32	5,686	165	6.71
South Asia	1,666	3,824	130	7,529	97	4.62
Southeast Asia	3,982	7,196	81	11,019	53	2.88
ADB DMCs	2,625	6,610	152	14,257	116	5.26

ADB = Asian Development Bank, DMC = developing member country, GDP = gross domestic product, PPP = purchasing power parity.

Source: International Model for Policy Analysis of Agricultural Commodities and Trade's GDP projections based on Organisation for Economic Co-operation and Development's forecasts.

3.5.2. Determinants of Supply: Productivity, Land Area, and Food Prices

Whether the past growth rates in production in Asia would continue in the next 15 years to meet growing demand or further increase to better address hunger and food security depends on the investment the region makes in the immediate future.

Investment allocations can be made by sustaining the sources of production growth in the past, or by identifying potential sources of growth that have not been tapped before, or by combining these approaches to target goals such as ending hunger. The preliminary analysis presented here is the first step in assessing investment requirements to end hunger.

Historical sources of growth in cereal production have been mainly focused on productivity (yield) increase for rice and wheat, and both yield increase and land expansion for maize (Table 3.10 and Figures 3.10a–3.10d). For the livestock sector, growth in production depends largely in increasing the number of (slaughtered) animals, which was partly determined by the stocks of live animals. Meat yields did not grow as fast but were highest for poultry meat production and slowest for pork production (Table 3.11 and Figures 3.11a–3.11d).

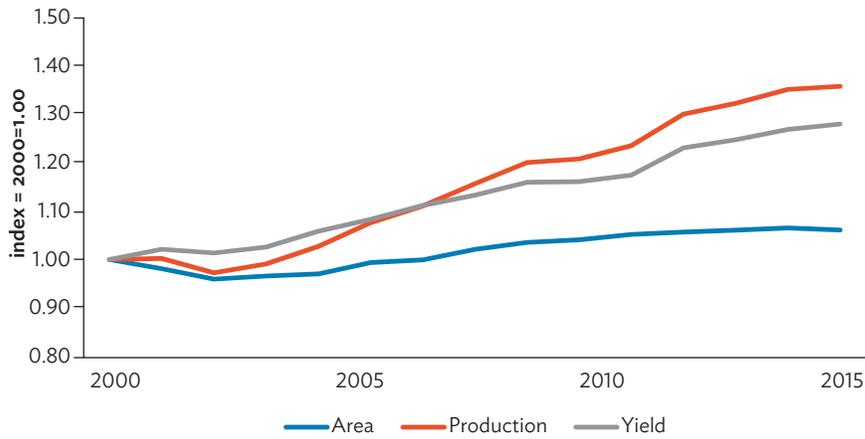
Table 3.10: Growth Rates in Area, Production, and Yield of Cereals, by ADB Region, 2000–2015 (%)

Region	Annual Growth Rates			
	Cereals	Rice	Maize	Wheat
Area Harvested				
Central and West Asia	1.06	0.89	0.59	1.27
East Asia	0.35	(0.11)	2.80	(0.98)
Pacific	0.72	3.13	(0.76)	
South Asia	0.02	0.09	2.55	0.70
Southeast Asia	1.22	1.23	1.25	0.61
ADB DMCs	0.46	0.44	2.39	0.33
Production				
Central and West Asia	2.82	0.61	6.30	2.88
East Asia	1.68	0.40	4.31	1.06
Pacific	3.24	5.12	1.56	
South Asia	2.01	1.95	5.48	1.89
Southeast Asia	3.20	2.87	5.18	4.94
ADB DMCs	2.13	1.64	4.57	1.67
Yield				
Central and West Asia	1.74	(0.27)	5.68	1.59
East Asia	1.32	0.51	1.47	2.06
Pacific	2.50	1.93	2.34	
South Asia	2.00	1.86	2.86	1.18
Southeast Asia	1.95	1.62	3.87	4.30
ADB DMCs	1.66	1.20	2.13	1.33

() = negative, ADB = Asian Development Bank, DMC = developing member country.

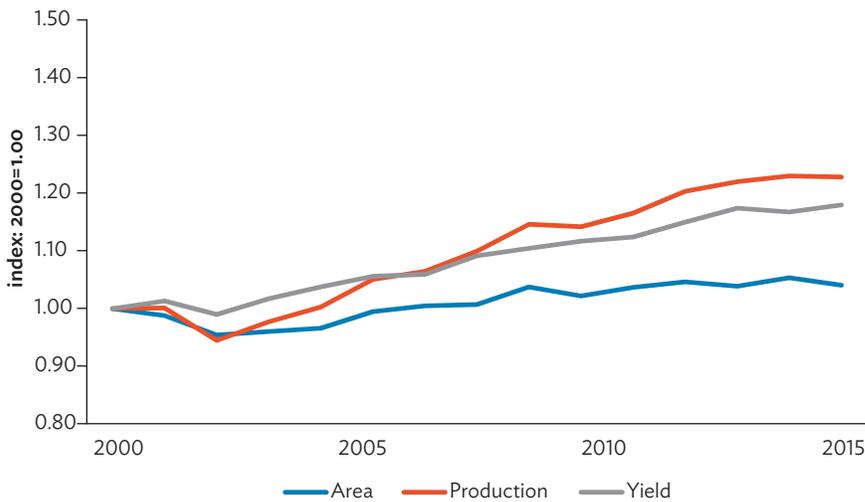
Source of raw data: FAOSTAT online.

Figure 3.10a: Historical Trends of Cereal Production, Area, and Yield, ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank.
Source: FAOSTAT online.

Figure 3.10b: Historical Trends in Rice Production, Area, and Yield, ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank.
Source: FAOSTAT online.

Figure 3.10c: Historical Trends of Maize Production, Area, and Yield, ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank.
Source: FAOSTAT online.

Figure 3.10d: Historical Trends of Wheat Production, Area, and Yield, ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank.
Source: FAOSTAT online.

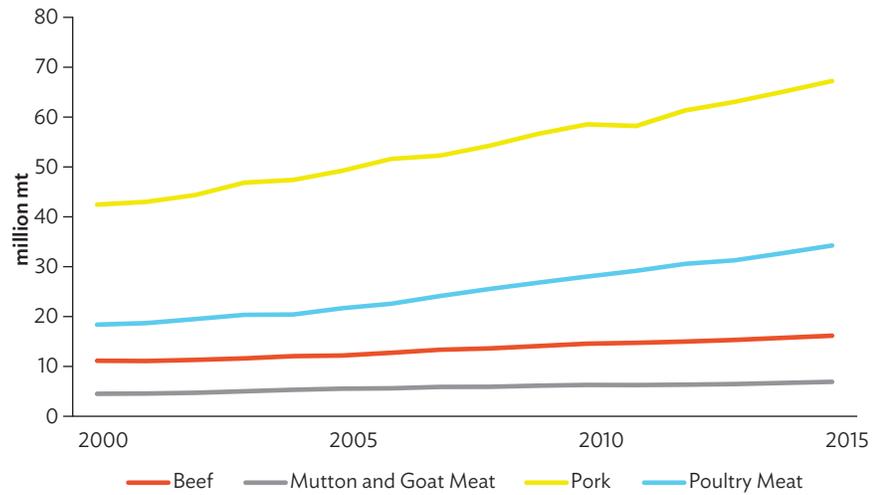
Table 3.11: Growth Rates of Determinants of Meat Production, by ADB Region, 2000–2015 (%)

Region	Annual Growth Rates			
	Beef	Pork	Poultry Meat	Sheep and Goat Meat
Stock of Animals				
Central and West Asia	3.96	(1.66)	9.96	2.74
East Asia	1.29	1.73	2.00	2.20
Pacific	0.71	1.25	1.72	2.52
South Asia	0.49	(2.09)	4.62	1.39
Southeast Asia	1.38	2.37	4.14	3.69
ADB DMCs	1.22	1.70	3.22	2.12
Number of Animals Slaughtered				
Central and West Asia	4.43	(1.81)	8.24	1.90
East Asia	2.16	3.31	3.18	2.61
Pacific	(0.09)	1.41	2.71	(3.09)
South Asia	0.99	(2.17)	6.25	1.42
Southeast Asia	4.31	4.22	5.04	1.99
ADB DMCs	2.47	3.30	4.17	2.20
Production				
Central and West Asia	4.40	(2.14)	8.93	2.08
East Asia	2.34	3.05	3.31	3.38
Pacific	(0.48)	1.43	4.27	(4.37)
South Asia	1.25	(2.18)	8.05	1.28
Southeast Asia	3.81	4.60	5.67	3.74
ADB DMCs	2.69	3.15	4.44	2.79
Yield				
Central and West Asia	(0.17)	(0.33)	0.64	0.17
East Asia	1.32	0.51	1.47	2.06
Pacific	2.50	1.93	2.34	0.00
South Asia	2.00	1.86	2.86	1.18
Southeast Asia	1.95	1.62	3.87	4.30
ADB DMCs	1.66	1.20	2.13	1.33

ADB = Asian Development Bank, DMC = developing member country.

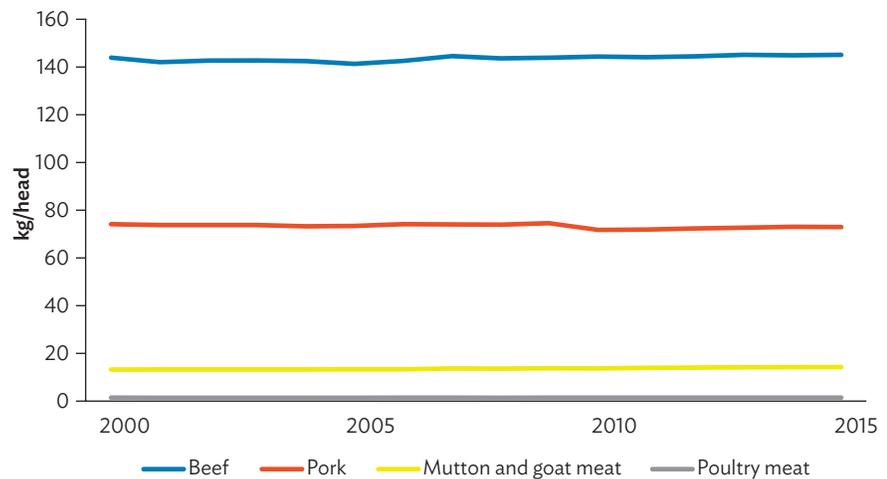
Source of basic data: FAOSTAT online.

Figure 3.11a: Historical Trends in Meat Production in ADB Developing Member Countries, 2000–2015



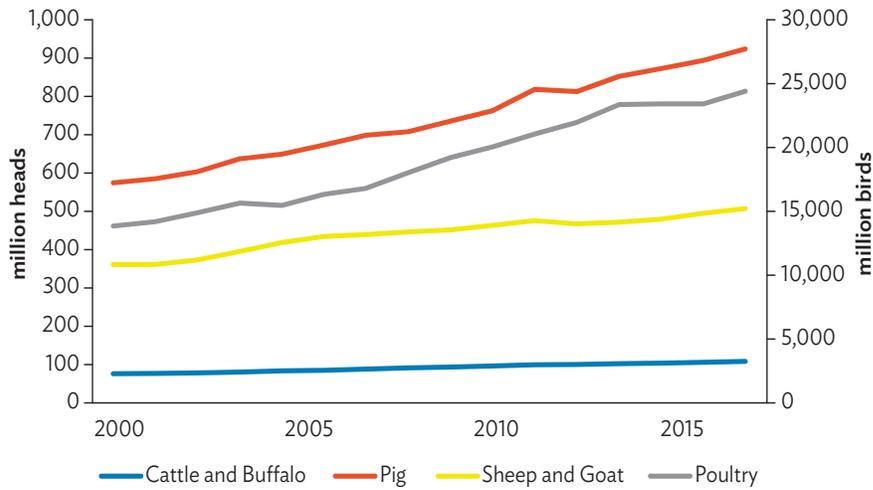
ADB = Asian Development Bank, mt = metric ton.
Source: FAOSTAT online.

Figure 3.11b: Historical Trends in Yields of Meat Products in ADB Developing Member Countries, 2000–2015



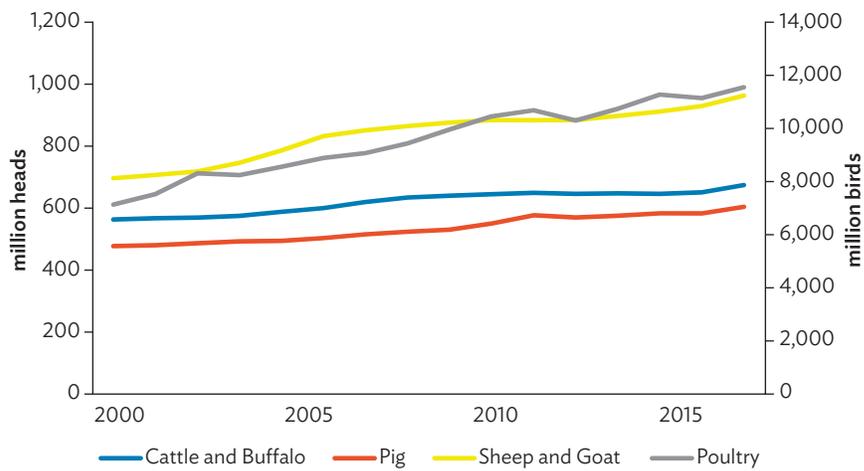
ADB = Asian Development Bank, kg = kilogram.
Source: FAOSTAT online.

Figure 3.11c: Historical Trends in the Number of Slaughtered Animals in ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank.
Source: FAOSTAT online.

Figure 3.11d: Historical Trends in the Number of Stock of Animals in ADB Developing Member Countries, 2000–2015



ADB = Asian Development Bank.
Source: FAOSTAT online.

These sources of production growth in the past and untapped potential sources of production growth can be the basis of investments for food security to 2030. An example of such investment is funding for agricultural research and development (R&D) to sustain crop productivity and investment in irrigation infrastructure (expansion and intensity) to expand agricultural land area and create more productive irrigated lands. Similarly, for livestock, investment in R&D can improve the sector's productivity that has been stagnant in the recent past. Unlike in crop production, land area is not as limiting in livestock production. Expansion in the stocks and the number of producing animals means more investment and incentives to encourage commercial livestock production, and promotion of developing marketable surplus for small farmers and producers. Other investments that were assessed in the study include rural infrastructure such as roads, rail, electricity, and post-harvest losses (PHL).

Effects of Climate Change on Agricultural Productivity

Another investment opportunity is offered by the adaptation of food production to the effects of climate change.

Although typically the negative impacts of climate change²⁰ are estimated to be more pronounced in 2050, the effects—which could be substantial in absolute terms—are already projected to be slowly appearing by 2030. Tables 3.12–3.13 present the climate shock index and effective impact of climate change on biophysical crop productivity (prior to economic feedbacks). These estimates are limited to crop production, and although no estimates of the direct impact of climate change on livestock production are available, these are implicit through the production of feeds. These shocks also do not consider the additional productivity growth from investments and productivity change. In 2030, climate change is projected to reduce crop productivity by as much as 9.6% of rainfed maize, 7.8% percent of maize, and 7.3% of irrigated sugarcane.

Table 3.12: Estimate of Impact of Climate Change on Crop Productivity in ADB Developing Member Countries, 2030 and 2050

Commodity	Climate Shock Index on Yields			
	2030		2050	
	Irrigated	Rainfed	Irrigated	Rainfed
Cereals	0.9452	0.9303	0.9006	0.8714
Maize	0.8955	0.8728	0.8177	0.7687
Rice	0.9421	0.9443	0.8900	0.8930
Wheat	0.9827	0.9751	0.9718	0.9553
Fruits and Vegetables	0.9685	0.9534	0.9395	0.9130
Banana	0.9379	0.9488	0.8802	0.9010
Vegetables	0.9713	0.9512	0.9448	0.9096

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²⁰ The effects of climate change vary by crop and by geographic location—positive for some crops and in some locations, but on average have negative impacts on crop productivity.

Table 3.12 continued

Commodity	Climate Shock Index on Yields			
	2030		2050	
	Irrigated	Rainfed	Irrigated	Rainfed
Oilseeds	0.9628	0.9645	0.9289	0.9319
Groundnut	0.9222	0.9233	0.8549	0.8554
Soybean	0.9451	0.9778	0.8981	0.9633
Pulses	0.9428	0.9623	0.8925	0.9278
Beans	0.9518	0.9673	0.9092	0.9369
Chickpeas	0.9233	0.9455	0.8560	0.8955
Cowpeas	0.9597	0.9605	0.9210	0.9226
Roots and Tubers	0.9125	0.9446	0.8606	0.9048
Cassava	0.9636	0.9943	0.9284	0.9888
Potato	0.8900	0.8758	0.8285	0.7962
Sweet Potato	0.9830	0.9715	0.9665	0.9441
Yams	0.9823	0.9658	0.9649	0.9328
Sugar	0.9034	0.9333	0.8219	0.8793

ADB = Asian Development Bank.

Note: Index is 2015 = 1.00.

Source: IMPACT estimates based on the Decision Support System for Agrotechnology Transfer model. <https://dssat.net/>.

Table 3.13: Projected Impact of Climate Change on Crop Yields in ADB Developing Member Countries, 2030 and 2050

Commodity	2030		2050	
	Irrigated	Rainfed	Irrigated	Rainfed
	(% change in yield ^a)			
Cereals	(4.1)	(5.2)	(8.6)	(11.2)
Maize	(7.8)	(9.6)	(15.8)	(20.4)
Rice	(4.3)	(4.2)	(9.6)	(9.4)
Wheat	(1.3)	(1.8)	(2.4)	(3.8)
Fruits and Vegetables	(2.4)	(3.5)	(5.3)	(7.6)
Oilseeds	(2.8)	(2.7)	(6.2)	(5.9)
Pulses	(4.3)	(2.8)	(9.4)	(6.3)
Roots and Tubers	(6.3)	(4.0)	(11.6)	(8.1)
Sugar	(7.3)	(5.0)	(15.7)	(10.5)

() = negative, ADB = Asian Development Bank.

^a Compared to the no climate change scenario.

Source: IMPACT estimates based on Decision Support System for Agrotechnology Transfer model. <https://dssat.net/>.

3.6. IMPACT Simulations of Alternative Investments for Food Security to 2030

The International Food Policy Research Institute's (IFPRI's) IMPACT²¹ is well-suited to explore alternative scenarios, impacts, and policy and investment responses at global, regional, and country scales. The IMPACT modeling system allows analysis of socioeconomic and climate pathways with different assumptions about policy, agricultural R&D, and investments—to understand the possible impacts on food security and other agricultural outcomes and to assess the investment costs required for climate change adaptation and for reducing hunger. An overview of the IMPACT modeling system is provided in Appendix 1 and the full list of commodities, countries, and regions covered are shown in Appendix Tables A2a.1 to A2a.3. The modeling system incorporates a linkage with the GLOBE global general equilibrium model, which is used to assess the economy-wide impacts of climate change and agricultural investments, including GDP, household income, and employment. Chapter 4 describes the GLOBE model and integration with IMPACT, together with the economy-wide results, and a full description of GLOBE is in Appendix 2.

3.6.1. Setting the Baseline Scenario

This section takes off from the previous section on identifying investment opportunities from the performance of the agriculture sector in the past that focused more on yield and productivity growth, area and/or animal stock expansion, and adaptation to the effects of climate change. These investment opportunities are simulated with the use of the IMPACT tool and evaluated by comparing with a baseline scenario.

There are three types of baseline investment scenario that relate to historical productivity growth and climate change. These include investment scenarios that assume the amount and type of investment that can sustain the historical crop and livestock productivity growth and area expansion to 2030, with and without the influence of climate change, defined and represented as:

- (i) **No climate change.** This no climate change (NoCC) investment scenario sustains historical agricultural productivity growth into the near future to 2030 and assumes an absence of climate change and/or any productivity impacts from it. Population and GDP growth are taken from the Shared Socioeconomic Pathway 2 (SSP2) from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 5th AR). SSP2 is a middle-of-the-road scenario that is based on historical trends on economic and demographic growth. Appendix 1 has additional details on SSPs.
- (ii) **Hadley Centre's Global Environmental Model.** The Hadley Centre Global Environmental Model (HGEM) climate change scenario utilizes the HGEM

²¹ A detailed IMPACT methodology can be found in S. Robinson et al. 2015. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3. *IFPRI Discussion Paper 1483*. Washington, D.C.: IFPRI. <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825>.

general circulation model together with SSP2 and Representative Circulation Pathway (RCP) 8.5, which has the highest rate of climate change utilized in the IPCC 5th AR. Therefore, this scenario preserves the baseline agricultural productivity growth, economic growth, and population growth to 2030, but imposes climate change to assess its impacts. Appendix 1 has more details on RCPs and methods.²²

- (iii) **Defensive research and development.** This is an investment scenario that assumes only an amount and type of investment that maintains and protects the gains in productivity, by preserving an annual investment stream for agricultural R&D at the 2015 level. This can also be conceptualized as investment in productivity maintenance research aimed only at avoiding yield losses or declines, and not intended for yield improvements. In this scenario, only endogenous productivity and area expansion due to changes in prices over time are considered. It is simulated only under climate change.

3.6.2. Production, Area, and Yield

Table 3.14 presents the results of IMPACT simulations on projected crop and livestock production, crop area, and yield in 2030 under alternative baseline investment scenarios.

Table 3.14: Projected Production Yield and Harvested Area in ADB Developing Member Countries, by Investment Scenario, With and Without Climate Change, 2030

Commodity	Projections for 2030						
	Base Year 2015	NoCC	Change from 2015	HGEM	Change from 2015	Def-R&D	Change from 2015
Production	('000 mt)		(%)	('000 mt)	(%)	('000 mt)	(%)
Meat Products	112,130	141,913	26.6	141,118	25.9	120,578	7.5
Beef and buffalo meat	16,487	24,011	45.6	23,986	45.5	17,506	6.2
Sheep and goat meat	7,379	9,958	35.0	9,953	34.9	8,178	10.8
Pork	58,741	63,078	7.4	62,631	6.6	62,452	6.3
Poultry meat	29,523	44,867	52.0	44,549	50.9	32,442	9.9
Cereals	914,483	1,071,506	17.2	1,017,197	11.2	858,910	(6.1)
Maize	237,207	302,136	27.4	278,304	17.3	204,365	(13.8)
Rice	393,109	436,563	11.1	418,796	6.5	382,136	(2.8)
Wheat	246,115	290,854	18.2	280,284	13.9	237,900	(3.3)
Fruits and Vegetables	944,141	1,234,086	30.7	1,209,216	28.1	1,082,317	14.6
Oilseeds	361,931	526,819	45.6	519,525	43.5	457,490	26.4
Pulses	27,734	33,664	21.4	32,272	16.4	27,636	(0.4)
Roots and Tubers	312,375	348,790	11.7	338,142	8.2	299,072	(4.3)
Sugarcane	665,347	883,849	11.7	842,924	2.9	716,661	(8.3)

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²² A comprehensive description of the IMPACT tool and methods for assessing climate change can be found in the source cited in footnote 22.

Table 3.14 continued

Commodity	Projections for 2030						
	Base Year 2015	NoCC	Change from 2015	HGEM	Change from 2015	Def-R&D	Change from 2015
Yield	(mt/ha)		(%)	(mt/ha)	(%)	(mt/ha)	(%)
Cereals	3.14	3.64	16.0	3.46	10.0	2.94	(6.3)
Maize	4.62	5.36	16.1	4.81	4.1	4.01	(13.1)
Rice	2.98	3.35	12.2	3.19	6.8	2.81	(5.7)
Wheat	3.13	3.64	16.2	3.55	13.6	3.06	(2.3)
Fruits and Vegetables	16.45	19.63	19.3	19.26	17.1	17.69	7.5
Oilseeds	4.33	5.60	29.5	5.39	24.6	4.63	7.0
Pulses	0.88	1.10	25.1	1.06	20.3	0.86	(2.3)
Roots and Tubers	18.75	20.40	8.8	19.43	3.7	17.76	(5.3)
Sugarcane	65.31	72.94	11.7	67.21	2.9	59.92	(8.3)
Area	('000 ha)		(%)	('000 ha)	(%)	('000 ha)	(%)
Cereals	291,121	294,173	1.0	294,389	1.1	291,967	0.3
Maize	51,382	56,380	9.7	57,887	12.7	50,925	(0.9)
Rice	131,794	130,432	(1.0)	131,467	(0.2)	135,931	3.1
Wheat	78,653	79,999	1.7	78,857	0.3	77,827	(1.1)
Fruits and Vegetables	57,398	62,862	9.5	62,780	9.4	61,188	6.6
Oilseeds	83,655	94,024	12.4	96,336	15.2	98,803	18.1
Pulses	31,522	30,591	(3.0)	30,483	(3.3)	32,150	2.0
Roots and Tubers	16,661	17,097	2.6	17,400	4.4	16,836	1.0
Sugarcane	10,187	12,118	19.0	12,541	23.1	11,961	17.4

() = negative, ADB = Asian Development Bank, Def-R&D = defensive research and development, ha = hectare, HGEM = Hadley Centre Global Environment Model, mt = metric ton, NoCC = no climate change scenario.

Source: IMPACT simulation results.

Results show that under NoCC, projected production of meat is estimated to increase by 26.6%, cereals by 17.2%, fruits and vegetables by 30.7% and oilseeds by 45.6% without climate change. Projected yield increases are highest for oilseeds with 29.5%, pulses 25.1%, and for fruits and vegetables 19.6%.

Production and yield levels under HGEM are projected to be lower due to the impacts of climate change. Growth in production can still be as high as 50.9% (poultry meat) while yield can be as much as 24.6% (oilseeds). Projected area expansions, on the other hand, are highest in this scenario, as a response of producers to higher prices triggered by negative biophysical yield effects of climate change. Reduction in crop yields is less than the initial biophysical shocks due to producer responses to the induced price increases.

Defensive R&D investment projects a worst-case scenario for the food security pathway to 2030. Under this scenario, livestock production is projected to have minimal increases compared to 2015, and far below the corresponding HGEM investment scenario. Projections of crop area, production, and yield for this scenario are mostly diminishing from 2015 values, except for fruits and vegetables with an increase of 7.5% and oilseeds with an increase of 7.0% , and highest land expansion for oilseed crops at 18.1%.

With the above projections of different productivity growth pathways, any investment scenario for food security at a minimum must have the ability to at least maintain the historical productivity growth and the potential to counter the impacts of climate change that are projected to be more severe with time. The succeeding simulations and analyses, therefore, are set to use the HGEM scenario as the baseline from which all alternative investments for food security are evaluated with respect to the different indicators of food security—availability, accessibility, and impact on hunger and nutrition.

3.6.3. Hadley Centre Global Environmental Model as the Baseline Scenario of Climate Change

As the baseline for analysis, simulation results for the HGEM scenario are presented upfront in terms of yield effects, yield and production effects, world prices, net trade position, food consumption, and nutrition. Since climate change affects the entire world agriculture, some of the tables include projections for non-ADB DMCs and the world. Relative to ADB DMCs, the non-ADB DMCs can also be represented as the rest-of-the-world group, while the world as a group includes the ADB DMCs as well. For the ADB regional groupings, note that although simulation results are given separately for India and the PRC, the regional results for East Asia include that for the PRC and the South Asia results include that for India as well.

Productivity

Figure 3.12 and Tables 3.15a–3.15b show that climate change, on average, are projected to negatively affect crop productivity of ADB DMCs and non-ADB DMCs alike.²³ However, except for pulses, the detrimental impacts of climate change are notably lower for ADB DMCs than for non-ADB DMCs, and thus, lower also than the world in general. Climate change is projected to have adverse effects on yields in ADB DMCs by only 1.9% in 2030, as compared with 5.5% for non-ADB DMCs and 4.0%, on average, for the world.

²³ Note, however, that the yield values in Table 3.15a are different from the yield effects presented in Table 3.13. Values in Table 3.13 are solely due to biophysical effects of climate change on yields, while values in Table 3.15 also include the economic response of producers to changes in prices due to climate shocks.

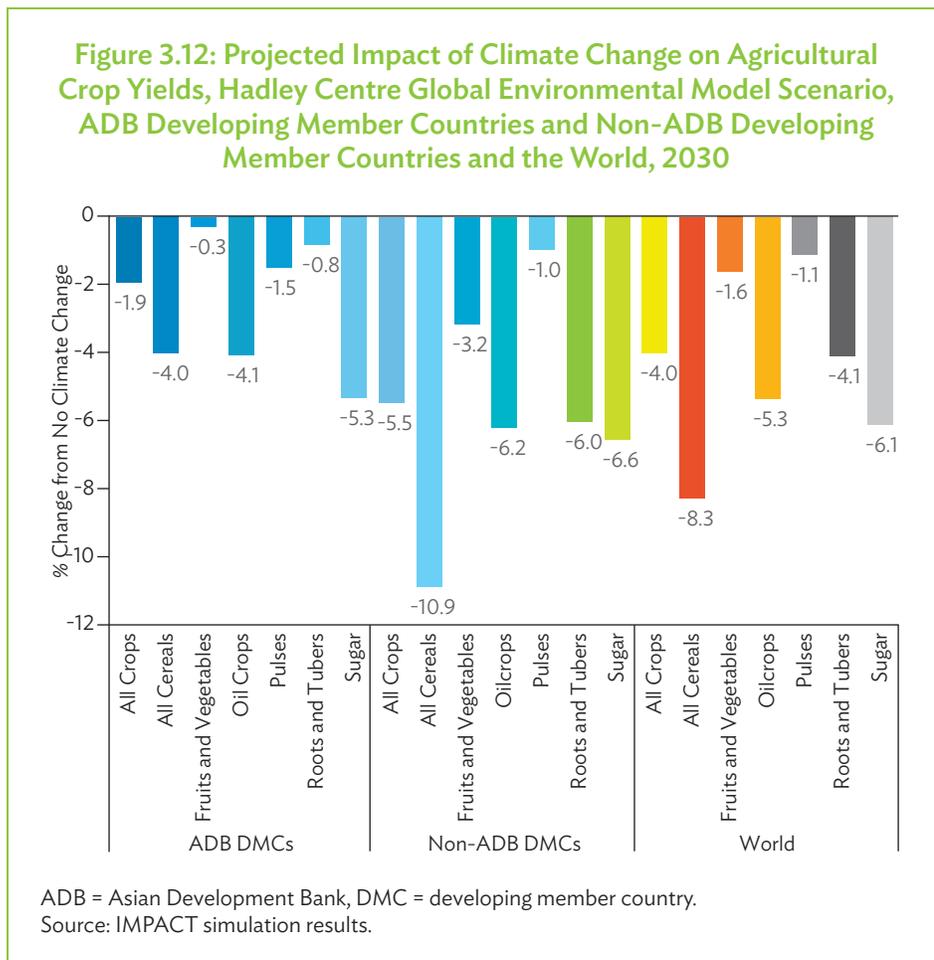


Table 3.15a: Projected Impact of Climate Change on Crop Yields and Production Under the Hadley Centre Global Environment Model Scenario, 2030

Commodity	ADB DMCs	Non-ADB DMCs	World	Central and West Asia	East Asia	Pacific	South Asia	Southeast Asia	PRC	India
	(% change from NoCC)									
Yield										
All Crops	(1.93)	(5.47)	(4.01)	(2.27)	0.59	(0.69)	(4.56)	(2.95)	0.61	(4.59)
All Cereals	(4.01)	(10.89)	(8.27)	(4.95)	(1.89)	(5.12)	(6.13)	(5.34)	(1.92)	(6.76)
Fruits and Vegetables	(0.29)	(3.15)	(1.61)	(2.46)	2.04	1.05	(5.23)	(2.49)	2.10	(5.41)
Oil crops	(4.08)	(6.19)	(5.35)	(1.98)	0.98	(3.69)	(7.51)	(2.90)	1.00	(7.61)
Pulses	(1.49)	(0.98)	(1.13)	(10.35)	2.24	(4.35)	(1.27)	(3.55)	2.24	(1.14)
Roots and Tubers	(0.82)	(6.04)	(4.10)	(1.37)	(1.35)	(0.24)	(1.29)	1.03	(1.31)	0.49

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Table 3.15a continued

Commodity	ADB	Non-	World	Central	East	Pacific	South	Southeast	PRC	India
	DMCs	ADB		and						
(% change from NoCC)										
Sugar	(5.34)	(6.56)	(6.12)	(5.06)	(0.41)	(1.54)	(5.11)	(8.99)	(0.41)	(5.05)
Production										
All Crops	(1.36)	(4.86)	(3.42)	(2.22)	1.39	0.03	(4.05)	(2.28)	1.41	(4.10)
All Cereals	(4.91)	(12.88)	(9.84)	(5.93)	(2.36)	(6.17)	(7.53)	(5.73)	(2.40)	(8.48)
Fruits and Vegetables	0.05	(3.12)	(1.42)	(1.07)	2.97	1.38	(6.48)	(1.98)	3.05	(6.75)
Oil crops	(0.07)	(0.68)	(0.36)	3.62	3.94	(2.88)	(1.41)	(0.50)	3.95	(1.37)
Pulses	(0.98)	0.51	(0.04)	(11.83)	2.48	(6.07)	(0.13)	(4.93)	2.50	0.10
Roots and Tubers	3.27	(3.86)	(1.36)	4.19	1.90	0.70	6.13	4.07	1.95	9.84
Sugar	(1.99)	(0.96)	(1.29)	(0.84)	1.84	0.86	(1.99)	(4.99)	1.84	(1.89)

() = negative, ADB = Asian Development Bank, DMC = developing member country, NoCC = no climate change scenario, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.15b: Projected Impact of Climate Change on Livestock Production under the Hadley Centre Global Environment Model Scenario, 2030

Commodity	ADB	Non-	World	Central	East	Pacific	South	Southeast	PRC	India
	DMCs	ADB		and						
(% change from NoCC)										
All Meat Products	(0.23)	(1.94)	(1.31)	(0.88)	(0.01)	1.16	(1.79)	0.08	0.08	(2.07)
Beef	(1.01)	(0.42)	(0.56)	(0.13)	(0.58)	0.54	(2.03)	(2.21)	(0.57)	(2.26)
Lamb	(0.17)	(0.23)	(0.20)	(0.12)	0.11	0.17	(0.77)	0.23	0.11	(0.76)
Poultry	(2.07)	(2.71)	(2.49)	(4.20)	(2.74)	2.83	(1.85)	(0.10)	(2.77)	(2.29)
Dairy	(1.03)	0.34	(0.17)	(0.80)	0.04	0.22	(1.48)	(1.58)	0.09	(1.49)

() = negative, ADB = Asian Development Bank, DMC = developing member country, NoCC = no climate change scenario, PRC = People's Republic of China.

Source: IMPACT simulation results.

The most pronounced differential effects are projected for roots and tubers with only 0.8% decline for ADB countries but with as much as 6.0% reduction for non-ADB countries. This is followed by fruits and vegetables (-0.3% for ADB countries and -3.2% for non-ADB countries), and cereals (-4.0% for ADB countries and -10.9% for non-ADB countries). Consequently, production effects of climate change on these crops are estimated to be even milder for ADB countries relative to non-ADB countries—and with positive values for roots and tubers (3.3%) and fruits and vegetables (0.1%).

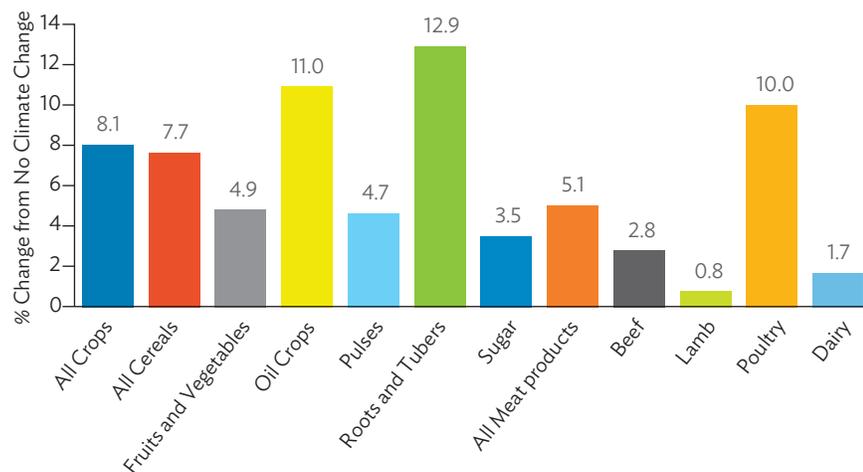
At the country and regional levels, the location-specificity of the impact of climate change is clearly indicated by average positive impacts for all crops at 0.61% for the PRC and 0.59% for East Asia. Other crops with positive net yield effects of climate change include fruit and vegetables (2.1%), oil crops (1.0%), and pulses (2.2%). The Pacific region has positive yield effects on fruits and vegetables (1.1%), and in Southeast Asia on roots and tubers (1.0%). However, for India, South Asia, and Central and West Asia, productivity losses are much higher and a cause of concern. Yields for India are projected to drop by 4.6% for all crops, 6.8% for cereals, 5.4% for fruits and vegetables, and by 7.6% for oil crops. Yields in Central and West Asia are estimated to deteriorate for all crops by 2.3%, cereals by 5.0%, sugar by 5.1%, and pulses by 10.4%.

Through the indirect effects of climate change on feed crops, primarily maize, livestock production is projected to weaken by as much as 2.1% for poultry, -1.0% for dairy products and 1.0% for beef in ADB countries in 2030.

World Prices

Because the effects of climate change are global and trigger the worsening of productivity everywhere, world prices are projected to increase in 2030, on average, by 8.1% for all crops, and by 5.1% for all meat products (Figure 3.13). Results of projections indicate that the most increase is in root crops and tubers (12.9%), oil crops (11.0%), and poultry meat (10.0%). The least increases are projected for lamb and goat meat (0.8%) and dairy products (1.7%).

Figure 3.13: Projected Effects of Climate Change on World Prices of Food Commodities, Hadley Centre Global Environmental Model Scenario, 2030

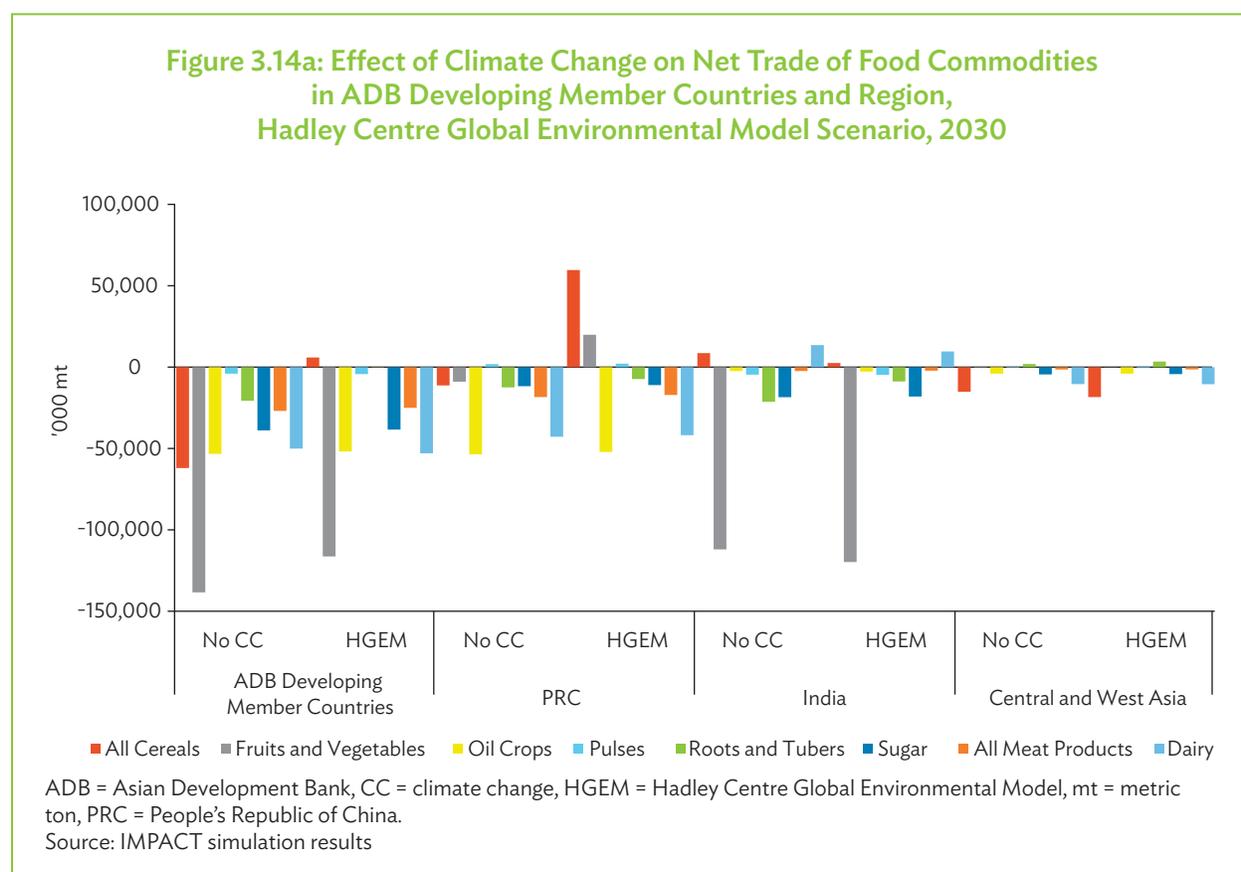


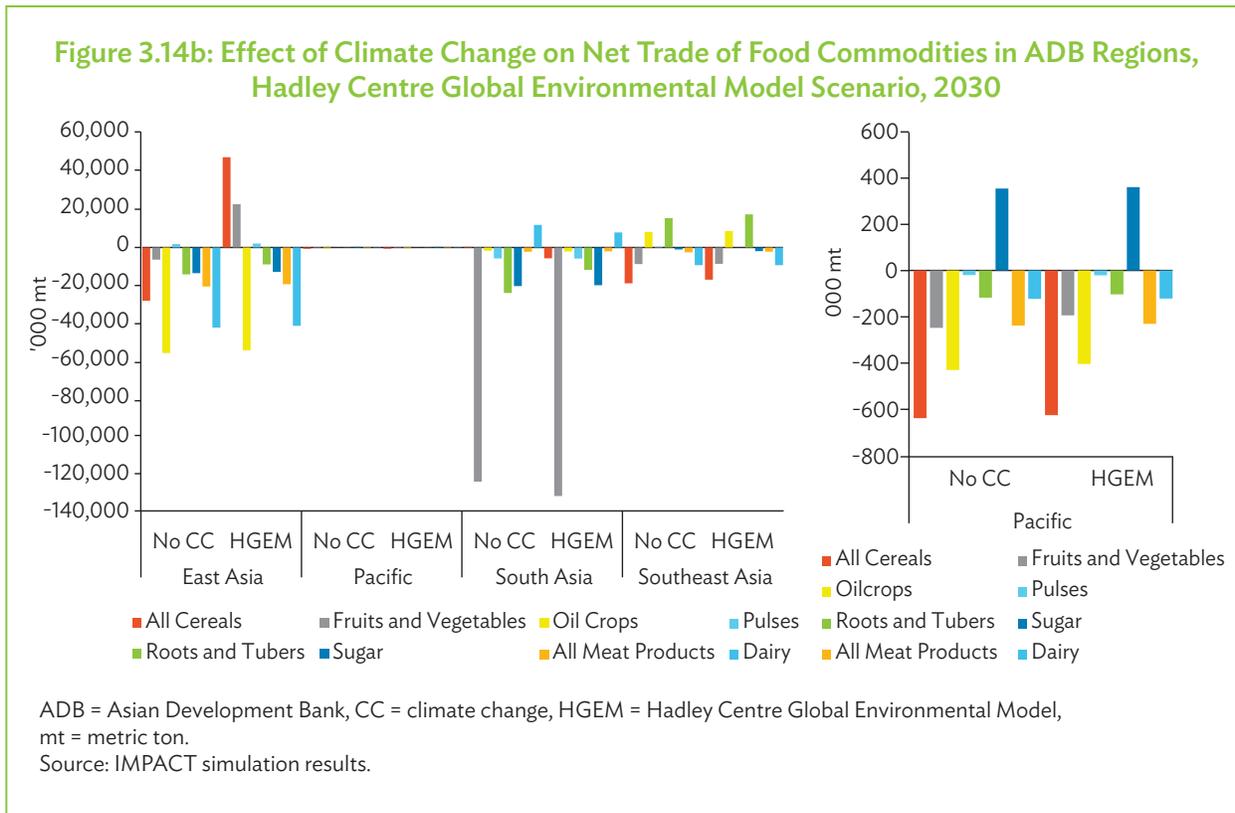
Source: IMPACT simulation results.

Net Trade

The lower impacts of climate change on productivity of crops and livestock commodities in ADB DMCs and regions relative to non-ADB DMCs contribute to a slight improvement in the region's net trade for some commodities and a worsening for other commodities. Higher world commodity prices due to climate change globally induce a partially offsetting increase in production in the ADB regions. The improvement in net trade for some commodities is due also to the decline in income and rise in prices due to climate, which reduces demand. Whether the total effect on trade is positive or negative depends on the responsiveness of production and demand to changes in climate, prices, and income. Figures 3.14a–3.14b show the impact of climate change on the net trade for crop and livestock commodities in ADB DMCs and regions. For some commodities in ADB regions as a whole, imports are projected to reverse to net exports. For example, for cereals (6.0 million metric tons [mt] of exports) and root crops (0.2 million mt), but for pulses, imports are projected to increase by 0.3 million mt in 2030 due to climate change. Net imports of livestock products are also projected to slightly decline overall for all meat products with minor increases for dairy products.

Similar projected impacts hold for the PRC (reduction in crop and livestock imports), East Asia, and the Pacific. India is projected to import more of fruits and vegetables and pulses, and export less of cereals. The rest of the regions are projected to import more of food crops and less of livestock products.





Food Consumption

The general effects of climate change on food security are reflected in the projected amount of food available for consumption. Despite the relatively moderate impacts of climate change on ADB DMCs and better trade position, per capita consumption of food (crops and livestock) is projected to decline for all regions—DMCs and non-DMCs, India, the PRC, and the Asian regions (Figure 3.15 and Tables 3.16a–3.16b). This highlights that despite the site-specificity of the effects of climate change, on the bigger scale of countries or regions, the overall effect of climate change is the decline in productivity and the subsequent reduction of available food.

Table 3.16a: Effects of Climate Change on Per Capita Food Consumption Under the Hadley Centre Global Environment Model Scenario, 2030

Commodity	ADB DMCs		Non-ADB DMCs		PRC		India	
	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM
	(kg/capita/year)							
All Crops	541.3	531.4	486.1	477.6	745.5	736.2	475.5	463.0
All Cereals	155.3	153.4	137.3	136.2	152.3	150.6	144.4	142.5
Fruits and Vegetables	282.0	277.5	194.3	191.9	464.6	460.9	233.6	227.1
Oil crops	10.2	10.0	5.9	5.7	16.7	16.4	4.9	4.7

continued on next page

Table 3.16a continued

Commodity	ADB DMCs		Non-ADB DMCs		PRC		India	
	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM
	(kg/capita/year)							
Pulses	6.3	6.2	8.9	8.8	1.7	1.7	12.0	11.9
Roots and Tubers	51.6	48.8	91.1	86.7	82.3	78.8	38.2	35.1
Sugar	21.6	21.2	28.9	28.5	11.8	11.6	29.6	29.0
All Meat Products	39.0	38.5	52.8	52.1	79.2	78.4	9.6	9.3
Beef	7.0	7.0	17.0	16.9	10.8	10.7	2.8	2.8
Lamb	2.8	2.8	2.8	2.8	5.1	5.1	1.2	1.2
Poultry	11.7	11.4	20.4	19.9	19.9	19.2	5.0	4.8
Dairy	80.7	79.9	118.4	118.1	83.2	82.6	100.0	98.5

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, kg = kilogram, NoCC = no climate change scenario, PRC = People's Republic of China.

Source: IMPACT simulation results.

Higher rates of decline in consumption of all commodity groups are projected for ADB DMCs than for non-ADB DMCs; and the rates are highest for India and South Asia (Figure 3.15).

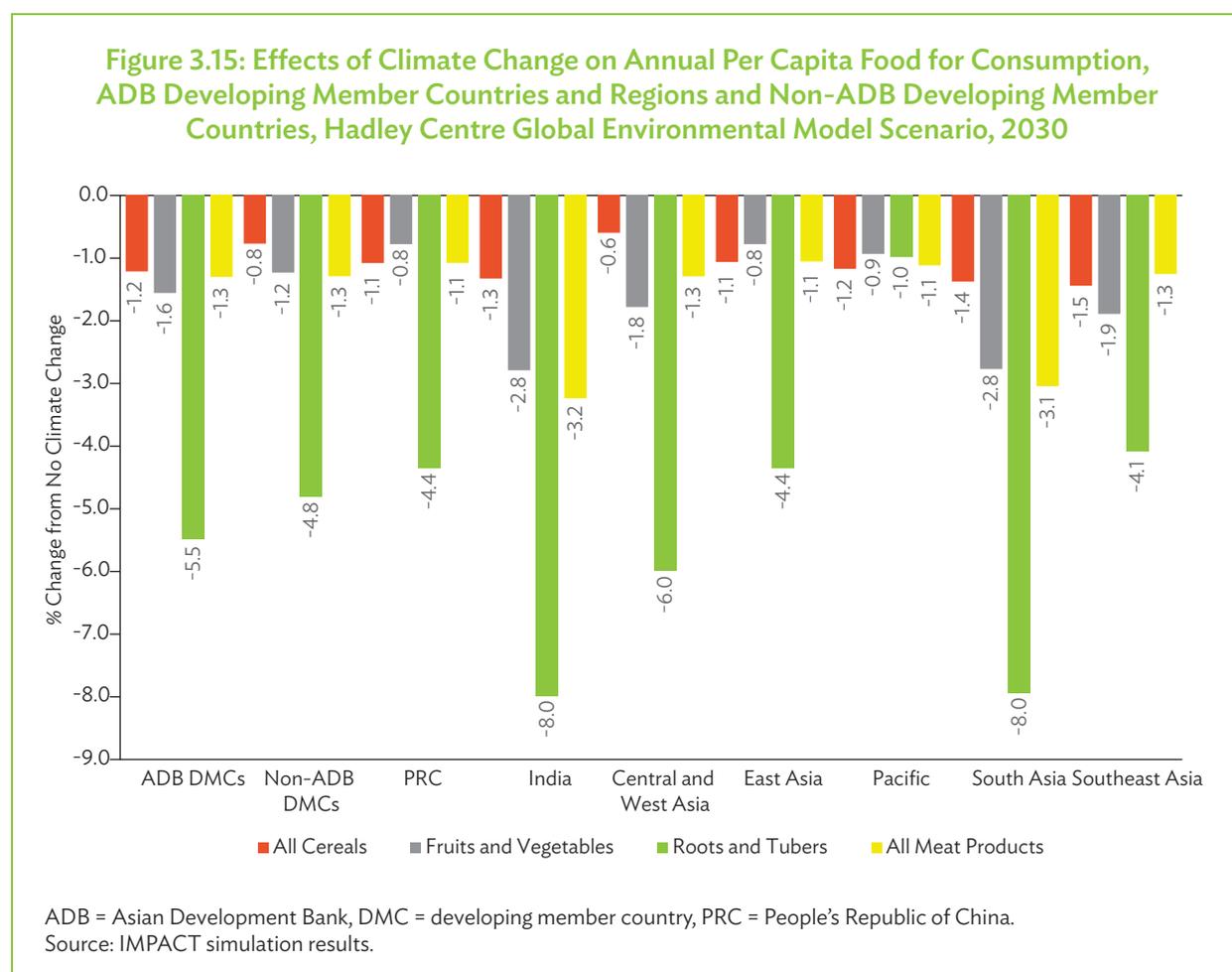


Table 3.16b: Effects of Climate Change on Per Capita Food Consumption in ADB Developing Member Countries, by Region Under the Hadley Centre Global Environment Model Scenario, 2030

Commodity	Central and West Asia		East Asia		Pacific		South Asia		Southeast Asia	
	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM	NoCC	HGEM
	(kg/capita/year)									
All Crops	354.6	349.2	737.7	728.5	548.4	541.2	462.6	450.4	437.5	429.4
All Cereals	161.7	160.8	151.8	150.2	46.8	46.2	151.4	149.3	171.3	168.8
Fruits and Vegetables	121.7	119.5	459.0	455.4	170.5	168.9	215.6	209.7	174.7	171.4
Oil crops	0.7	0.6	16.5	16.2	110.1	107.2	5.2	5.0	13.2	12.9
Pulses	4.5	4.5	1.7	1.7	2.4	2.4	11.4	11.2	3.6	3.6
Roots and Tubers	26.4	24.9	80.1	76.6	186.8	185.0	39.2	36.1	35.5	34.0
Sugar	26.4	25.9	12.2	12.1	11.3	11.2	27.1	26.6	24.5	24.2
All Meat Products	24.0	23.7	79.7	78.8	29.4	29.1	9.6	9.3	38.2	37.7
Beef	12.3	12.2	11.2	11.1	3.6	3.6	3.1	3.0	5.8	5.8
Lamb	5.2	5.2	5.1	5.1	1.3	1.3	1.4	1.3	0.7	0.7
Poultry	5.0	4.9	19.8	19.2	6.6	6.4	4.7	4.5	16.7	16.3
Dairy	147.4	146.6	81.3	80.7	9.6	9.5	90.6	89.3	19.6	19.5

ADB = Asian Development Bank, HGEM = Hadley Centre Global Environment Model, kg = kilogram, NoCC = no climate change scenario.

Source: IMPACT simulation results.

Hunger and Nutrition

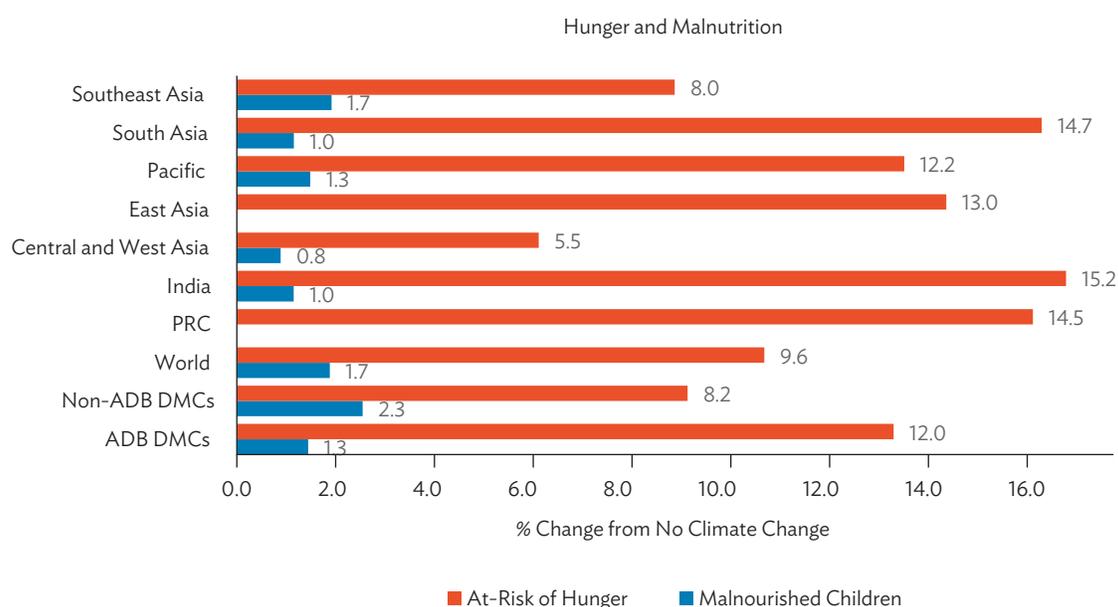
The impacts of climate change on nutrition and food security are indicated by the changes in the number of malnourished children (5 years old and below) and the number of people at-risk of hunger, determined and estimated by available energy foods (kilocalories per capita per day).

Under the assumption of NoCC, the total number of malnourished children globally is projected to decline from 145 million in 2015 to 125 million in 2030. But with climate change, the estimated reduction is up to 127 million malnourished children. Similarly, the number of hungry people in the world at 872 million in 2015 is also projected to be reduced to 662 million by 2030, but with climate change, the estimated decline is set to 727 million.

In ADB DMCs, the number of malnourished children at 93 million in 2015 will fall to 75 million in 2030 under NoCC and only to 76 million with climate change. On the other hand, the number of hungry people at 507 million in 2015 (13% of the population) is projected to decline to 324 million (7.5% of population) in 2030 and to 362 million (8.4% of population) due to climate change.

The same trend was observed in reducing, if not eliminating, hunger and malnutrition under the HGEM scenario for all the ADB DMCs. Under this scenario, India is expected to add 15 million and the PRC 11 million hungry people. In terms of percentages, the number of people at-risk of hunger are projected to increase by 14.5% in the PRC and 15.2% in India and similarly with their respective East Asia (13.0%) and South Asia (14.7%) regions (Figure 3.16; Tables 3.17a–3.17b).

Figure 3.16: Effects of Climate Change on the Number of Malnourished Children and Population At-Risk of Hunger, Developing Member Countries and Regions, Non-ADB Developing Member Countries, and World, Hadley Centre Global Environmental Model Scenario, 2030



ADB = Asian Development Bank, DMC = developing member country, PRC = People's Republic of China.

Note: The PRC and East Asia achieve very low levels of child malnutrition under the no climate change scenario. The percentage increase in numbers of malnourished children in East Asia due to climate change is 42%, or an additional 140,000 malnourished children.

Source: IMPACT simulation results.

Table 3.17a: Effects of Climate Change on Food Security Under the Hadley Centre Global Environment Model Scenario, 2030

Food Security Indicators	ADB DMCs			Non-ADB DMCs			World			PRC			India		
	2015	NoCC	HGEM	2015	NoCC	HGEM	2015	NoCC	HGEM	2015	NoCC	HGEM	2015	NoCC	HGEM
Energy Cons (Kcal/capita/day)	2,750	3,018	2,978	2,970	3,051	3,019	2,852	3,034	2,998	3,216	3,616	3,578	2,426	2,697	2,654
Total Malnourished Children (million)	93.1	75.4	76.4	52.0	49.7	50.8	145.0	125.1	127.3	4.1	0.4	0.5	54.6	45.5	45.9
Share of Population At-Risk of Hunger (%)	13.0	7.5	8.4	10.8	8.5	9.2	12.0	8.0	8.8	9.7	5.5	6.3	14.7	6.6	7.6
Population at-Risk of Hunger (million)	507	324	362	365	337	365	872	662	727	132	76	87	193	101	116

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, Kcal = kilocalorie, NoCC = no climate change scenario, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.17b: Effects of Climate Change on Food Security Under the Hadley Centre Global Environment Model Scenario, 2030

Food Security Indicators	Central and West Asia			East Asia			Pacific			South Asia			Southeast Asia		
	2015	NoCC	HGEM	2015	NoCC	HGEM	2015	NoCC	HGEM	2015	NoCC	HGEM	2015	NoCC	HGEM
Energy Food Cons (Kcal/capita/day)	2,492	2,625	2,602	3,214	3,606	3,569	2,482	2,745	2,711	2,432	2,696	2,653	2,601	2,841	2,799
Total Malnourished Children (million)	11.2	11.1	11.1	4.2	0.4	0.5	0.4	0.4	0.4	64.2	53.5	54.0	13.2	10.2	10.4
Share of Population At-Risk of Hunger (%)	19.1	14.5	15.3	9.5	5.4	6.1	12.3	4.1	4.6	14.8	6.8	7.8	13.9	10.0	10.8
Population At-Risk of Hunger (million)	59	55	58	135	78	89	1.44	0.59	0.67	226	121	139	87	70	75

ADB = Asian Development Bank, HGEM = Hadley Centre Global Environment Model, Kcal = kilocalorie, NoCC = no climate change scenario.

Source: IMPACT simulation results.

Climate Change and Investment for Food Security

The impacts of changes in climate on food productivity are projected to be more pronounced in later years, 2050 onwards, although preliminary effects will start to appear in 2030. Productivity impacts of climate change are more evident and widely documented for crop commodities compared with livestock. The production of livestock is indirectly affected by climate change though it will impact feed crops and cereals such as maize.

The effects of changes in climate are not uniform for all countries and for all crop commodities, but on average globally, are towards declining yields. Compared with non-ADB DMCs (and the world), the impacts of climate change are less severe for countries in Asia and the Pacific, but by country and region comparisons, South Asia and Central and West Asia remain to be causes for concern with all crop yields projected to drop substantially.

World prices of food commodities are projected to rise by as much as 8.1% overall for all food crops. With high food prices, accessibility and consumption would be reduced and the prevalence of hunger and malnutrition could intensify.

Investment for food security for ADB regions at the minimum should be able to counteract the negative impacts of climate change on yields and subsequent decline in production. But this may not be enough to tackle the less accessibility and diminishing consumption because of high food prices. Since increases in the world prices of food are supposed to be caused by slackening of crop productivity worldwide, productivity-enhancement investments in ADB regions should be able to compensate for such losses globally, which are collectively higher than losses in the ADB regions alone. It is anticipated that investments made outside of ADB regions would complement the investment in the ADB regions. Another option to offset the detrimental effects of climate change is substantial investment in ADB countries to over-compensate for local effects of climate enough to move prices down to NoCC levels.

3.7. Investment in Productivity Enhancement

This section presents two sets of investment alternatives for enhancing land and water productivity as the means of counteracting the damaging impacts of climate change and achieve food security and nutrition goals of the ADB DMCs and regions. The first set includes investment in agricultural R&D and the other set includes investment in irrigation expansion and water use efficiency.

3.7.1. Investment in Agricultural Research and Development

New and innovative agricultural technologies are continually being developed by agricultural R&D to expand agricultural productivity and improve food security and nutrition, and to combat the ill effects of climate change—both for mitigation and adaptation to climate change.

The international agricultural research centers (IARCs) around the world have been at the forefront in the development of productivity increasing technologies. At the national level, the national agricultural research system (NARS) is an active partner of agricultural research centers and acts as the direct link to farmers in disseminating knowledge and information based on scientific research. Whether maintaining or improving on existing technologies, both IARCs and NARS are at the forefront of achieving the next green revolution—in biotechnology, plant breeding, or gene-based technology.

In addition to varietal improvement and seed technology, other categories of technologies may include: (i) farm management technologies and practices such as no-till, integrated soil fertility management (ISFM), water harvesting, and precision agriculture; and (ii) crop protection technologies geared against new strains of pests, diseases, and weeds anticipated to evolve with the onset of climate change.

Three scenarios are simulated under the R&D investment category based on increased investment in IARCs; investment in NARS; and investment in high-impact and high-efficient research. These are further defined and described below as:

- (i) **Hi-IARCs.** This stands for increased investment in IARCs typified by the CGIAR centers globally and across commodity groups. Estimates of yield gains for this scenario were from CGIAR center researchers compiled by the IMPACT team at IFPRI. Potential yield gains range from 20% to 35% for cereals; 15% to 20% for fruits and vegetables; 15% to 30% for roots and tubers; and 10% to 20% for livestock. Yield gains are accelerated in early years, achieving 60% of the potential in 15 years and peak yields in 30 years.
- (ii) **Hi+NARS.** This combines high investment in IARCs and high investment in NARS. The complementarity can achieve higher yield gains, and the extension work of the NARS with the farmers increases the level of technology adoption. Under this scenario, yield gains can be 30% higher than Hi-IARCs alone.
- (iii) **Hi+NARS+EFF.** This scenario adds investment in advanced technologies for higher research efficiency to Hi+NARS. In this scenario, the lag time from discovery to adoption is reduced and the productivity impact of research is increased. Investment in research efficiency through advanced R&D technology generates higher returns by creating efficiencies in the discovery, development, and dissemination of new technologies. Potential yield gains are similar to Hi+NARS, but yield increases are accelerated in early years (10 to 15 years), while the peak is achievable in 20 to 25 years. This also requires the highest investment rate and capital outlay during the early years (5 to 10 years).

Agricultural Research and Development Investments in the Reference Scenario

As noted above, one of the primary drivers of long run productivity growth is technology driven by investment in agricultural R&D. Projected investments in agricultural R&D in the reference scenario by both CGIAR and NARS in Asia and the Pacific are based on historical trends computed from the Agricultural Science and Technology Indicators (ASTI) database and Stads (2016), simulating historical trends and changes in trend by time period.

The projected annual investments in agricultural R&D by the CGIAR (IARCs) and Asia and the Pacific NARS over the 2016–2030 projection period for the reference scenario (as well as the investment scenarios for irrigation and infrastructure) are shown in Table 3.18. The projected average annual CGIAR investment in Asia and the Pacific is \$330 million per year, while the NARS investment is \$7.1 billion per year. The NARS investments are heavily concentrated in East Asia, reflecting recent history, followed by South Asia. The reference scenario investments are consistent with recent data on actual public investment by Asia and the Pacific NARS in agricultural R&D. Public agricultural R&D investments in 2013 in 25 low- and middle-income countries in Asia and the Pacific totaled \$8.4 billion (in real 2011 prices), (ASTI Global Update, 2019) or \$6 billion in real 2005 prices for comparison with the reference value agricultural R&D investments shown in Table 3.18.

In addition to public expenditures on agricultural R&D, private sector investment in agricultural R&D plays an important role in agricultural growth. Globally, private agricultural R&D reached \$12.9 billion in 2014 (in PPP \$), doubling from 1990. Of this amount, developing countries account for \$1.7 billion, or 13% of the total.²⁴ Although a directly comparable estimate is not available for the Asia and Pacific region for 2014, estimates for 2000 showed that the Asia and Pacific region accounted for 77% of developing country private agricultural R&D (and the PRC and India account for half of the expenditures in the region) (Pardey et al. 2006). Applying this factor to global private expenditures in 2014 gives an estimate of \$1.3 billion (in 2005) for the Asia and Pacific region private sector investments in 2014, or about 22% as high as public R&D expenditure. Allowing for a 3% increase (which is the trend growth, 1990 to 2014, for global private R&D expenditures) gives \$1.34 billion as the 2015 base year value of Asia and the Pacific private sector investments in the model. Private sector investment outside of the Asia and Pacific region can also have impacts on productivity growth in the region. Using the same approach, private sector investment in agricultural R&D in the rest of the world in 2015 is set at \$11.5 billion (in 2005), allowing for 3% growth from the 2014 estimated value. Projected growth in private sector investment for the baseline is set at 3% per year for all scenarios, reflecting the trend growth. Alternative scenarios for private sector investment in agricultural R&D are not simulated, given the focus of this report on public investments. Investments in public sector agricultural R&D in regions other than Asia and the Pacific are likewise maintained at the projected levels in the reference scenario, to isolate the impact of investments in Asia and the Pacific in the alternative scenarios.

²⁴ K. Fuglie. 2016. The Growing Role of the Private Sector in Agricultural Research and Development Worldwide. *Global Food Security*. 10. pp. 29–38. <http://dx.doi.org/10.1016/j.gfs.2016.07.005>.

Table 3.18: Average Annual Public Investments in Asia and the Pacific, Reference Scenario, 2016–2030 (\$ billion, 2005)

Region	R&D			Water			Rural Infrastructure				Total for Region
	IARCs	NARS	Total	Irrigation	Water Use Efficiency	Total	Road	Rail	Electricity	Total	
Central and West Asia	0.10	0.25	0.35	0.43	0.52	0.95	0.27	0.32	0.27	0.86	2.16
East Asia	0.02	5.10	5.12	2.91	1.59	4.50	4.77	1.35	5.50	11.62	21.24
Pacific	0.00	0.01	0.01	0.02	0.01	0.03	0.06	0.02	0.07	0.15	0.19
South Asia	0.16	1.09	1.25	3.08	1.54	4.62	2.33	2.38	2.81	7.52	13.39
Southeast Asia	0.05	0.65	0.70	1.15	0.63	1.78	0.92	0.26	1.06	2.24	4.72
Total for Asia and the Pacific	0.33	7.10	7.43	7.59	4.29	11.88	8.35	4.33	9.71	22.39	41.70

IARC = international agricultural research center, NARS = national agricultural research center, R&D = research and development.

To translate these R&D investments into changes in agricultural productivity growth in the reference and alternative investment scenarios, this study developed an R&D investment–yield model. Investments in research take time to bear fruit, as new ideas can take years to develop and diffuse widely. To capture these lags, the investment–yield estimation model is based on the perpetual inventory method, where research investments contribute to the stock of knowledge over time. Knowledge itself becomes passe as older technologies become obsolete or irrelevant. Productivity grows if the stock of knowledge develops at a rate faster than the stock of knowledge decays. The lag structure in the perpetual inventory method used here follows a gamma distribution where R&D investments reach peak impact 10 years after initial investment and then decline over time to reach zero 10 years after peak impact.

Research capacity varies significantly by region, and to reflect these differences this study used elasticities of productivity with respect to research investments from the literature.²⁵ This study also utilized another paper to incorporate spillover effects, where spillover elasticities represent regional capacity to access and apply outside knowledge along with distance metrics to estimate the applicability of outside research to regional agriculture.²⁶ There are varying returns to research investment not only by region, but also by type of public research institution. These differences are represented by different elasticities that show greater efficiency by the CGIAR

²⁵ R. E. Evenson and D. Gollin. 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*. 300 (5620). pp. 758–762. <https://science.sciencemag.org/content/300/5620/758>; A. Nin-Pratt. 2015. Inputs, Productivity, and Agricultural Growth in Africa South of the Sahara. *IFPRI Discussion Paper 1432*. Washington, D.C.: IFPRI. <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129095>; A. Nin-Pratt et al. 2015. Productivity and the Performance of Agriculture in Latin America and the Caribbean: From the Lost Decade to the Commodity Boom. *IDB Working Paper Series 608*. Inter-American Development Bank (IDB). <http://cdm15738.contentdm.oclc.org/cdm/ref/collection/p15738coll5/id/5105>; and A. Nin-Pratt. 2016. Inputs, Productivity, and Agricultural Growth in Sub-Saharan Africa. In W. H. Greene et al, eds. *Productivity and Efficiency Analysis*. Springer.

²⁶ J. M. Alston et al. 2011. The Economic Returns to U.S. Public Agricultural Research. *American Journal of Agricultural Economics*. 93 (5). pp. 1257–1277. <https://doi.org/10.1093/ajae/aar044>.

system as compared to that of NARS'.²⁷ However, as shown in Table 3.18, investment in agricultural R&D by NARS in Asia and the Pacific are far larger than by the CGIAR.

Using the same methodology, this study also jointly estimated the projected investment costs and impacts of the three alternative R&D scenarios Hi-IARCs, Hi+NARS, and Hi+NARS+EFF. The investment costs for these scenarios are summarized in Table 3.19.

Table 3.19: Annual Additional Investment Cost for Agricultural Research and Development of Hi-IARCs, Hi+NARS, and Hi+NARS+EFF Scenarios in Asia and the Pacific, 2016–2030
(\$ billion, 2005)

Region	Average Annual Cost		
	Hi-IARCs	Hi+NARS	Hi+NARS+EFF
Central and West Asia	0.04	0.16	0.22
East Asia	0.01	0.30	0.36
South Asia	0.10	0.25	0.38
Southeast Asia	0.05	0.28	0.35
Total for Asia and the Pacific	0.20	1.00	1.31

Hi+NARS+EFF investment in advanced technologies for higher research efficiency to Hi+NARS.

Hi-IARCs = increased investment in IARCs typified by the CGIAR centers globally and across commodity groups, Hi+NARS = intensified NARS research.

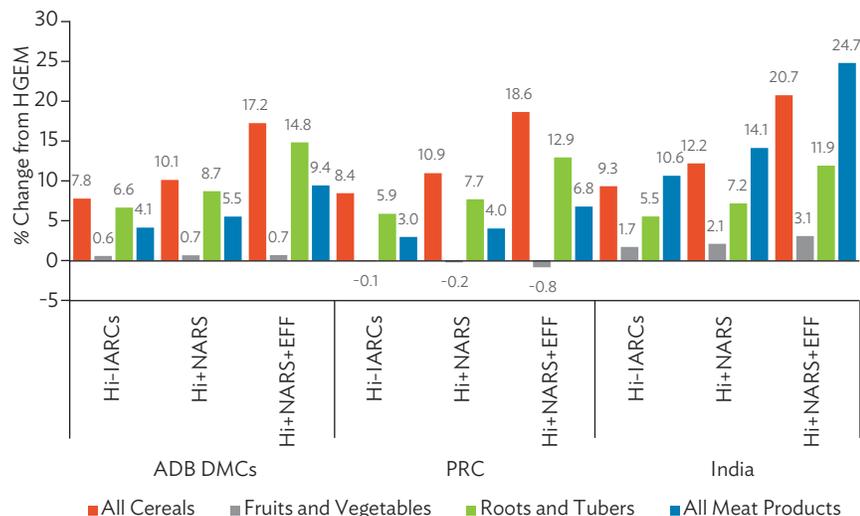
Simulation Results for Agricultural Research and Development Scenarios

Productivity

All three R&D scenarios are yield-enhancing investments for crops and livestock while having only a small impact on crop area. In addition to the exogenous biophysical yield increase infused on crops and livestock through R&D, endogenous changes in yields are also induced by producers' response to changes in prices of inputs and outputs, as part of the economic module of IMPACT. The net results of the biophysical and market effects on yield and production levels are simulated by IMPACT and presented in Figures 3.17a–3.17b and Tables 3.20a–3.20d.

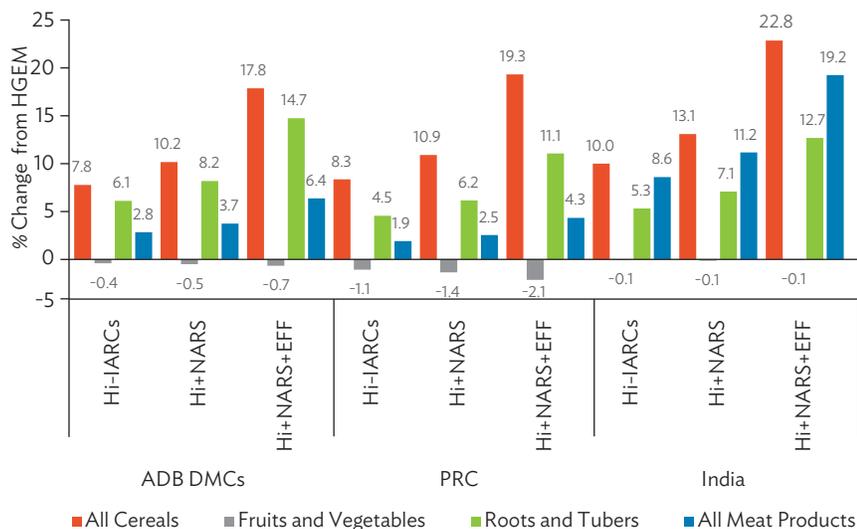
²⁷ R. E. Evenson and D. Gollin. 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*. 300 (5620). pp. 758–762. <https://science.sciencemag.org/content/300/5620/758>.

Figure 3.17a: Impact of Investment in Research and Development on Crop and Livestock Yields, ADB Developing Member Countries, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, PRC = People’s Republic of China. Source: IMPACT simulation results.

Figure 3.17b: Impact of Investment in Research and Development on Crop and Livestock Production, ADB Developing Member Countries, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, PRC = People’s Republic of China. Source: IMPACT simulation results.

Table 3.20a: Projected Impact of Investment on Research and Development on Crop and Livestock Yields in ADB Developing Member Countries, 2030

Commodity	ADB DMCs			PRC			India		
	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF
	(% change from HGEM)								
All Crops	2.79	3.61	5.95	2.70	3.46	5.64	2.85	3.69	6.10
All Cereals	7.76	10.10	17.20	8.44	10.94	18.59	9.31	12.16	20.70
Fruits and Vegetables	0.59	0.67	0.70	(0.08)	(0.22)	(0.84)	1.71	2.10	3.07
Oil crops	2.14	2.67	4.24	1.46	1.87	2.97	1.33	1.68	2.62
Pulses	7.93	10.41	17.72	4.06	5.30	8.82	9.43	12.36	20.94
Roots and Tubers	6.63	8.70	14.80	5.86	7.68	12.91	5.52	7.16	11.89
All Meat Products	4.13	5.51	9.40	2.96	4.02	6.76	10.62	14.09	24.74
Beef	6.84	8.98	15.42	5.34	6.99	11.85	10.92	14.40	24.98
Lamb	7.24	9.52	16.34	5.38	7.04	11.93	10.92	14.40	24.98
Poultry	6.11	8.00	13.64	5.31	6.96	11.79	10.86	14.32	24.82
Dairy	9.13	12.02	20.81	5.35	7.00	11.86	10.87	14.32	24.84

ADB = Asian Development Bank, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.20b: Projected Impact of Investment on Research and Development on Crop and Livestock Yields, by ADB Region, 2030

Commodity	Central and West Asia			East Asia			Pacific			South Asia			Southeast Asia		
	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF
	(% change from HGEM)														
All Crops	3.09	3.98	6.59	2.68	3.43	5.59	2.81	3.63	5.90	2.91	3.77	6.23	2.94	3.80	6.26
All Cereals	7.78	10.19	17.54	8.40	10.90	18.52	5.07	6.46	10.64	8.66	11.31	19.23	4.71	6.11	10.16
Fruits and Vegetables	0.32	0.34	0.28	(0.06)	(0.19)	(0.80)	9.04	11.77	19.80	1.68	2.08	3.06	2.49	3.22	5.30
Oil crops	(0.25)	(0.32)	(0.67)	1.45	1.86	2.95	0.38	0.41	0.33	1.25	1.57	2.42	3.19	4.06	6.52
Pulses	8.62	11.31	19.22	4.06	5.30	8.82	4.76	6.21	10.45	9.44	12.37	20.98	7.73	10.12	17.24
Roots and Tubers	8.03	10.50	17.84	5.84	7.65	12.85	5.01	6.55	11.10	5.41	7.02	11.66	9.84	12.98	22.72
All Meat Products	6.83	9.13	15.56	2.98	4.04	6.80	2.21	2.82	4.82	10.60	14.03	24.56	3.40	4.41	7.45
Beef	6.67	8.78	15.17	5.35	7.00	11.87	5.34	6.99	11.86	10.93	14.42	25.02	5.32	6.94	11.78
Lamb	7.04	9.26	15.99	5.38	7.04	11.94	5.34	6.99	11.87	10.91	14.38	24.94	5.37	7.03	11.92
Poultry	8.97	11.81	20.46	5.32	6.96	11.79	5.30	6.94	11.78	10.78	14.19	24.59	5.31	6.93	11.77
Dairy	8.14	10.71	18.61	5.33	6.97	11.83	4.96	6.48	10.98	10.92	14.39	24.97	5.99	7.84	13.40

ADB = Asian Development Bank, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, HGEM = Hadley Centre Global Environment Model.

Source: IMPACT simulation results.

Table 3.20c: Projected Impact of Investment on Research and Development on Crop and Livestock Production in ADB Developing Member Countries, 2030

Commodity	ADB Countries			PRC			India		
	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF
	(% change from HGEM)								
All Crops	2.31	3.06	5.51	2.14	2.86	5.27	2.58	3.41	6.06
All Cereals	7.77	10.16	17.84	8.35	10.89	19.30	9.99	13.07	22.83
Fruits and Vegetables	(0.41)	(0.50)	(0.66)	(1.08)	(1.36)	(2.14)	(0.08)	(0.14)	(0.07)
Oil crops	1.20	1.59	2.79	0.93	1.38	2.51	0.69	1.01	1.80
Pulses	7.29	9.70	17.10	3.37	4.75	9.23	8.39	11.10	19.31
Roots and Tubers	6.10	8.18	14.72	4.55	6.15	11.06	5.32	7.08	12.66
All Meat Products	2.83	3.73	6.36	1.90	2.54	4.33	8.58	11.16	19.23
Beef	6.14	8.01	13.74	4.47	5.80	9.76	10.91	14.34	25.17
Lamb	5.63	7.37	12.47	3.89	5.10	8.52	8.62	11.21	19.03
Poultry	4.75	6.12	10.40	4.20	5.37	9.14	8.80	11.34	19.24
Dairy	7.10	9.31	15.96	3.37	4.40	7.25	8.76	11.48	19.75

ADB = Asian Development Bank, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, HGEM = Hadley Centre Global Environment Model, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.20d: Projected Impact of Investment on Research and Development on Crop and Livestock Production, by ADB Region, 2030

Commodity	Central and West Asia			East Asia			Pacific			South Asia			Southeast Asia		
	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	Hi-IARCs	Hi+NARS	Hi+NARS+EFF
	(% change from HGEM)														
All Crops	2.59	3.39	5.81	2.13	2.84	5.22	2.30	3.02	5.29	2.62	3.46	6.14	2.20	2.90	5.20
All Cereals	7.33	9.64	16.84	8.30	10.84	19.19	4.81	6.09	10.90	9.14	11.97	20.88	4.22	5.51	9.60
Fruits and Vegetables	(0.11)	(0.13)	(0.12)	(1.04)	(1.31)	(2.07)	8.85	11.53	19.62	0.07	0.06	0.27	2.23	3.02	5.70
Oil crops	(0.09)	0.01	0.02	0.93	1.38	2.51	(0.09)	(0.16)	(0.25)	0.64	0.94	1.67	1.32	1.73	3.00
Pulses	7.81	10.31	17.74	3.38	4.76	9.25	4.46	6.18	12.08	8.45	11.19	19.50	8.93	11.68	20.26
Roots and Tubers	10.20	13.53	23.72	4.52	6.12	11.00	4.48	5.97	10.66	5.31	7.08	12.64	10.32	13.77	25.06
All Meat Products	6.09	7.97	13.78	1.92	2.55	4.35	1.25	1.74	2.96	8.72	11.36	19.57	1.82	2.36	3.88
Beef	6.02	7.91	13.61	4.47	5.81	9.77	4.43	5.84	9.83	10.63	13.96	24.41	4.34	5.55	9.37
Lamb	5.92	7.79	13.39	3.91	5.11	8.54	4.12	5.36	8.93	8.83	11.50	19.56	3.72	4.83	7.97
Poultry	8.25	10.65	18.67	4.19	5.36	9.14	4.23	5.71	9.60	8.88	11.50	19.56	3.68	4.81	8.02
Dairy	6.56	8.63	14.96	3.35	4.38	7.24	3.28	4.35	7.29	8.75	11.47	19.74	3.85	5.01	8.47

ADB = Asian Development Bank, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, HGEM = Hadley Centre Global Environment Model.

Source: IMPACT simulation results.

Yield levels of crops and livestock are estimated to improve above HGEM levels by as much as 5.6% for all crops and as high as 9.4% for all meat products, on average, for all ADB DMCs (Table 3.20a). For food crops, the highest yield improvement is projected for pulses (17.7%), cereals (17.2%), and roots and tubers (14.8%). All livestock commodities are also estimated to have high yield gains with dairy products at 20.8%, followed by lamb meat 16.3%, and beef at 9.0%. These high gains in yields for both crops and livestock are projected under the Hi+NARS+EFF scenario. In general, maximum yield gains are estimated to be achieved at Hi+NARS+EFF, followed by Hi+NARS, and then by Hi-IARCs scenarios for all ADB DMCs, India, the PRC, and ADB regions, except when the percent changes are negative (i.e., less than HGEM values).

A comparison of India and the PRC indicated that projected yield gains of crops and livestock commodity or groups under R&D scenarios are most of the time higher for India. In general, yield gains in India are higher for livestock products than for crops—beef (25.2%) for livestock and cereals (22.8%) among food crops under the Hi+NARS+EFF scenario. In the PRC, yield gains are estimated to be highest in cereals (19.3%) and root crops (11.1%), and in beef (9.8%) and poultry meat (9.14%) for livestock under the Hi+NARS+EFF scenario.

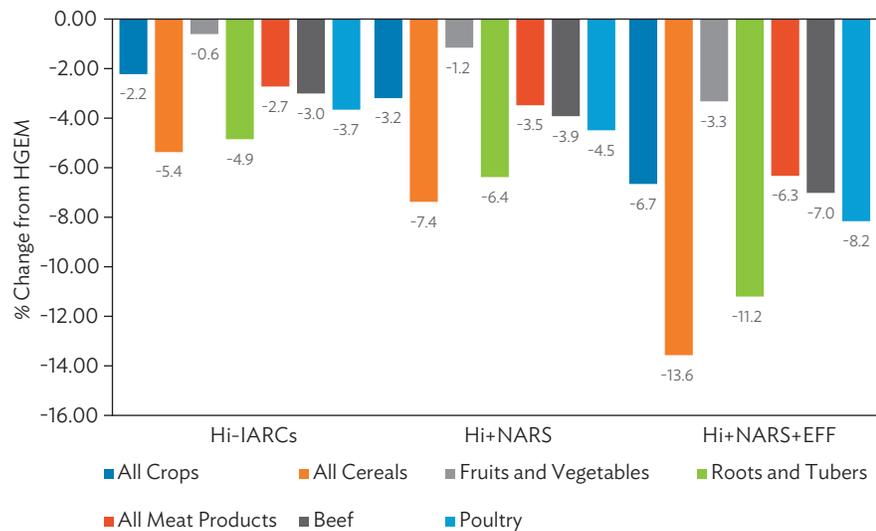
The regional analysis indicated the influence of India in South Asia and the PRC in East Asia, but not necessarily the top yield gainers. Highest yield gains are projected for Central and West Asia at 6.6% for all crops and at 19.2% for pulses, and the Pacific at 19.8% for fruits and vegetables under the Hi+NARS+EFF scenario (Table 3.20b).

Yield is shown as the single major determinant of production, since production results demonstrate similar patterns in ranking and to some extent percentage values with the yield results. India and South Asia are likely to have the highest production gains for all crops (6.1%) and all meat products (19.2%), including top values for beef production (25.2%), cereals (22.8%) and lamb and poultry meat (19.6%). Southeast Asia has the highest gains for root crops (25.1%) and pulses (20.3%), and the Pacific region for fruits and vegetables (19.6%).

World Prices

With projected high gains in yields and production, investment in R&D scenarios are also anticipated to affect world prices of food commodities. World price projections are presented in Figure 3.18, showing price reduction of as much as 13.6% for cereals, 11.2% for root crops, and 8.2% for poultry meat, under the Hi+NARS+EFF scenario. The Hi+NARS scenario gives the next lowest set of prices with declines of 7.4% for cereals, 6.4% for root crops, and 4.5% for poultry meat. The Hi-IARCs scenario can lower cereal prices by 5.4%, root crops by 4.9%, and poultry meat by 3.7%.

Figure 3.18: Projected Impact of Research and Development Investment on World Prices of Food Commodities, 2030



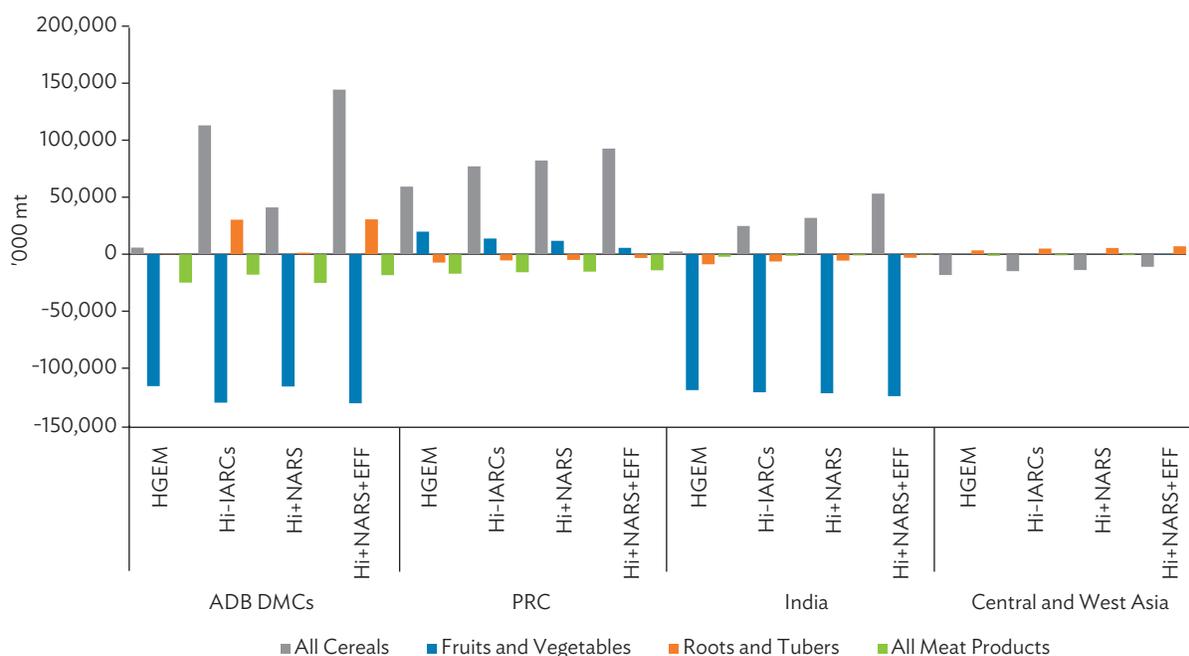
HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS.

Source: IMPACT simulation results.

Net Trade

All three R&D investment scenarios are projected to improve the trade position of ADB DMCs by increasing exports for cereals and root crops and decreasing imports of meat products for the Hi-IARCs and Hi+NARS+EFF scenarios (Figures 3.19a–3.19b). Fruits and vegetables net trade positions will be worse-off due to increased imports under the Hi-IARCs and Hi+NARS+EFF scenarios. The net impact of the R&D scenarios and the other investment scenarios on trade depends on the size of some offsetting effects from the scenarios. The higher production tends to increase exports or reduce imports, while the lower commodity prices induced by the higher production will increase per capita consumption, which tends to reduce exports or increase imports. In addition, as will be shown in detail in Chapter 4, these investments result in higher economy-wide GDP and household income, which will reduce exports or increase imports. When exports decline (or imports increase) due to higher incomes and lower prices, it will lead to higher consumption that will sufficiently balance out the higher production generated by the scenarios and this results in a positive outcome.

Figure 3.19a: Projected Net Trade of Food Commodities Under the Hadley Centre Global Environmental Model Reference Scenario and Research and Development Scenarios, ADB Developing Member Countries and Region, 2030



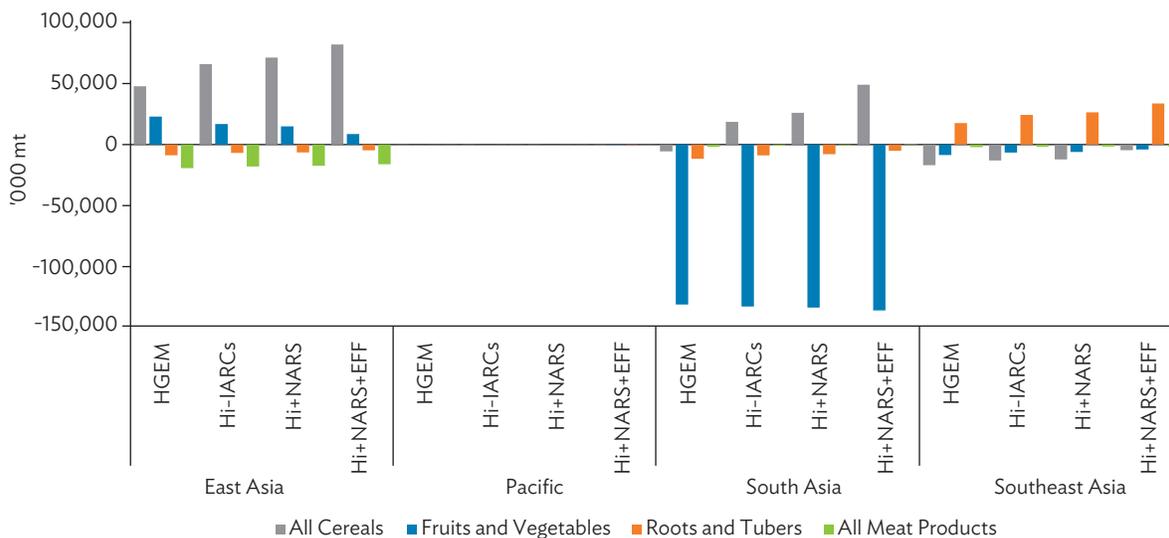
ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, mt = metric ton, PRC = People’s Republic of China.

Source: IMPACT simulation results.

The PRC’s net trade positions will be better-off at all three R&D scenarios for cereals (by increasing exports), root crops, and meat products (by declining imports), with the improvements the largest for the Hi+NARS+EFF scenarios, while fruits and vegetables will be worse-off by declining exports in all three scenarios in descending order. The declining exports in fruits and vegetables are due to the inability to model increased investments for these commodities, together with the real effect of increasing incomes due to increased R&D investments for other crops (which will be described in Chapter 4).

India’s net trade positions for cereals are also by improving exports in the same ascending order of the three R&D scenarios but in lesser magnitude. Similarly, meat products are better-off through declining imports.

Figure 3.19b: Projected Net Trade of Food Commodities Under the Hadley Centre Global Environmental Model Reference Scenario and Research and Development Scenarios, ADB Regions, 2030



ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, mt = metric ton.

Source: IMPACT simulation results.

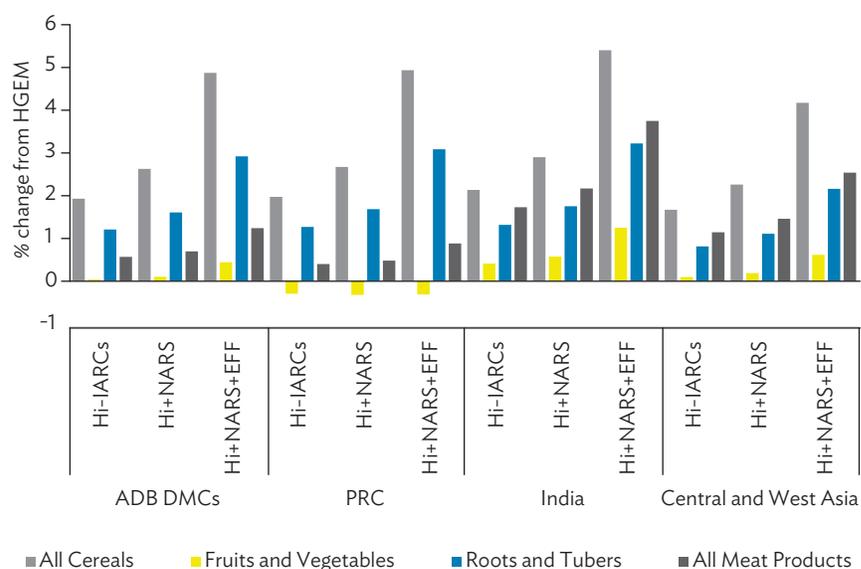
East Asia is dominated by the PRC and South Asia by India, hence similar patterns of change in their net trade positions under the three R&D scenarios were observed. Central and West Asia net trade positions are likely to be made better for cereals and meat products (decreasing imports) and root crops (increasing exports). The Pacific region’s net trade positions are to be made worse for cereals (increasing imports); better-off for fruits and vegetables, root crops (reverting from net importer to net exporter), and meat products (reducing imports). Southeast Asia’s net trade positions are improved for cereals, fruits and vegetables and meat products (lessening imports), and for root crops (expanding exports).

Food Consumption

With increased yields and production and lower world prices, annual per capita consumption of food commodities is projected to improve in 2030 from HGEM values, and highest under the Hi+NARS+EFF scenario at the aggregate ADB DMCs level. Under this scenario, consumption can be as high as 4.8% for cereals, 2.9% for root crops, and 1.2% for meat products, and exhibit a very modest increase of 0.43% for fruits and vegetables.

At the country and regional levels, values for India (and South Asia) are at maximum for cereals at 5.4%, meat products at 3.7%, and root crops at 3.2% (Figure 3.20a). The Pacific region is likely to have the highest increase at 2.5% for fruits and vegetables (Figure 3.20b). The PRC (and East Asia) demonstrates the next highest potential increase in cereal consumption at 4.9% and root crops at 3.06%, but with probable decline in fruits and vegetables consumption at 0.32%. Southeast Asia is second highest for fruits and vegetables at 1.8%. The general pattern reveals rise in consumption of all food commodities, except for fruits and vegetables in the PRC and the rest of East Asia. This trend was observed to be highest under the Hi+NARS+EFF although maximum peak is under the Hi+NARS scenario.

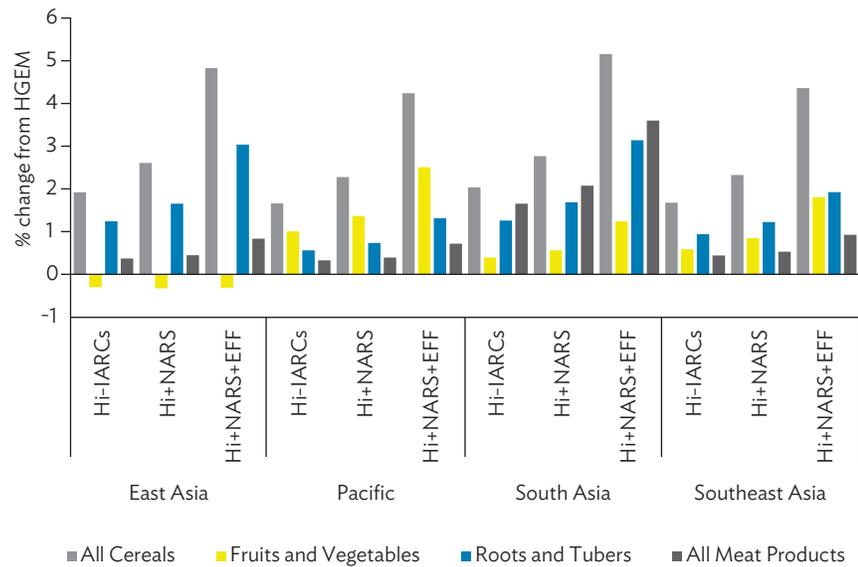
Figure 3.20a: Projected Impact of Research and Development Investment on Consumption of Food Commodities, ADB Developing Member Countries and Region, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, PRC = People's Republic of China.

Source: IMPACT simulation results.

Figure 3.20b: Projected Impact of Research and Development Investment on Consumption of Food Commodities, ADB Regions, 2030



ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS.

Source: IMPACT simulation results.

Hunger and Nutrition

The number of hungry people and the number of malnourished children in 2030 are expected to worsen with climate change (Figure 3.16 and Tables 3.17a–3.17b), from 324 million to 362 million (11.6%) for hungry people and from 75.4 million to 76.4 million (1.3%) for malnourished children in ADB DMCs.

Investment in R&D, by enhancing yield and production, has the effect of lowering prices and increasing household income, making food more available and accessible, and consequently reduces the number of malnourished children and hungry people. Table 3.21 presents the number of hungry people and malnourished children under the alternative scenarios compared to HGEM. As would be expected, the biggest reductions in the number of hungry people and malnourished children are the largest under the Hi+NARS+EFF scenario, followed by the Hi+NARS, and Hi-IARCs scenarios.

Table 3.21: Projected Impact of Investment in Research and Development on Hunger and Nutrition, by ADB Region, 2030

Region	Malnourished Children				Population At-Risk of Hunger			
	HGEM	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	HGEM	Hi-IARCs	Hi+NARS	Hi+NARS+EFF
	(million)							
ADB DMCs	76.4	75.5	75.2	74.2	362	328	316	278
PRC	0.5	0.4	0.3	0.2	87	77	73	59
India	45.9	45.5	45.4	44.9	116	103	99	86
Central and West Asia	11.1	11.0	11.0	10.9	58	55	53	50
East Asia	0.5	0.4	0.3	0.2	89	78	74	60
Pacific	0.4	0.4	0.4	0.4	0.67	0.61	0.59	0.55
South Asia	54.0	53.5	53.4	52.8	139	124	118	103
Southeast Asia	10.4	10.2	10.2	10.0	75	71	69	64

ADB = Asian Development Bank, Hi-IARC = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, HGEM = Hadley Centre Global Environment Model, PRC = People's Republic of China.

Source: IMPACT simulation results.

For ADB DMCs as a group, the highest reduction in the number of malnourished children is projected under the Hi+NARS+EFF scenario, which results in a projected decline by 2.9% equivalent to a reduction of 2.2 million in the number of malnourished children from HGEM 2030 values. By region, absolute reductions in the number of malnourished children are highest for South Asia with 1.18 million, followed by East Asia with 0.37 million. India and the PRC dominate these changes.

The population at-risk of hunger for ADB DMCs as a group is projected to drop to 278 million in 2030, from 362 million under HGEM values, a 28% reduction compared to HGEM under the Hi+NARS+EFF scenario. Moreover, this scenario is projected to reduce the number of hungry people by 45% compared to the 2015 number of 507 million, nearly halving hunger from 2015. In these scenarios, and the scenarios to follow, agricultural investments have the bigger impacts on hunger than on childhood malnutrition. Other factors, such as health and nutrition programs, clean water and sanitation, and childhood care, play a larger role in determining childhood malnutrition compared to agricultural investments. These factors are also important for hunger outcomes, but agricultural investments play a large role.

Summary of Research and Development Scenarios

The influence of R&D scenarios on production is through yield enhancement rather than area expansion. Yield levels of crops and livestock are projected to rise by 5.6% for all crops in 2030 compared to the reference scenario, and by 9.4% for all meat products in ADB DMCs under the Hi+NARS+EFF scenario.

World price projections indicate price reductions of as much as 13.6% for cereals, 11.2% for root crops, and 8.2% for poultry meat under the Hi+NARS+EFF scenario.

R&D investment scenarios have the potential of improving the trade position of ADB DMCs by enhancing exports for cereals and root crops and reducing imports of meat products under the Hi-IARCs and Hi+NARS+EFF scenarios.

With better yields and production and lower world prices, annual per capita consumption of food commodities is anticipated to improve in 2030 at the aggregate ADB DMCs level from HGEM values and highest for the Hi+NARS+EFF scenario. Under this scenario, consumption can be as high as 4.8% for cereals, by 2.9% for root crops, and 1.2% for meat products, and show a very modest increase of 0.43% for fruits and vegetables.

The number of malnourished children is projected to drop under the Hi+NARS+EFF scenario, by 2.9% (2.2 million people) people from the HGEM values in 2030. The population at-risk of hunger is projected to fall from 362 million HGEM values to 278 million under the Hi+NARS+EFF scenario, equivalent to -28.3%.

Among the R&D scenarios, Hi+NARS+EFF had the most favorable impacts on productivity and food security, with a relatively small additional investment resulting in large gains in production, consumption, and food security.

On the measure of the effectiveness of investments to adapt to climate change are whether the investments result in long-term results that are better than the NoCC scenario—i.e., they fully compensate for the impacts of climate change. In terms of adaptation to climate change, the productivity gains from all R&D scenarios are projected to more than compensate for the impacts of climate change, with yield levels higher in 2030 by 1%–4% for crops compared to the NoCC scenario; and by 6% to 11% for livestock. With respect to food security, the Hi-IARCs scenario results in a level of hunger (328 million) that is nearly as low as the NoCC level of 324 million hungry in 2030, and Hi+NARS and Hi+NARS+EFF achieve levels of hunger much lower than the NoCC scenario.

3.7.2. Investment in Irrigation Expansion and Water Use Efficiency

The second set of scenarios analyzed is investment in irrigation. In addition to increasing land productivity by provision of water, it also serves to improve the effective land area by opening up new areas to agriculture and by boosting the cropping intensity of previously rainfed areas. Production is enriched through intensified cropping and by the switch from relatively low-yield rainfed production to higher-yield irrigated production technology.

Investments to upgrade and modernize irrigation systems and in technologies and farm practices that enhance the efficient use of irrigation water like alternate wet-dry irrigation, drip irrigation, and precision agriculture not only conserve irrigation water

but also increase yields by applying the desirable amount of water at the appropriate time and precise location.

The two irrigation investment scenarios are defined as:

- (i) **IRREXP.** This stands for investment in irrigation expansion and development. For Asia and the Pacific, this scenario simulates expansion of existing irrigation area by 14% compared to 2015, and results in irrigated area that is 6% higher in 2030 than the HGEM reference scenario. The projected expansion in irrigated area varies widely across river basins and therefore countries (Tables 3.23b–3.23c). Projected expansion rates depend on recent trends in irrigated area and investment, and the potential for expansion based on water availability in different river basins. Existing agricultural rainfed areas feasible for irrigation are given priority, up to 50% of the 2015 rainfed area, after which new lands are developed for agriculture use to satisfy the irrigation investment scenario.
- (ii) **IRREXP-WUE.** This investment scenario utilizes the same increase in irrigated area expansion as IRREXP, plus additional investment in modernization of irrigation to facilitate advanced irrigation technologies and practices to improve water use efficiency. At the basin level, water-use efficiency (WUE) is simulated as increasing basin efficiency by 12%–35% in 15 years to 2030. The improvements in efficiency are specific to each river basin and depends on available water resources and the potential improvement from the 2015 WUE level. Average river basin WUE in 2015 is around 0.53 and is projected to be 0.54 in 2030 in the reference scenario. The average basin efficiency in 2030 under the IRREXP-WUE scenarios is 0.68.

Irrigation Investments in the Reference and Alternative Scenarios

Water is a critical resource for agriculture. In IMPACT, water resource management is modeled endogenously by linking the partial equilibrium to a suite of water models.²⁸ Water availability, including rainfall, streamflow, and evaporation, is determined in a hydrological model that downscales precipitation and temperature from climate scenarios generated by the general circulation model (GCM). Water supply and demand by sector is determined in a water simulation model that allocates water across irrigation, livestock, domestic use, and industrial use. Water supply and demand are solved in 154 river basins globally and are linked annually to the IMPACT economic model (footnote 30). Two of the key drivers in this model are assumptions on rates of growth in irrigation expansion together with water storage capacity (surface and groundwater), and irrigation WUE. The realized water demand and withdrawals are therefore constrained by water supply. The assumptions on future irrigated area and changes in WUE for the reference scenario are based on historical trends and available evidence on investment plans.

²⁸ S. Robinson et al. 2015. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3. IFPRI Discussion Paper 1483. Washington, D.C.: IFPRI. <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825>.

Expanding irrigation requires investments in water infrastructure, such as canals and dams. This study used data from the estimated unit total cost for new construction in a 2007 paper (footnote 30). Unit irrigation investment, costs from the FAO's AquaStat database were also used.²⁹ The total unit cost of new irrigation construction used in the report are summarized as costs per hectare (ha). The costs utilized are \$9,236/ha for East Asia, Southeast Asia, and the Pacific; \$3,812/ha in South Asia; and \$9,748/ha in Central and West Asia. To get the average annual total costs by region, these unit costs are multiplied by the increase in the irrigated area under the HGEM reference scenario (Table 3.23a).

Investments in irrigation can also improve basin-level WUE. The concept of WUE in the IMPACT tool is based on the concept of effective irrigation efficiency, which represents the ratio of irrigation water utilized by crops for evapotranspiration to total irrigation water consumption.³⁰ The effective irrigation efficiency concept is applied to irrigation at the river basin scale in the IMPACT model.

Improvement in WUE is achieved through the modernization of irrigation systems, including investment in improved water delivery infrastructure and improved institutional measures such as enhancing groundwater governance, farmer-led irrigation management, and water user associations. In the reference scenario, it is assumed that 10% of the irrigated area in Asia and the Pacific in 2015 (Table 3.23a) will have investments in modernization, phased evenly from 2015 to 2030. The investment cost of WUE improvement is therefore calculated as this irrigated area multiplied by the unit area cost of irrigation modernization. Based on various papers and sources as well as irrigation project assessments, the investment cost per hectare used for modernization is \$2,144/ha for Asia and the Pacific.³¹ The available evidence in the literature does not allow a further breakdown for each region within Asia and the Pacific.

The projected annual investment costs in Asia and the Pacific for irrigated area expansion and improvement in WUE in the reference scenario are shown in Table 3.18. The cost for irrigation expansion in the reference scenario is \$7.59 billion per year, of which \$3.08 billion is in South Asia and \$2.91 billion in East Asia. Annual investments in WUE improvement are projected to be \$4.29 billion, including \$1.59 billion in East Asia and \$1.54 billion in South Asia. Unfortunately, there are no available data available to benchmark the reference scenario, but ADB provides an estimate of annual investment requirement for irrigation investment in ADB member countries of \$12.31 billion from

²⁹ FAO Aquastat. <http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en>.

³⁰ N. Haie and A. Keller. 2008. Effective Efficiency as a Tool for Sustainable Water Resources Management. *JAWRA Journal of the American Water Resources Association*. 44 (4). pp. 961–968; and A. Keller and J. Keller. 1995. Effective Efficiency: A Water Use Efficiency Concept for Allocating Freshwater Resources. *IWMI Working Papers H043180*.

³¹ K. Palanisami. 1997. Economics of Irrigation Technology Transfer and Adoption. In *Irrigation Technology Transfer in Support of Food Security*. Water Reports No. 14. Harare, Zimbabwe: FAO. <http://www.fao.org/3/W7314E/w7314e0f.htm>; A. Inocencio et al. 2007. Cost of performance of irrigation projects: a comparison of Sub-Saharan Africa and other developing regions. *Research Report 109*. Colombo, Sri Lanka: International Water Management Institute. http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB109/RR109.pdf; and FAO Aquastat. <http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en>.

2005 and 2030,³² which is quite consistent with this study's reference scenario of average annual investments of \$11.88 billion.

The same methodology is used for computing the costs of irrigation expansion and improvement of WUE in the increased investment scenarios (IRREXP and IRREXP-WUE), but with the unit costs of irrigation applied to the expanded irrigated area under these scenarios, and with the assumption of investment in full modernization of one-third of the irrigated area by 2030. Table 3.22 presents the annual investment costs for expanding irrigation and improving WUE in Asia and the Pacific.

Table 3.22: Annual Additional Investment Cost Above the Reference Scenario Investments, for Expanding Irrigation and Improving Water Use Efficiency in Asia and the Pacific, 2016–2030
(\$ billion, 2005)

Region	Average Annual Cost		
	IRREXP	WUE	IRREXP-WUE
Central and West Asia	0.54	1.52	2.06
East Asia	0.62	4.74	5.36
Pacific	0.06	0.02	0.08
South Asia	1.71	4.57	6.28
Southeast Asia	4.14	1.86	6.00
Total for Asia and the Pacific	7.07	12.71	19.78

IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, WUE = water use efficiency.

Simulation Results for Irrigation Investment Scenarios

Area and Production

Improvement in production from the investment scenarios are primarily from area expansion, rather than increases in yield levels. The application of efficient water-use technologies and practices in IRREXP-WUE can also enhance productivity by the application of more precise amounts of irrigation water at the suitable time and location. Since food crops are the primary users of irrigation, the effects on livestock production are indirect, that is, through production of feed crops like maize and root crops. Note that because of current high rates of irrigation coverage in the PRC, no additional irrigation expansion is simulated for this country in these scenarios. However, since the PRC is investing in the development of technologies and practices for the improvement of WUE, it is included in the WUE part of the irrigation scenario.

Tables 3.23a–3.23e show the projected irrigated and rainfed area, and total area, production and yield changes under the HGEM reference scenario and the two alternative irrigation investment scenarios. Table 3.23a shows the changes in total water withdrawals under the three scenarios. In the HGEM reference scenario, total global

³² ADB. 2017. *Financing Asian Irrigation: Choices before Us*. Asian Development Bank, Manila. <https://www.adb.org/publications/financing-asian-irrigation-choices>.

water withdrawals are projected to increase by 12% from 2015 to 2030, from 3,430 cubic kilometers (km³) to 3,842 km³. These projections are highly consistent with the water supply-constrained projections in a 2016 study, using the GCAM model of the Pacific Northwest National Laboratory.³³ The study had global withdrawals of approximately 3,400 km³ in 2015 and 3,900 km³ in 2030.

Asia and the Pacific accounts for 62% of global water withdrawals in 2015 and withdrawals are projected to grow by 10% to 2030 in the reference scenarios (Table 3.23a). Within Asia and the Pacific, South Asia, mainly due to growth in water withdrawals in India, has the largest absolute increase to 2030 of 91 km³, while Central and West Asia have the largest percentage increase, 13%. East Asia has almost no growth in water withdrawals in the reference scenario, because investments in irrigated area are projected to be small. In the IRREXP scenario, substantial additional investments in irrigation are made in South and Southeast Asia, resulting in higher growth in irrigated area compared to the HGEM scenario than for other regions in Asia and the Pacific. Under the IRREXP-WUE scenario, water withdrawals are lower than for either the HGEM or IRREXP scenarios across Asia and the Pacific, because higher river basin water use efficiency allows consumptive use demands to be met with lower withdrawals.

Projected rainfed areas decline under the irrigation investment scenarios relative to both 2015 levels and to the projected rainfed areas in the HGEM reference scenario because some rainfed areas become irrigated (Table 3.23b). For ADB DMCs, increases in total harvested areas are projected to be highest for cereals and sugarcane, and estimated to be slightly higher under IRREXP rather than IRREXP-WUE, because improved water use efficiency reduces the incentive to expand the area. However, increases in production are projected to be higher in the IRREXP-WUE scenario despite the lower area increases, because of the significant gains in yield levels for this scenario (Tables 3.23c–3.23e). At the country and regional levels, India is projected to have the highest expansion in irrigated land area for cereals (4.31%), root crops (4.33%), and sugarcane production (4.14%)—all under the IRREXP scenario. Area increases under the IRREXP-WUE scenario are at lower rates than for IRREXP-WUE, but result in higher production gains, especially for cereals (8.86%) and sugarcane (6.78%) because gains in WUE increase yields.

Table 3.23a: Total Water Withdrawals in 2015 and Projected in 2030, Under Alternative Scenarios
(km³)

	2015	HGEM	IRREXP	IRREXP-WUE
		2030	2030	2030
Total Asia and the Pacific	2,120	2,324	2,379	2,194
Central and West Asia	461	521	522	511
East Asia	567	587	587	551
Pacific	1	1	1	1

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³³ S. H. Kim et al. 2016. Balancing Global Water Availability and Use at Basin Scale in an Integrated Assessment Model. *Climatic Change*. 136 (2). pp. 217–231. <https://doi.org/10.1007/s10584-016-1604-6>.

Table 3.23a *continued*

	2015	HGEM	IRREXP	IRREXP-WUE
		2030	2030	2030
South Asia	906	997	1,019	938
Southeast Asia	185	219	251	193
Rest of the World	1,310	1,518	1,516	1513
Total World	3,430	3,842	3,895	3,706
PRC	560	580	580	546
India	830	912	931	868

HGEM = Hadley Centre Global Environment Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements.

Table 3.23b: Projected Impact of Investment in Irrigation Expansion and Improved Water Use Efficiency on Irrigated and Rainfed Crop Area, by ADB Region, 2030

Area Harvested	2015	HGEM	IRREXP	IRREXP-WUE
		2030	2030	2030
('000 ha)				
Irrigated				
ADB DMCs	265,766	286,087	303,129	302,782
PRC	97,309	102,231	101,998	101,778
India	86,313	97,622	105,732	105,742
Central and West	32,009	33,284	34,868	34,909
East Asia	98,719	103,654	103,415	103,193
Pacific	41	43	49	49
South Asia	95,998	108,185	117,149	117,131
Southeast Asia	38,998	40,921	47,648	47,500
Rainfed				
ADB DMCs	267,830	271,201	264,605	263,448
PRC	67,893	69,170	69,045	68,722
India	97,118	90,856	87,889	87,494
Central and West Asia	17,736	18,290	18,095	18,024
East Asia	68,466	69,689	69,563	69,238
Pacific	1,586	1,721	1,713	1,709
South Asia	109,164	103,104	99,777	99,323
Southeast Asia	70,879	78,397	75,457	75,154

ADB = Asian Development Bank, ha = hectare, HGEM = Hadley Centre Global Environment Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.23c: Projected Impact of Investment in Irrigation Expansion and Improved Water Use Efficiency on Crop Area and Production, ADB Developing Member Countries, 2030

Commodity	ADB DMCs		PRC		India	
	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE
(% change from HGEM)						
Area Harvested						
All Crops	1.87	1.60	(0.21)	(0.53)	2.73	2.52
All Cereals	2.77	2.56	(0.66)	(0.81)	4.31	4.33
Fruits and Vegetables	0.55	0.31	0.41	(0.02)	0.24	0.29
Oil crops	0.65	0.27	0.11	(0.40)	0.81	0.28
Pulses	0.65	0.46	0.19	(0.25)	0.38	0.16
Roots and Tubers	0.89	0.68	(0.04)	(0.22)	4.33	3.69
Sugar	3.61	2.57	(0.17)	(0.80)	4.14	2.73
Production						
All Crops	1.45	2.88	(0.17)	0.52	2.06	5.12
All Cereals	2.17	5.27	(0.78)	2.70	3.92	8.86
Fruits and Vegetables	0.37	0.27	0.14	(0.12)	(0.26)	-0.08
Oil crops	1.22	1.41	0.08	0.32	1.49	2.39
Pulses	0.70	0.65	0.04	(0.40)	0.40	0.35
Roots and Tubers	0.97	0.77	(0.17)	(0.34)	4.88	4.23
Sugar	2.56	5.82	(0.22)	(0.82)	2.09	6.78

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.23d: Projected Impact of Investment in Irrigation Expansion and Efficient Water Use on Crop Area and Production, by ADB Region, 2030

Commodity	Central and West Asia		East Asia		Pacific		South Asia		Southeast Asia	
	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE
(% change from HGEM)										
Area Harvested										
All Crops	2.69	2.63	(0.21)	(0.53)	(0.16)	(0.36)	2.67	2.44	3.17	2.80
All Cereals	2.23	2.40	(0.66)	(0.82)	4.10	4.11	4.06	3.99	5.63	4.83
Fruits and Vegetables	4.67	4.18	0.41	0.00	0.07	(0.04)	0.32	0.40	0.03	0.02
Oil crops	2.08	0.20	0.11	(0.39)	(1.30)	(1.55)	0.85	0.33	0.86	0.86
Pulses	2.11	1.57	0.20	(0.24)	(0.42)	(1.14)	0.35	0.15	1.87	2.13
Roots and Tubers	2.08	1.57	(0.04)	(0.22)	0.25	0.11	4.00	3.55	0.03	0.00
Sugar	2.13	0.29	(0.17)	(0.80)	(0.10)	(0.57)	3.92	2.59	6.06	5.66

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Table 3.23d continued

Commodity	Central and West Asia		East Asia		Pacific		South Asia		Southeast Asia	
	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE	IRREXP	IRREXP-WUE
(% change from HGEM)										
Production										
All Crops	1.57	9.11	(0.16)	0.53	(0.56)	(0.77)	2.06	4.83	3.24	3.02
All Cereals	1.81	8.69	(0.79)	2.64	(1.32)	5.54	3.73	7.79	6.74	5.75
Fruits and Vegetables	5.29	5.40	0.17	(0.07)	(0.44)	(0.45)	(0.16)	0.03	0.87	0.92
Oil crops	0.84	5.79	0.08	0.32	(2.11)	(2.32)	1.49	2.36	1.38	1.46
Pulses	2.58	3.25	0.05	(0.38)	(0.61)	(1.30)	0.37	0.32	2.27	2.61
Roots and Tubers	1.93	1.71	(0.17)	(0.33)	0.25	0.16	4.61	4.11	0.11	0.12
Sugar	(0.78)	12.82	(0.22)	(0.82)	(0.30)	(0.89)	2.04	6.46	6.94	6.43

HGEM = Hadley Centre Global Environment Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements.

Source: IMPACT simulation results.

Table 3.23e: Projected Impact of Investment on IRREXP-WUE on Crop Yields, by ADB Region, 2030

Commodity	ADB DMCs	PRC	India	Central and West Asia	East Asia	Pacific	South Asia	Southeast Asia
	(% change from HGEM)							
All Crops	1.26	1.07	2.52	6.26	1.08	-0.42	2.30	0.30
All Cereals	2.64	3.54	4.35	6.14	3.49	1.37	3.65	0.87
Fruits and Vegetables	-0.04	-0.11	-0.38	1.18	-0.07	-0.41	-0.37	0.90
Oil crops	1.14	0.71	2.11	5.58	0.71	-0.78	2.02	0.60
Pulses	0.20	-0.15	0.19	1.65	-0.15	-0.16	0.18	0.47
Roots and Tubers	0.09	-0.12	0.53	0.14	-0.11	0.05	0.54	0.12
Sugar	3.17	-0.02	3.95	12.49	-0.02	-0.33	3.78	0.73

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, PRC = People's Republic of China.

Source: IMPACT simulation results.

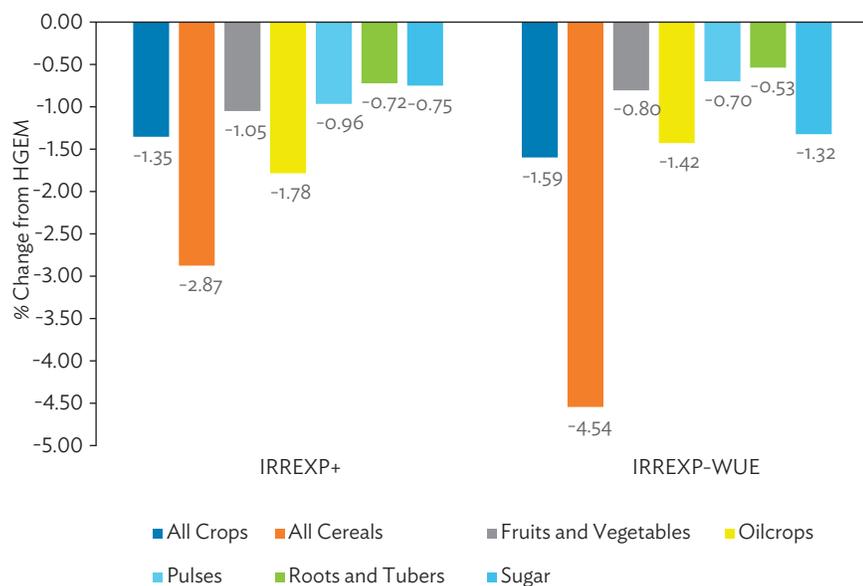
On a regional basis, the highest projected increases in harvest area are Southeast Asia for sugarcane under IRREXP (6.06%) and IRREXP-WUE (5.66%) followed by cereals (5.63%) under IRREXP. Expansion in land area for fruits and vegetables are also projected to be high in Central and West Asia both under IRREXP (4.67%) and IRREXP-WUE (4.18%). Production increases are highest for sugarcane (12.82%) and for cereals (8.69%), both under IRREXP-WUE in Central and West Asia. South and Southeast Asia have substantial projected increases in production for cereals and sugar as well.

Table 3.23e shows the projected yield gains in 2030 for the IRREXP-WUE scenario relative to the HGEM reference scenario. In ADB DMCs, yield gains are highest for sugarcane (3.17%) followed by cereals (2.64%). Overall, the highest yield gains are projected for sugarcane (12.49%) and for cereals (6.14%) in Central and West Asia.

World Prices

Reduction in world prices of food commodities from the irrigation scenarios are projected to be modest compared to R&D scenarios (Figure 3.21) because the impact on production is lower. World prices of cereals are estimated to be lower by 4.54% under the IRREXP-WUE irrigation scenario, and by 2.87% under the IRREXP scenario. Modeling results also showed that smaller price reductions are projected for fruits and vegetables (1.05%) and root crops (0.72%) under the IRREXP scenario.

Figure 3.21: Projected Impact of Investment in Irrigation Expansion and Water Use Efficiency on World Prices of Food Commodities, 2030

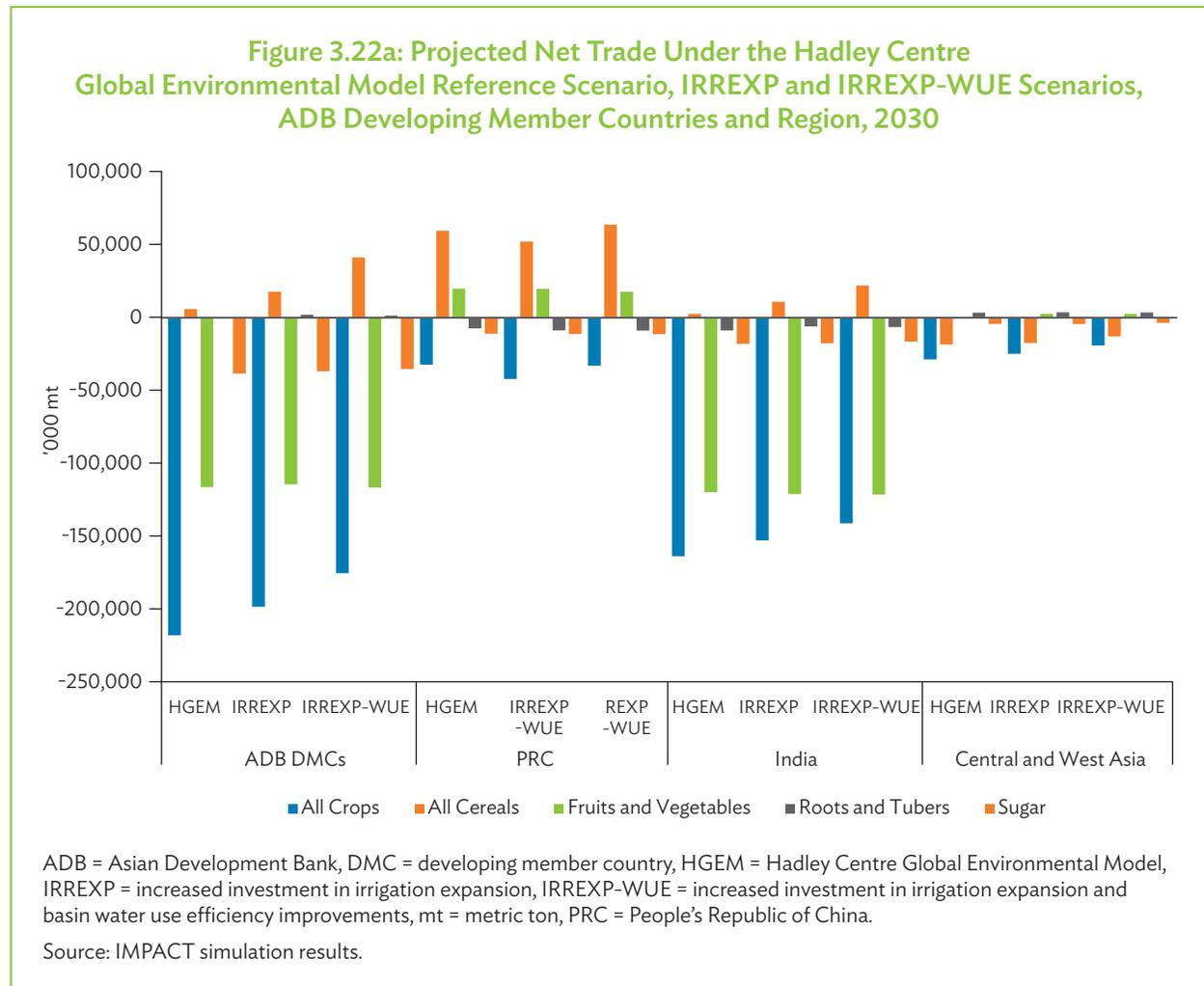


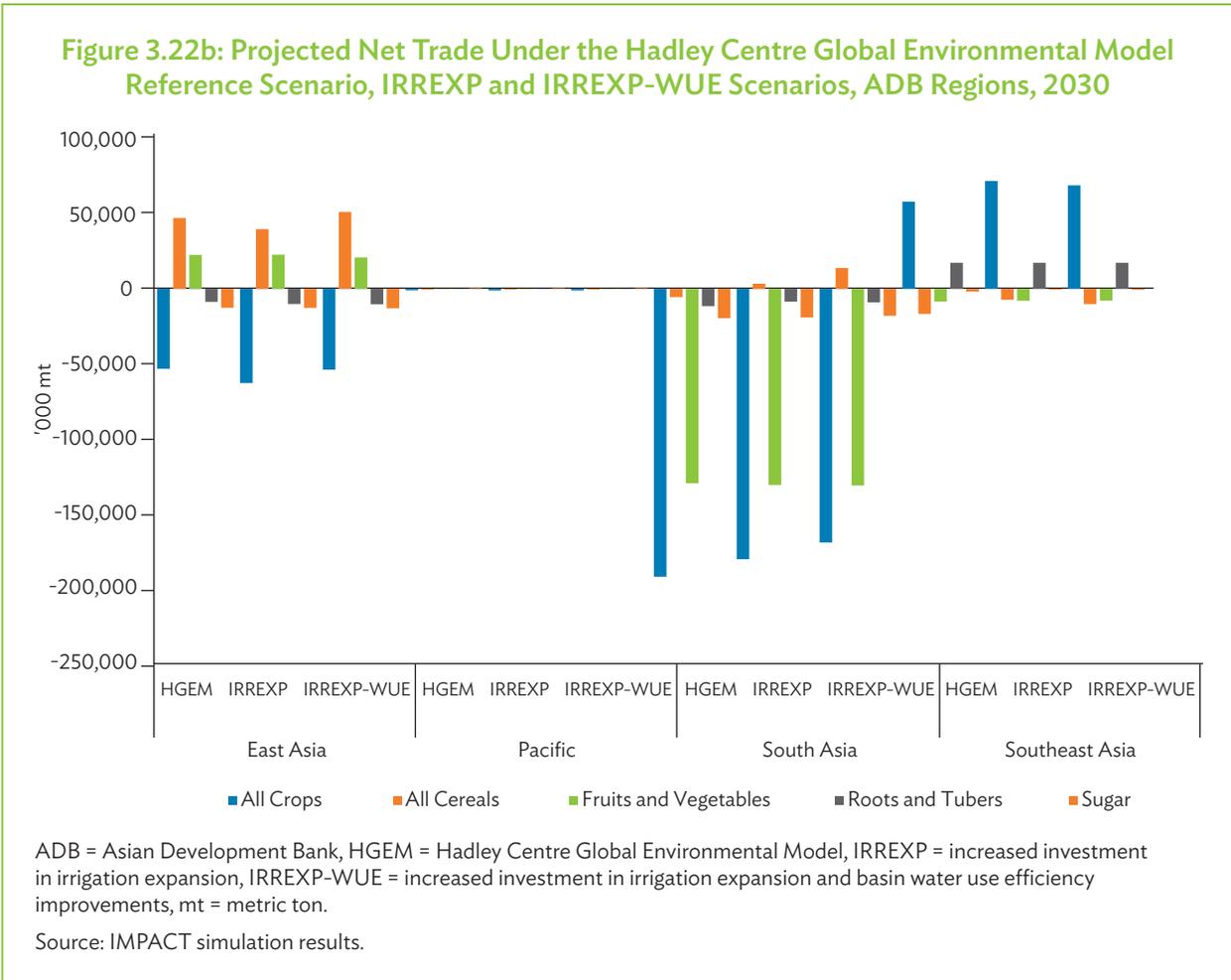
HGEM = Hadley Centre Global Environmental Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements.

Source: IMPACT simulation results.

Net Trade

In terms of net trade positions, improvements are projected for cereals (increases in exports) in ADB DMCs, the PRC, East Asia, India, and South Asia; and reduction of cereal imports in Central and West Asia (Figures 3.22a–3.22b).





Food Consumption and Food Security

Small increases in per capita consumption are projected for the irrigation scenarios in ADB DMCs as a whole in 2030 compared to the reference scenario, with the highest percentage increases for root crops (1.7%) and for fruits and vegetables (0.5%) under the IRREXP-WUE scenario (Tables 3.23a and 3.23b). The incremental production and resulting impacts on commodity prices and income generated by these scenarios are relatively small, since irrigation investment comes on the margin of already large existing investments. These scenarios result in relatively small projected improvements on the hunger and malnutrition situation of the region (Table 3.24).

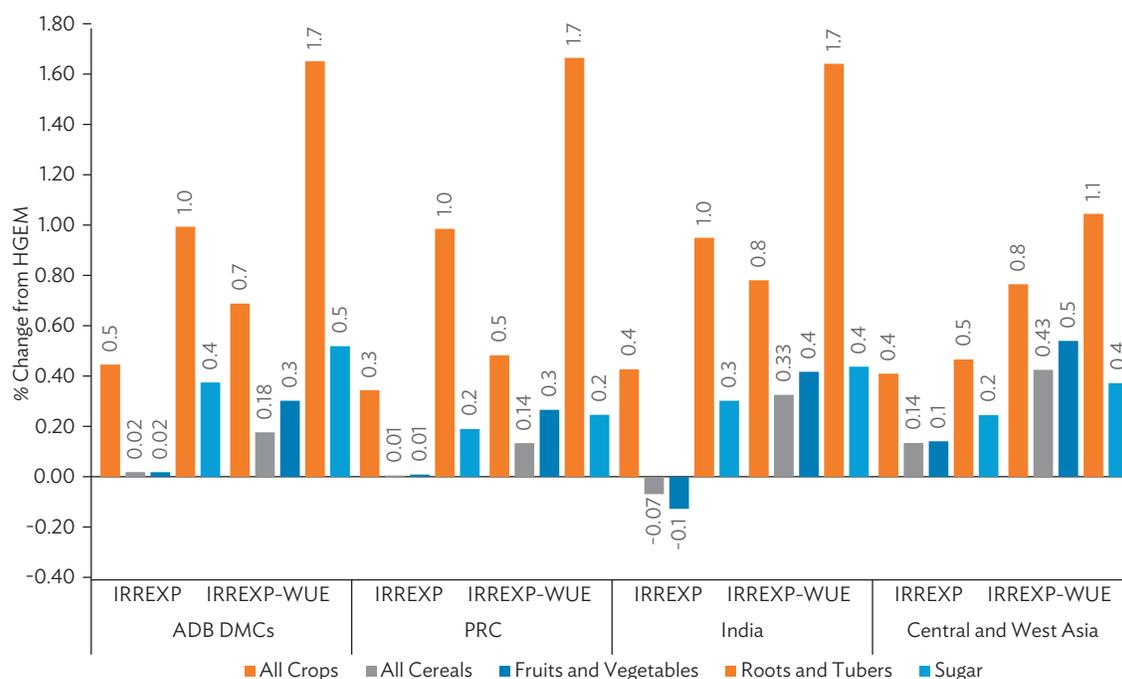
Table 3.24: Projected Impact of Investment in Irrigation Expansion and Water Use Efficiency on Hunger and Nutrition, by ADB Region, 2030

Region	Malnourished Children			Population At-Risk of Hunger		
	HGEM	IRREXP	IRREXP-WUE	HGEM	IRREXP	IRREXP-WUE
	(million)					
ADB DMCs	76.4	76.0	75.7	362	345	334
PRC	0.5	0.4	0.4	87	82	79
India	45.9	45.8	45.6	116	111	106
Central and West Asia	11.1	11.1	11.1	58	57	56
East Asia	0.5	0.5	0.4	89	84	80
Pacific Asia	0.4	0.4	0.4	0.67	0.62	0.61
South Asia	54.0	53.8	53.6	139	132	127
Southeast Asia	10.4	10.3	10.2	75	72	71

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PRC = People's Republic of China.

Source: IMPACT simulation results.

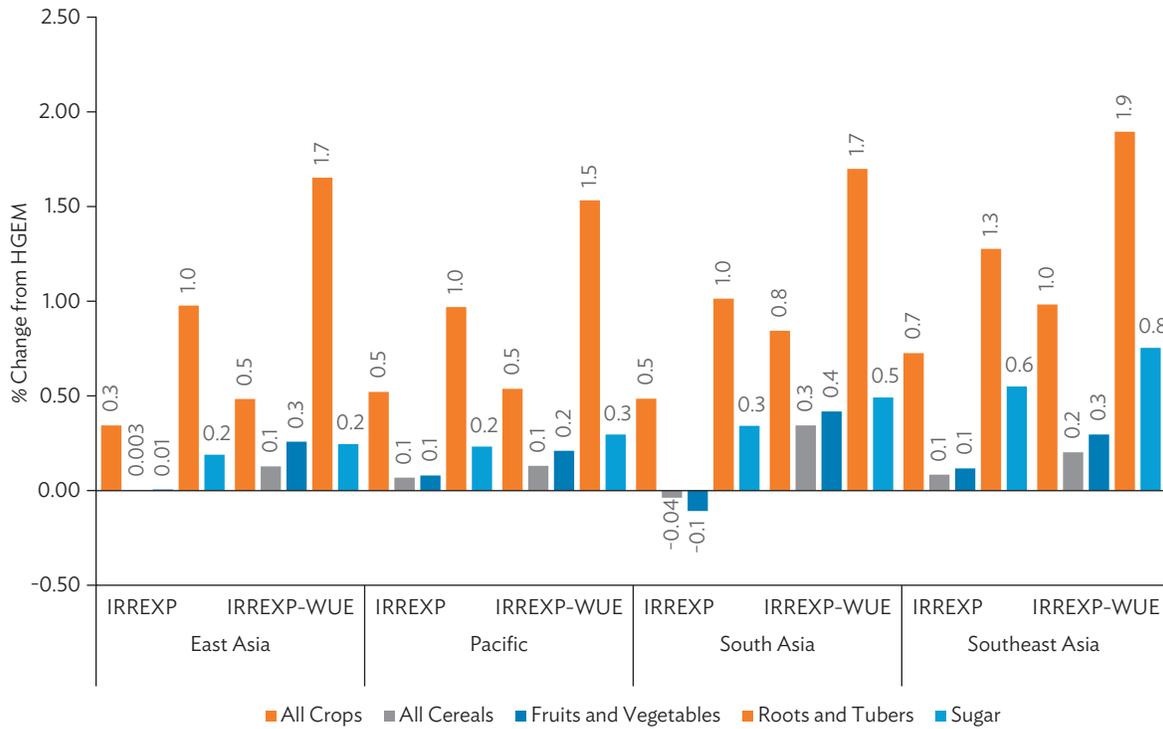
Figure 3.23a: Projected Impact of Investment in Irrigation Expansion and Water Use Efficiency on Consumption of Food Commodities, ADB Developing Member Countries and Region, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PRC = People's Republic of China.

Source: IMPACT simulation results.

Figure 3.23b: Projected Impact of Investment in Irrigation Expansion and Water Use Efficiency on Consumption of Food Commodities, ADB Regions, 2030



ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements.

Source: IMPACT simulation results.

Summary of Irrigation Investment Scenarios

Improvement in production from these investment scenarios are mainly from area expansion, rather than increases in yield levels, with some productivity gains from shifting fallow and rainfed lands to irrigation, and from gains in water use efficiency.

The effects on livestock production of these scenarios are indirect and small, through changes in the production of feed crops that reduce their prices. Increases in harvested areas are projected to be highest for cereals and sugarcane for IRREXP. However, increases in production are projected to be higher in the IRREXP-WUE scenario despite the lower area development, signifying gains in yield levels for this scenario.

Reduction in world prices of food commodities from the irrigation scenarios are estimated to be modest compared to R&D scenarios. World prices of cereals are likely to be lower by 4.54% under the IRREXP-WUE irrigation scenario.

Small increases in per capita consumption are projected for these irrigation scenarios in ADB countries—at the maximum of only 1.7% for root crops and 0.5% for fruits and vegetables under the IRREXP-WUE scenario.

In terms of climate change adaptation, both irrigation scenarios are projected to fully compensate for production losses projected with climate change, by 1.45 to 2.88 percentage points. Moreover, both are projected to be better than the NoCC scenario with an improvement of 0.07 to 1.47 percentage points.

3.7.3. Investment in Rural Infrastructure

There are investment opportunities other than enhancing yields and production that can improve food security in terms of making food more available and accessible. Investment in rural infrastructure that supports transport, processing, storage, and marketing of food commodities not only facilitates the efficient movement of produce from farm to market, but in the process reduces the marketing costs and post-harvest losses (PHL) by producers, market intermediaries, and consumers. The impacts of these investments are simulated jointly in the **RMM/PHL** scenario, because the same investments influence losses and margins.

The **RMM/PHL** scenarios assess the impacts of the rural investment scenario through these two pathways.

- (i) **RMM pathway.** This refers to investment in rural infrastructure that improves farm-to-market roads, bulk transport and storage facilities, market information systems (through the internet and radio), marketing infrastructure like contracts and commodities option markets. This involves the efficient movement of produce, through transport system; or the efficient connection between producers and consumers with or without market intermediaries through market information and marketing arrangements. Since this is applicable to all types of farm produce, this scenario is simulated in IMPACT by reducing by 50% the marketing margins of all the crops and livestock commodities in the model, phased over 15 years to 2030.
- (ii) **PHL pathway.** This refers to investment in rural infrastructure that promotes the reduction of PHL along the supply chain, by promoting the expansion of services for processing (including drying and milling), packaging, bulk storage, cold storage, and refrigerated container vans. This scenario, however, is limited only to cereals for which the technologies and facilities already exist or can readily be established along the supply chain. It is estimated that on average, post-harvest for cereals can be as high as 10% to 15% and are simulated in IMPACT to reduce losses to 7.5% in 15 years to 2030. Note that under the PHL scenario, production at the farm is not directly affected by the reduction of PHL. However, due to less post-harvest wastes in the supply chain, more of the produce becomes available to consumers. An example of this is investment in drying and milling facilities for rice. Whereas before,

the milling recovery rate can be as low as 50%–55% due to a high moisture content of the unmilled rice and traditional milling facilities, the milling recovery rate can now be as high as 60% to 70%, so the same amount of unmilled rice from the farm produces more milled rice for the consumers.

Investments in Rural Infrastructure in the Reference Scenario

As noted above, investments in rural infrastructure affect the projected marketing margins and PHL within the IMPACT model. The status of infrastructure is proxied by electric power consumption (kilowatt-hour per capita); roads capacity, in terms of annual goods transported (million ton-kilometer); paved roads as percentage of total roads; and railway capacity in terms of annual goods transported (million ton-kilometer). Trends in these variables were estimated using data from the World Bank World Development Indicators and utilized to project the future values for these variables in the reference scenario. These variables were chosen because they were shown to influence have a significant impact on post-harvest losses in an econometric analysis.³⁴

The infrastructure investment costs for the reference scenario were computed by multiplying the projected annual changes in these variables by the unit costs of each variable. The unit cost data were drawn from a variety of sources (footnote 37). For road infrastructure (both development and maintenance), information was taken from the World Bank's Road Cost Knowledge System (ROCKS). Costs for electricity were obtained from US Energy Information Administration.³⁵ The study also obtained costs per tons per kilometer of rail transportation from a technical report about the costing of railroads in Canada,³⁶ adjusted to Asian conditions. For the RMM/PHL scenario, the investment costs were computed as the annual investment required to reduce PHL to 7.5% and were estimated econometrically (footnote 37).

Table 3.18 summarizes the annual infrastructure investments for roads, rail, and electricity in Asia and the Pacific in the reference scenario. The total annual investment is \$22.4 billion, of which \$8.4 billion is for roads, \$4.3 billion for rail, and \$9.7 billion for electricity. East Asia and South Asia have the highest levels of total annual infrastructure investment with a total of \$11.6 billion for East Asia and \$7.5 billion for South Asia. Unfortunately, there are no data on recent expenditures on rural infrastructure in ADB DMCs that could provide a benchmark for rural infrastructure. ADB provided estimates of total infrastructure investments for several sectors,³⁷ but at a higher level of aggregation, not for rural infrastructure. Table 3.25 summarizes the annual investment costs for the RMM/PHL scenario.

³⁴ M. W. Rosegrant et al. 2018. Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth. In B. Lomborg, ed. *Prioritizing Development: A Cost Benefit Analysis of the United Nations' Sustainable Development Goals*. Cambridge, U.K.: Cambridge University Press. pp. 322–338. <https://doi.org/10.1017/9781108233767.020>.

³⁵ United States Energy Information Administration. <http://www.eia.gov/>.

³⁶ DAMF Consultants et. al. 2007. *Estimation of Unit Costs of Rail Transportation in Canada. Ontario: Transport Canada*. <http://publications.gc.ca/site/eng/338368/publication.html>

³⁷ ADB. 2017. *Meeting Asia's Infrastructure Needs*. Manila. <https://www.adb.org/publications/asia-infrastructure-needs>.

Table 3.25: Annual Additional Investment Cost in Asia and the Pacific for the Improved Infrastructure RMM/PHL Scenario, 2016–2030
(\$ billion, 2005)

Region	Rural Roads	Rails	Rural Electricity	Average Annual Cost
Central and West Asia	1.06	0.22	0.75	2.04
East Asia	3.94	0.83	2.80	7.58
Pacific	0.05	0.01	0.03	0.09
South Asia	2.41	0.51	1.72	4.64
Southeast Asia	0.76	0.16	0.54	1.46
Total for Asia and the Pacific	8.22	1.74	5.85	15.81

Simulation Results for the Rural Infrastructure Investment Scenarios

Production

The RMM and PHL scenarios work through different pathways than the R&D and irrigation investment scenarios. The investment is not directly for increasing production or productivity and the initial direct savings from reduced marketing costs and product losses do not accrue fully to the producers, but also to consumers. For the RMM scenario, consumers benefit through lower food prices while producers through higher output prices. In PHL, the consumers enjoy the benefit of having more food available to them for any given level of production.

Results of the simulations of these two scenarios are presented in Tables 3.26–3.27 and Figures 3.24, 3.25a–3.25b, and 3.26a–3.26b.

Table 3.26 shows that the farmers' response to RMM that reduces marketing costs is to produce more of the food commodity, primarily because reduced marketing margins raise the prices received by farmers for their output. The largest expansion in production in 2030 compared to the HGEM reference scenario in ADB DMCs are projected for pulses (5.10%), fruits and vegetables (3.79%), and dairy products (3.43%). In the regions, the highest percentage production increases are projected for pulses in Southeast Asia (6.29%), South Asia (5.92%), and in the Pacific (5.29%). Fruits and vegetables are projected to have the largest increase compared to HGEM in South Asia (4.91%) and East Asia (4.01%).

Table 3.26: Projected Impact of Investment in Rural Infrastructure on Crop and Livestock Production, and Food Demand, by ADB Region, 2030

Commodity	ADB DMCs	PRC	India	Central and West Asia	East Asia	Pacific	South Asia	Southeast Asia
RMM Scenario				(% change from HGEM)				
Production								
All Crops	2.22	4.11	1.27	4.28	4.08	0.88	1.29	(0.03)
All Cereals	2.70	2.51	3.26	3.17	2.50	2.75	3.09	2.29
Fruits and Vegetables	3.79	4.05	5.02	(3.61)	4.01	3.29	4.91	2.85
Pulses	5.10	3.58	5.87	(0.02)	3.57	5.29	5.92	6.29
Roots and Tubers	3.25	3.08	4.62	5.05	3.08	3.48	4.53	2.00
All Meat Products	3.17	3.02	3.20	3.47	3.01	2.20	3.23	3.66
Beef	3.29	3.66	2.41	3.40	3.65	3.31	2.78	2.51
Lamb	2.73	2.38	3.63	2.84	2.37	2.13	3.27	2.87
Poultry	2.79	2.18	3.99	4.90	2.22	3.56	3.90	3.48
Dairy	3.43	3.14	3.48	3.42	3.22	3.99	3.50	3.96
PHL Scenario				(% change from HGEM)				
All Cereals								
Production	0.96	1.23	1.32	1.91	1.21	1.51	1.07	(0.21)
Food Demand	4.81	4.82	5.22	3.53	4.77	4.38	5.12	4.86
Total Demand	5.93	10.06	3.87	4.43	9.62	4.20	3.90	2.73

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, PHL = post-harvest losses, PRC = People's Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

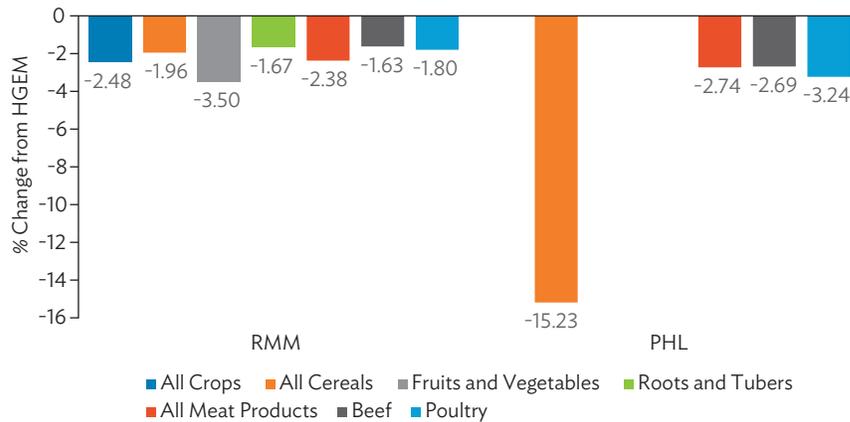
Source: IMPACT simulation results.

For the PHL scenario, the production responses are more modest: 1.91% for Central and West Asia and 1.51% for the Pacific. The increases in consumption, however, are high, due to the savings from post-harvest losses, which results in higher consumption for any given level of production. Consumption of cereals for food and total uses are projected to increase by 9.62% for East Asia and 5.12% for South Asia.

World Prices

The supply responses from producers under the RMM scenario are expected to reduce world prices of fruits and vegetables (-3.50%), meat products (-2.38%) and cereals (-1.96%). Under the PHL scenario, however, the increased availability of cereals will likely cause a significant 15.23% reduction in the price of cereals. Prices of meat products are also projected to decline by as much as 3.24% due to the increased availability of feed crops for livestock (Figure 3.24).

Figure 3.24: Projected Impact of Investment in Rural Infrastructure on World Prices of Food Commodities, ADB Developing Member Countries and Regions, 2030



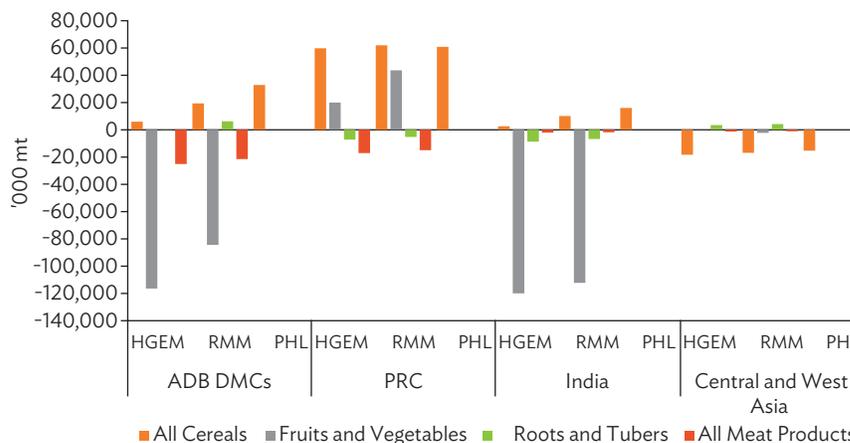
ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, PHL = post-harvest losses, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Net Trade

The net trade position of ADB DMCs are projected to improve under the RMM scenario for fruits and vegetables and meat (reduction in imports) and cereals and meat products (increase in exports) (Figures 3.25a and 3.25b).

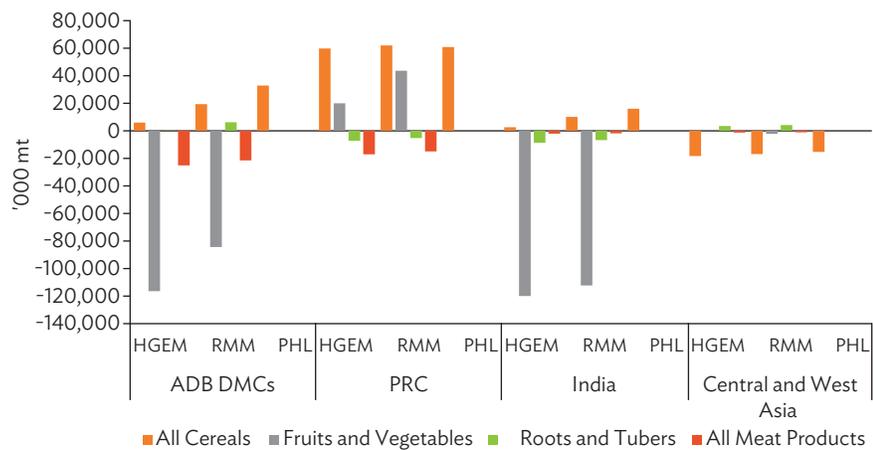
Figure 3.25a: Projected Impact of Investment in Rural Infrastructure on Net Trade of Food Commodities, ADB Developing Member Countries and Region, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, mt = metric ton, PHL = post-harvest losses, PRC = People's Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Figure 3.25b: Projected Impact of Investment in Rural Infrastructure on Net Trade of Food Commodities, ADB Developing Member Countries and Region, 2030



ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, mt = metric ton, PHL = post-harvest losses, RMM = increased infrastructure investment that reduces marketing margins.

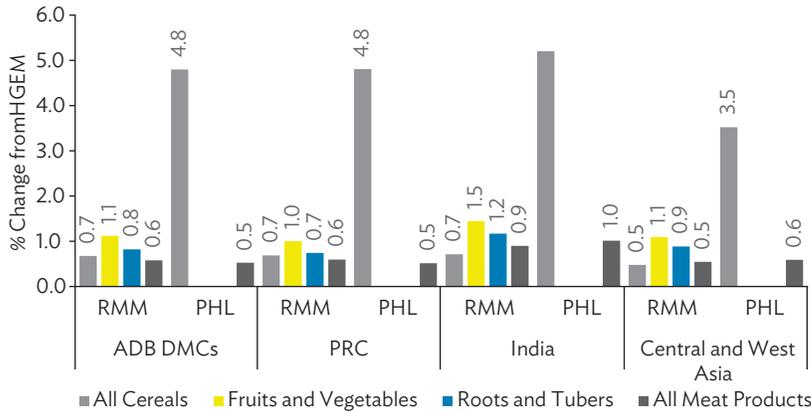
Source: IMPACT simulation results.

Because of the reduction in post-harvest losses, improved net trade positions are projected under the PHL scenario, i.e., increasing cereal exports for ADB DMCs, the PRC and East Asia, and India and South Asia, with a reduction of cereal imports for Central and West Asia and Southeast Asia.

Consumption and Hunger and Malnutrition

Modest increases in per capita food consumption are projected for DMCs under the RMM scenario—at the most 1.4% for fruits and vegetables and 1.2% for root crops both in South Asia (Figures 3.26a and 3.26b).

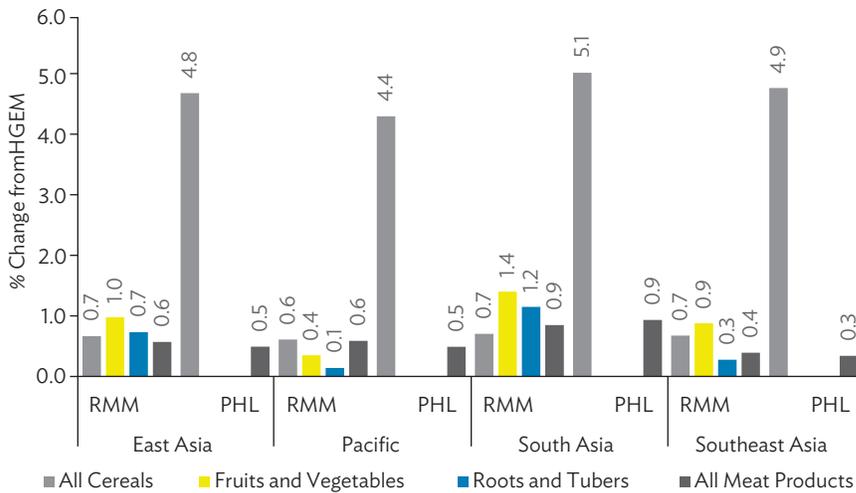
Figure 3.26a: Projected Impact of Investment in Rural Infrastructure on Consumption of Food Commodities, ADB Developing Member Countries and Region, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, PHL = post-harvest losses, PRC = People's Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Figure 3.26b: Projected Impact of Investment in Rural Infrastructure on Consumption of Food Commodities, ADB Regions, 2030



ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, PHL = post-harvest losses, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

However, for the PHL scenario, per capita cereal consumption is projected to be 5.1% higher for South Asia; 4.9% higher for Southeast Asia and 4.8% higher for East Asia.

Higher consumption of cereals and meat products imply better gains in achieving the goal of reducing hunger and child malnutrition under the PHL scenario, with a 23.9% reduction of people at-risk of hunger in ADB DMCs, equivalent to 67 million fewer hungry people in 2030 compared to HGEM (Table 3.27).

Table 3.27: Projected Impact of Investment in Rural Infrastructure on Hunger and Nutrition, ADB Developing Members Countries and Region, 2030

Region	Malnourished Children			Population At-Risk of Hunger		
	HGEM	RMM	PHL	HGEM	RMM	PHL
millions						
ADB DMCs	76.4	76.0	74.7	362	345	295
PRC	0.5	0.4	0.2	87	81	65
India	45.9	45.7	45.2	116	110	92
Central and West Asia	11.1	11.1	11.0	58	57	52
East Asia	0.5	0.4	0.2	89	83	67
Pacific	0.4	0.4	0.4	0.67	0.66	0.61
South Asia	54.0	53.8	53.1	139	132	110
Southeast Asia	10.4	10.3	10.1	75	73	65

ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, PHL = post-harvest losses, PRC = People's Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Summary of RMM and PHL Scenarios

Under the RMM scenario, consumers benefit through lower food prices while under the PHL scenario, consumers enjoy the benefit of having more food available to them.

The farmers' response to RMM is to produce more of the food commodity, while under the PHL scenario, higher consumption dominates.

The supply responses from producers under the RMM scenario are estimated to lower world prices of fruits and vegetables (-3.50%), meat products (-2.38%) and cereals (-1.96%). Under the PHL scenario, improved availability of cereals led to a significant 15% reduction in the price of cereals.

The net trade position of ADB DMCs are projected to be favorable under the RMM scenario for fruits and vegetables and meat products and under the PHL scenario for expanding exports of cereals.

Only modest increases in consumption are projected for countries and ADB region under the RMM scenario. However, under the PHL scenario, cereal consumption will likely reach as high 5.5% with a high 23.9% reduction of people at-risk of hunger in the ADB regions, equivalent to 67 million less hungry people.

In terms of climate change adaptation, the appropriate measure for RMM is production effects on food crops and livestock, while for PHL scenario, the impact on the available cereals for food is the more appropriate comparison.

The production impacts of RMM on crops and livestock are projected to more than compensate for the effects of climate change, with production by as much as 2.22% more for crops and by 3.17% for for livestock, although it is projected to be only marginally better by 0.83% for crops when compared to the NoCC scenario. For livestock, RMM is projected to be 2.25% better.

The PHL scenario can compensate for the effects of climate change on the availability of cereals as much as 4.81%, and by 3.53% over the NoCC levels.

3.7.4. Comprehensive Investment for Improvement in Food Security

This section provides a comparison of select R&D, irrigation, and rural infrastructure investment scenarios to draw out the comparative impacts. Included scenarios are:

- (i) **Hi+NARS+EFF.** This was selected from the set of R&D investment scenarios, with investment on high research efficiency added to increased investment in IARCs and NARS.
- (ii) **IRREXP-WUE.** This was selected from the set of investment in irrigation scenarios, adding investment in WUE to investment in irrigation expansion.
- (iii) **COMP.** This refers to a comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios.
- (iv) **RMM/PHL.** This refers to investment in rural infrastructure.
- (v) **COMP2.** This is a comprehensive investment scenario that combines the Hi+NARS+EFF, IRREXP-WUE, and RMM/PHL scenarios, to explore if hunger can be eliminated in Asia and the Pacific in 2030.

Simulation Results for Selected Investment Scenarios

Simulation results for the COMP scenario and comparative tables and figure with the other selected scenarios are presented in Tables 3.28a–3.30b and Figures 3.27a–3.28b.

Productivity

The projected impacts of the select scenarios on crop production, area harvested, and yields show that the combined COMP scenario benefits positively on the high productivity influence of Hi+NARS+EFF and the land area and some yield contribution of IRREXP-WUE, to achieve the highest projected crop production for ADB DMCs and the regions.

The combined influence of the R&D and irrigation scenarios to land and water productivity scenarios on crop yields results in high yield projections for the COMP scenario for ADB DMCs—highest for cereals (20%), pulses (18%), and root crops (15%) (Table 3.28a).

Table 3.28a: Projected Impact of Selected Food Investments on Crop Production, Yield, and Area in ADB Developing Member Countries, 2030

Commodity	ADB DMCs			PRC			India		
	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP
	(% change from HGEM)								
Crop Production									
All Crops	5.51	2.88	8.63	5.27	0.52	5.96	6.06	5.12	11.73
All Cereals	17.84	5.27	24.17	19.30	2.70	22.69	22.83	8.86	33.55
Fruits and Vegetables	(0.66)	0.27	(0.34)	(2.14)	(0.12)	(2.28)	(0.07)	(0.08)	(0.02)
Oil crops	2.79	1.41	4.02	2.51	0.32	2.40	1.80	2.39	3.85
Pulses	17.10	0.65	17.92	9.23	(0.40)	8.91	19.31	0.35	19.78
Roots and Tubers	14.72	0.77	15.39	11.06	(0.34)	10.73	12.66	4.23	17.26
Crop Area Harvested									
All Crops	--	1.60	1.55	--	(0.53)	(0.48)	--	2.52	2.84
All Cereals	--	2.56	3.40	--	(0.81)	0.33	--	4.33	6.31
Fruits and Vegetables	--	0.31	(0.83)	--	(0.02)	(1.14)	--	0.29	(2.52)
Oil crops	--	0.27	(1.33)	--	(0.40)	(1.15)	--	0.28	(0.82)
Pulses	--	0.46	0.12	--	(0.25)	0.41	--	0.16	(0.98)
Roots and Tubers	--	0.68	0.67	--	(0.22)	(1.69)	--	3.69	4.56
Crop Yield									
All Crops	5.95	1.26	7.20	5.64	1.07	6.62	6.10	2.52	8.88
All Cereals	17.20	2.64	20.09	18.59	3.54	22.29	20.70	4.35	25.62
Fruits and Vegetables	0.70	(0.04)	0.50	(0.84)	(0.11)	(1.16)	3.07	(0.38)	2.57
Oil crops	4.24	1.14	5.42	2.97	0.71	3.59	2.62	2.11	4.71
Pulses	17.72	0.20	17.78	8.82	(0.15)	8.46	20.94	0.19	20.98
Roots and Tubers	14.80	0.09	14.62	12.91	(0.12)	12.64	11.89	0.53	12.14

-- = no significant difference from HGEM, () = negative, ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PRC = People's Republic of China.

Source: IMPACT simulation results.

Similar combined effects are observed for the regions, with South Asia projected to have the highest yield gains for cereals (24%), pulses (21%), and root crops (12%) (Tables 3.28a). Central and West Asia followed with 25% yield gains for cereals, 21% for pulses, and 18% for root crops (Table 3.28b). This is due to the significant yield improvement contribution of IRREXP-WUE to the COMP scenario in this region, which is also reflected in the region's production results. East Asia ranks next with 17% for cereals, 13% for root crops, and 18% for pulses.

Table 3.28b: Projected Impact of Selected Food Security Investments on Livestock Production, by ADB Regions 2030

Commodity	Central and West Asia			East Asia			Pacific			South Asia			Southeast Asia		
	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP
(% change from HGEM)															
Crop Production															
All Crops	5.81	9.11	15.51	5.22	0.53	5.92	5.29	(0.77)	4.44	6.14	4.83	11.47	5.20	3.02	8.24
All Cereals	16.84	8.69	26.90	19.19	2.64	22.51	10.90	5.54	17.85	20.88	7.79	30.28	9.60	5.75	16.23
Fruits and Vegetables	(0.12)	5.40	5.51	(2.07)	(0.07)	(2.15)	19.62	(0.45)	18.88	0.27	0.03	0.43	5.70	0.92	6.82
Oil crops	0.02	5.79	5.64	2.51	0.32	2.40	-0.25	(2.32)	(2.63)	1.67	2.36	3.70	3.00	1.46	4.34
Pulses	17.74	3.25	21.26	9.25	(0.38)	8.95	12.08	(1.30)	10.47	19.50	0.32	19.93	20.26	2.61	23.35
Roots and Tubers	23.72	1.71	25.83	11.00	-0.33	10.68	10.66	0.16	10.60	12.64	4.11	17.12	25.06	0.12	24.19
Crop Area Harvested															
All Crops	--	2.63	2.22	--	(0.53)	(0.48)	--	(0.36)	(0.59)	--	2.44	2.69	--	2.80	2.21
All Cereals	--	2.40	1.80	--	(0.82)	0.29	--	4.11	4.99	--	3.99	5.58	--	4.83	4.60
Fruits and Vegetables	--	4.18	4.04	--	0.00	(1.10)	--	(0.04)	(0.16)	--	0.40	(2.08)	--	0.02	0.63
Oil crops	--	0.20	0.62	--	(0.39)	(1.13)	--	(1.55)	(2.07)	--	0.33	(0.69)	--	0.86	(2.46)
Pulses	--	1.57	0.35	--	(0.24)	0.45	--	(1.14)	0.51	--	0.15	(0.88)	--	2.13	4.86
Roots and Tubers	--	1.57	6.79	--	(0.22)	(1.69)	--	0.11	(0.33)	--	3.55	4.63	--	0.00	1.53
Crop Yield															
All Crops	5.64	6.26	13.22	6.10	1.08	6.58	5.95	(0.42)	5.33	0.45	2.30	8.77	2.81	0.30	6.27
All Cereals	18.59	6.14	24.66	20.70	3.49	22.16	17.20	1.37	12.25	(1.75)	3.65	23.39	6.05	0.87	11.12
Fruits and Vegetables	(0.84)	1.18	1.41	3.07	(0.07)	(1.07)	0.70	(0.41)	19.07	(0.23)	(0.37)	2.56	0.17	0.90	6.15
Oil crops	2.97	5.58	4.99	2.62	0.71	3.56	4.24	(0.78)	(0.57)	(0.76)	2.02	4.42	1.49	0.60	6.97
Pulses	8.82	1.65	20.84	20.94	(0.15)	8.46	17.72	(0.16)	9.91	(0.54)	0.18	20.99	6.04	0.47	17.64
Roots and Tubers	12.91	0.14	17.83	11.89	(0.11)	12.58	14.80	0.05	10.97	(1.00)	0.54	11.94	4.85	0.12	22.31

-- = no significant difference from HGEM, () = negative, ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements.

Source: IMPACT simulation results.

Improvements in yields are further reflected in the projected gains in production, which are also highest for cereals (24%), pulses (18%), and root crops (15%) for the COMP scenario in the ADB DMCs aggregate. Similar trends are projected in the regions, with highest production gains in India for cereals (34%), pulses (20%), and root crops (17%). This is followed by Central and West Asia with 27% production gains for cereals, 26% for root crops, and 21% for pulses. The PRC and East Asia comes next with both 23% production gains for cereals; 10% for the PRC and 11% for East Asia for root crops; and both 9% for pulses.

Livestock productivity for the COMP scenario comes solely from the Hi+NARS+EFF, since IRREXP-WUE has no significant effects on livestock yields and production, resulting in yield and production gains similar to Hi+NARS+EFF (Tables 3.28c–3.28d).

Table 3.28c: Projected Impact of Selected Food Security Investments on Livestock Production and Number in ADB Developing Member Countries, 2030

Commodity	ADB DMCs			PRC			India		
	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP
	(% change from HGEM)								
Production									
All Meat Products	6.36	--	6.41	4.33	--	4.34	19.23	--	19.57
Beef	13.74	--	14.01	9.76	--	9.94	25.17	--	25.88
Lamb	12.47	--	12.48	8.52	--	8.47	19.03	--	19.04
Poultry	10.40	--	10.69	9.14	--	9.57	19.24	--	19.40
Dairy	15.96	--	16.19	7.25	--	7.26	19.75	--	20.00
Yield									
All Meat Products	9.40	--	9.22	6.76	--	6.40	24.74	--	24.93
Beef	15.42	--	15.43	11.85	--	11.85	24.98	--	24.98
Lamb	16.34	--	16.35	11.93	--	11.93	24.98	--	24.98
Poultry	13.64	--	13.68	11.79	--	11.79	24.82	--	24.82
Dairy	20.81	--	20.86	11.86	--	11.86	24.84	--	24.84

— = no significant difference from HGEM, () = negative, ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, PRC = People's Republic of China.

Source: IMPACT simulation results.

Table 3.28d: Projected Impact of Selected Food Security Investments on Livestock Production, by ADB Regions 2030

Commodity	Central and West Asia			East Asia			Pacific			South Asia			Southeast Asia		
	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP	Hi+NARS+EFF	IRREXP-WUE	COMP
(% change from HGEM)															
Production															
All Meat Products	13.78	--	14.07	4.35	--	4.39	2.96	--	2.79	19.57	--	19.86	3.88	--	3.78
Beef	13.61	--	13.73	9.77	--	9.95	9.83	--	9.71	24.41	--	25.00	9.37	--	9.59
Lamb	13.39	--	13.50	8.54	--	8.49	8.93	--	8.85	19.56	--	19.59	7.97	--	7.87
Poultry	18.67	--	19.71	9.14	--	9.56	9.60	--	9.19	19.56	--	19.67	8.02	--	7.95
Dairy	14.96	--	15.38	7.24	--	7.26	7.29	--	7.29	19.74	--	19.99	8.47	--	8.73
Yield															
All Meat Products	6.76	--	14.98	24.74	--	6.45	9.40	--	5.00	0.55	--	24.75	3.87	--	7.46
Beef	11.85	--	15.16	24.98	--	11.87	15.42	--	11.87	-0.02	--	25.03	3.66	--	11.82
Lamb	11.93	--	15.98	24.98	--	11.94	16.34	--	11.87	0.00	--	24.93	6.90	--	11.92
Poultry	11.79	--	20.48	24.82	--	11.79	13.64	--	11.77	-0.11	--	24.60	4.53	--	11.81
Dairy	11.86	--	18.77	24.84	--	11.84	20.81	--	11.04	-0.56	--	24.98	7.37	--	13.36

— = no significant difference from HGEM, () = negative, ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements.

Source: IMPACT simulation results.

World Prices

The combined influences of Hi+NARS+EFF and IRREXP-WUE are projected to have significant reductions in the world prices of major food commodities under the combined COMP scenario. The highest reduction is projected for the prices of cereals (-18%), pulses and root crops (-12% each), and lamb meat (-12%). Table 3.29 also shows the potential modest contributions of RMM investment to the reduction of world prices. PHL's potential contributions are also shown in the table—modest for livestock products but can be very significant for cereals.

Table 3.29: Projected Impact of Selected Food Security Investment on World Prices of Food Commodities in ADB Developing Member Countries, 2030

Commodity	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(% change from HGEM)				
All Crops	(2.5)	(3.2)	(6.7)	(1.6)	(8.8)
All Cereals	(2.0)	(15.2)	(13.6)	(4.5)	(17.9)
Fruits and Vegetables	(3.5)	--	(3.3)	(0.8)	(4.6)
Oil crops	1.5	--	(7.4)	(1.4)	(9.4)
Pulses	(2.2)	--	(11.0)	(0.7)	(12.3)
Roots and Tubers	(1.7)	--	(11.2)	(0.5)	(12.3)
Sugar	(0.5)	--	(1.0)	(1.3)	(2.5)
All Meat Products	(2.4)	(2.7)	(6.3)	(0.5)	(7.2)
Beef	(1.6)	(2.7)	(7.0)	(0.4)	(7.7)
Lamb	(2.6)	(1.5)	(11.4)	(0.1)	(11.7)
Poultry	(1.8)	(3.2)	(8.2)	(0.6)	(9.6)
Dairy	(1.3)	(1.0)	(6.4)	(0.1)	(6.7)

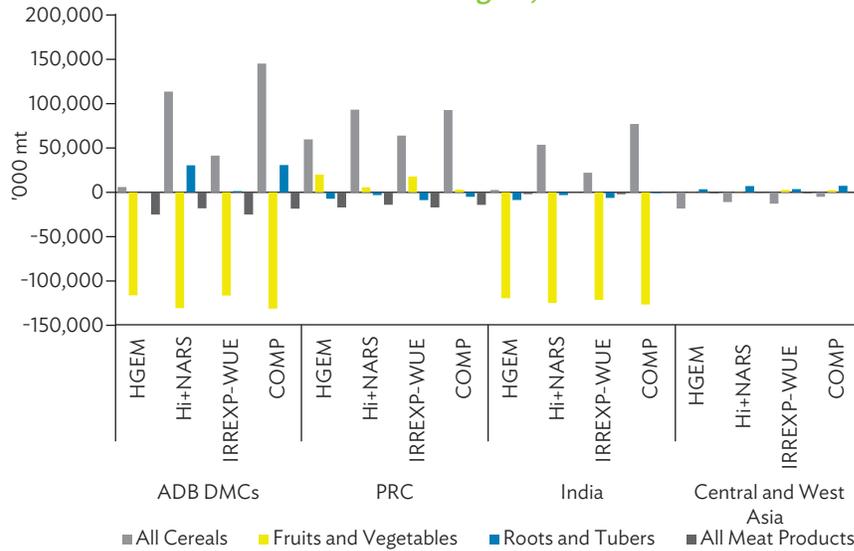
— = no significant difference from HGEM, () = negative, ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PHL = post-harvest losses, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Net Trade

The trade effects of the combined COMP scenario are projected to be substantial for cereals with projected additional exports of 140 metric tons (mt) from HGEM values for ADB DMCs, especially for India with 75 million mt and the PRC with 30 million mt cereals exports gains over HGEM values (Figures 3.27a–3.27b).

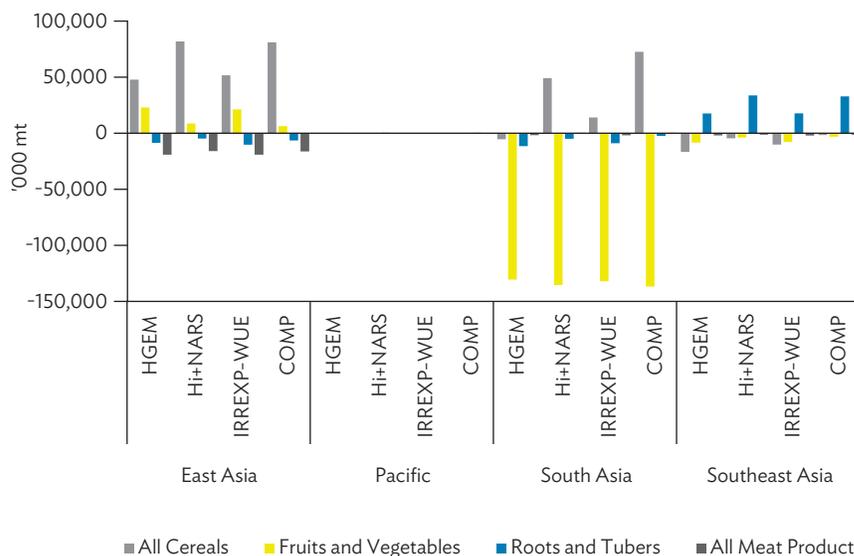
Figure 3.27a: Projected Impact of Selected Food Security Investment on Net Trade of Food Commodities, ADB Developing Member Countries and Region, 2030



ADB = Asian Development Bank, DMC = developing member country, HGEM = Hadley Centre Global Environmental Model, Hi+NARS = intensified NARS research, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, mt = metric ton, PRC = People's Republic of China.

Source: IMPACT simulation results.

Figure 3.27b: Projected Impact of Selected Food Security Investment on Net Trade of Food Commodities, ADB Regions, 2030



ADB = Asian Development Bank, HGEM = Hadley Centre Global Environmental Model, Hi+NARS = intensified NARS research, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, mt = metric ton.

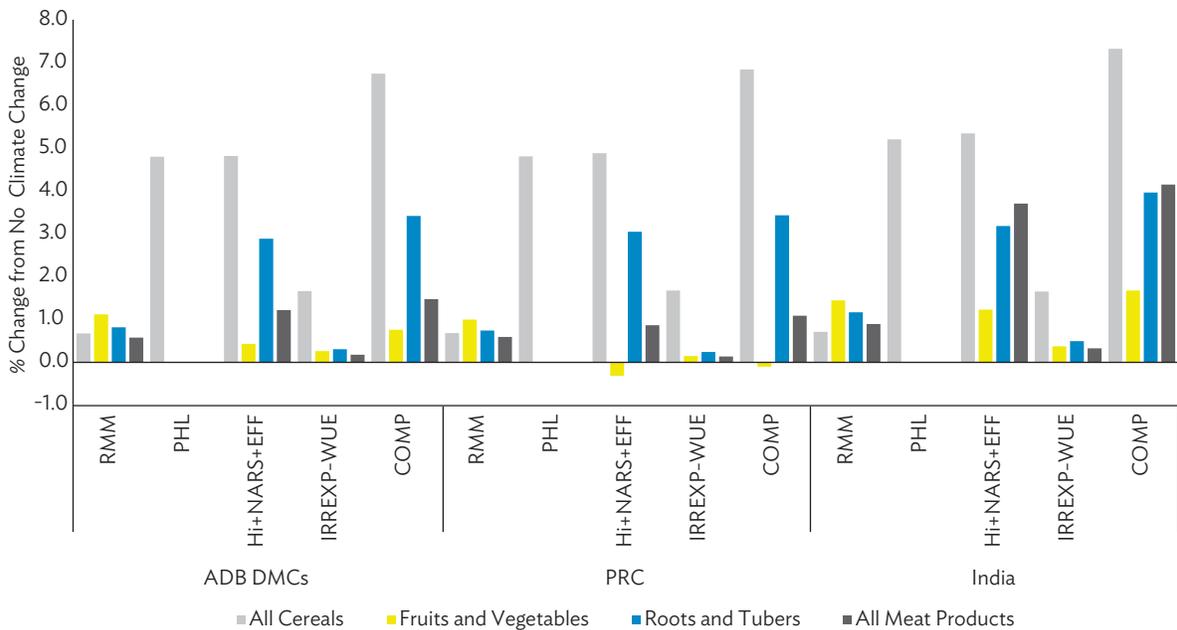
Source: IMPACT simulation results.

Consumption

Similar to the additive contribution of Hi+NARS+EFF and IRREXP-WUE scenarios in the reduction of prices to the combined COMP scenario, the projected increases in the consumption of food under the COMP scenario are reflective of the two scenarios. Figure 3.28a shows that the annual per capita consumption of cereals in ADB DMCs is projected to increase by 6.8%, root crops 3.4%, and meat products by 1.5% over HGEM values.

On a percentage basis, regional gains are highest for cereals in South Asia (7.2%), East Asia (6.8%) and Southeast Asia (6.4%). Consumption gains for meat products are highest for South Asia (4.1%) followed by Central and West Asia with a 3.0% gain (Figure 3.28b).

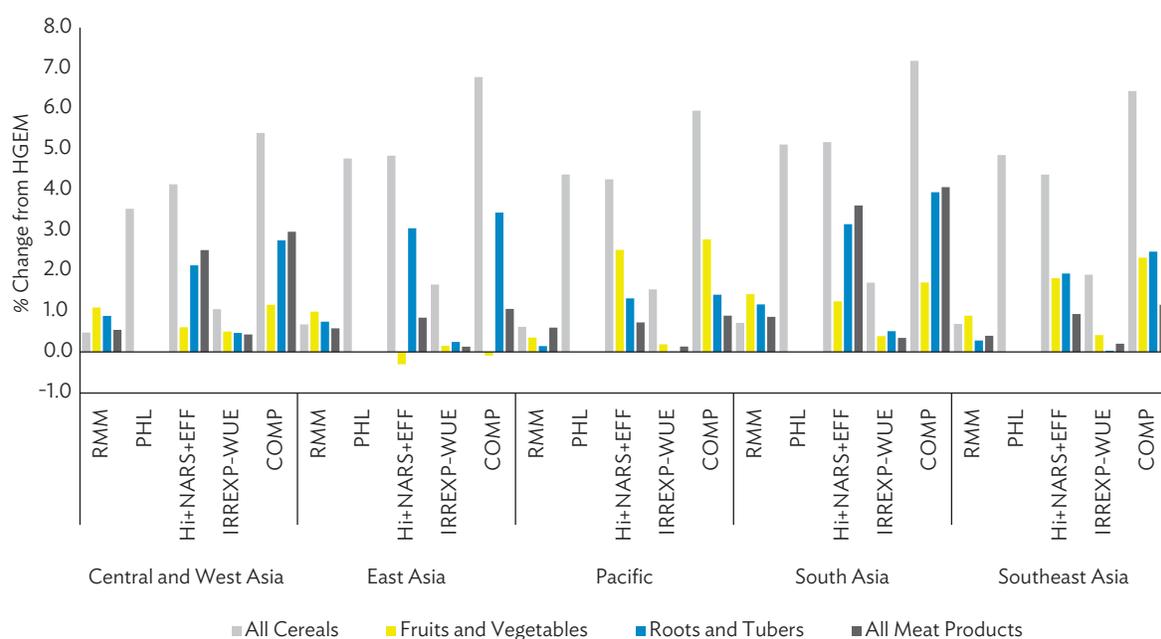
Figure 3.28a: Projected Impact of Selected Food Security Investment on Consumption of Food Commodities, ADB Developing Member Countries, 2030



ADB = Asian Development Bank, DMC = developing member country, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PHL = post-harvest losses, PRC = People’s Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Figure 3.28b: Projected Impact of Selected Food Security Investment on Consumption of Food Commodities, ADB Regions, 2030



ADB = Asian Development Bank, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PHL = post-harvest losses, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Hunger and Malnutrition

Substantial gains in the goals of eliminating hunger and malnutrition are projected with the combined Hi+NARS+EFF and IRREXP-WUE scenarios into the COMP scenario (Tables 3.30a–3.30b).

Table 3.30a: Projected Impact of Selected Investments on Childhood Malnutrition in ADB Developing Member Countries, by ADB Region, 2030

Region	Malnourished Children							
	2015	NoCC	HGEM	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(million)							
ADB DMCs	93.1	75.4	76.4	76.0	74.7	74.2	75.7	73.5
PRC	4.14	0.37	0.52	0.44	0.23	0.15	0.40	0.02
India	54.6	45.5	45.9	45.7	45.2	44.9	45.6	44.6
Central and West Asia	11.2	11.1	11.1	11.1	11.0	10.9	11.1	10.8
East Asia	4.2	0.4	0.5	0.4	0.2	0.2	0.4	0.0
Pacific	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

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Table 3.30a continued

Region	Malnourished Children							
	2015	NoCC	HGEM	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(million)							
South Asia	64.2	53.5	54.0	53.8	53.1	52.8	53.6	52.4
Southeast Asia	13.2	10.2	10.4	10.3	10.1	10.0	10.2	9.9

ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, NoCC = no climate change, PHL = post-harvest losses, PRC = People's Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

Table 3.30b: Projected Impact of Selected Security Investments on Hunger in ADB Developing Member Countries, by ADB Region, 2030

Region	Population At-Risk of Hunger							
	2015	NoCC	HGEM	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(million)							
ADB DMCs	507	324	362	345	295	278	334	247
PRC	132	76	87	81	65	59	79	47
India	193	101	116	110	92	86	106	77
Central and West Asia	59	55	58	57	52	50	56	47
East Asia	135	78	89	83	67	60	80	48
Pacific	1.44	0.59	0.67	0.66	0.61	0.55	0.61	0.52
South Asia	226	121	139	132	110	103	127	92
Southeast Asia	87	70	75	73	65	64	71	59

ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, NoCC = no climate change, PHL = post-harvest losses, PRC = People's Republic of China, RMM = increased infrastructure investment that reduces marketing margins.

Source: IMPACT simulation results.

The number of malnourished children in ADB DMCs are projected to be reduced by 3.9% from HGEM values of 76.4 million to 73.5 million. In absolute values, the highest decline in malnutrition is projected for South Asia, with 1.58 million fewer malnourished children in 2030 compared to HGEM.

The number of hungry people is projected to be significantly reduced under the COMP scenario compared to the HGEM reference scenario. For ADB DMCs as a whole, this is projected to be 115 million fewer hungry people, equivalent to a 32% decline from HGEM values of 362 million to 278 million in 2030. The largest reductions are from the PRC, at 40 million fewer hungry people (equivalent to 46% fewer hungry children), and from India, 39 million fewer (34%).

From a climate adaptation perspective, the COMP scenario is projected to more than compensate for the productivity impacts of climate change on crop and livestock yields and projected to have higher crop yields over NoCC values by 5.14% and by 10.86% livestock yields in ADB DMCs. With this scenario, world prices of food crops and livestock products are projected to be lower than HGEM values, by 8.77% for food crops and 7.24% for livestock products; and by 1.39% for food crops and 2.53% for livestock products compared to NoCC scenario. The child malnutrition and hunger outcomes are far better under the COMP scenario than under NoCC and HGEM, achieving a 45% reduction in hunger from 2015, nearly halving hunger by 2030.

Tables 3.30c and 3.30d show the summary of food security results by income groups, to explore if progress is different across these groups. The income groups are determined based on the year 2015 and are defined in terms of PPP dollars. As shown in Table 3.30c, the lowest income class has the smallest reduction in the number of malnourished children, both in percentage and absolute terms. Even under the COMP scenario, the reduction is only from 13 million malnourished children in 2015 to 11.6 million in 2030. The lowest income countries perform better in reducing hunger by nearly half under COMP (Table 3.30d).

The second income group, “> \$2,000–\$5,000,” which includes India, has by far the largest number of malnourished children and hungry people in 2015, and has the largest absolute reductions in these measures due to the investment scenarios. The number of malnourished children and hungry people decline the most compared to the HGEM reference scenario, by 1.76 million (malnourished children) and 54 million (hungry people) in the “> \$2,000–\$5,000” income group under the COMP scenario (Tables 3.30c and 3.30d). Percentage reductions, however, are projected to be highest from the “>10,000” income group, with a 53% reduction in malnourished children and 45% in hungry people compared to HGEM under the COMP scenario. Led by the PRC, malnourished children are nearly eliminated in this income group by 2030, while the number of hungry people are reduced by two-thirds.

Table 3.30c: Projected Impact of Selected Investments on Childhood Malnutrition, ADB Developing Member Countries, the People’s Republic of China, India, and by Income Group, 2030

Region	Malnourished Children							
	2015	NoCC	HGEM	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(million)							
ADB DMCs	93.1	75.4	76.4	76.0	74.7	74.2	75.7	73.5
PRC	4.1	0.37	0.52	0.44	0.23	0.15	0.40	0.02
India	54.6	45.5	45.9	45.7	45.2	44.9	45.6	44.6
Income Group: 2015 per capita GDP, real 2005 PPP\$								
< \$2,000	13.0	11.9	12.0	12.0	11.8	11.7	11.9	11.6
> \$2,000–\$5,000	69.4	58.5	59.1	58.9	58.1	57.8	58.7	57.4

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Table 3.30c continued

Region	Malnourished Children							
	2015	NoCC	HGEM	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(million)							
> \$5,000–\$10,000	6.0	4.1	4.2	4.2	4.1	4.0	4.2	4.0
> \$10,000	4.7	0.8	1.0	0.9	0.7	0.6	0.9	0.5

ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, GDP = gross domestic product, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, NoCC = no climate change, PPP = purchasing power parity, PRC = People’s Republic of China.

Note: ≤\$2000: Afghanistan, Bangladesh, Myanmar, Nepal, Timor-Leste; > \$2,000–\$5,000: Cambodia, Fiji, India, Kyrgyz Republic, Lao People’s Democratic Republic, Pakistan, Papua New Guinea, Philippines, Solomon Islands, Tajikistan, Uzbekistan, Vanuatu, Viet Nam; > \$5,000–\$10,000: Armenia, Azerbaijan, Bhutan, Georgia, Indonesia, Mongolia, Other Indian Ocean, Other Pacific Ocean, Sri Lanka, Thailand; > \$10,000: Kazakhstan, Malaysia, Other Southeast Asia, PRC, Republic of Korea, Turkmenistan.

Source: IMPACT simulation results.

Table 3.30d: Projected Impact of Selected Investments on Hunger in ADB Developing Member Countries, by Income Group, 2030

Region	Population At-Risk of Hunger							
	2015	NoCC	HGEM	RMM	PHL	Hi+NARS+EFF	IRREXP-WUE	COMP
	(million)							
ADB DMCs	507	324	362	345	295	278	334	247
PRC	132	76	87	81	65	59	79	47
India	193	101	116	110	92	86	106	77
Income Group	(2015 per capita GDP, real 2005 PPP\$)							
< \$2,000	49	34	39	37	30	29	35	26
> \$2,000–\$5,000	279	177	197	189	164	155	183	143
> \$5,000–\$10,000	44	35	37	36	33	32	35	29
> \$10,000	136	78	89	84	67	61	81	49

ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, GDP = gross domestic product, HGEM = Hadley Centre Global Environment Model, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, NoCC = no climate change, PPP = purchasing power parity, PRC = People’s Republic of China.

Note: ≤\$2000: Afghanistan, Bangladesh, Myanmar, Nepal, Timor-Leste; > \$2,000–\$5,000: Cambodia, Fiji, India, Kyrgyz Republic, Lao People’s Democratic Republic, Pakistan, Papua New Guinea, Philippines, Solomon Islands, Tajikistan, Uzbekistan, Vanuatu, Viet Nam; > \$5,000–\$10,000: Armenia, Azerbaijan, Bhutan, Georgia, Indonesia, Mongolia, Other Indian Ocean, Other Pacific Ocean, Sri Lanka, Thailand; > \$10,000: Kazakhstan, Malaysia, Other Southeast Asia, PRC, Republic of Korea, Turkmenistan.

Source: IMPACT simulation results.

3.7.5. Ending Hunger in Asia and the Pacific

As shown in the preceding sections, hunger cannot be eliminated by 2030 even under the COMP scenario. To determine what it would cost to eliminate hunger in the Asia and Pacific Region by 2030, there is a need to define the meaning of eliminating hunger. Defining the indicator for this goal in practical terms is difficult. Even in developed countries, a part of the population remains hungry and people move in and out of hunger due to various factors, including climate and economic shocks. The Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD), and the World Food Programme's (WFP) *Achieving Zero Hunger* report utilizes “a prudential threshold of 5% of the population” as effectively achieving zero hunger.³⁸ This study adopts the same threshold to assess the cost of eliminating hunger and achieving food security in Asia and the Pacific.

To further explore the cost of ending hunger by 2030, this study ran another scenario, COMP2, that incorporates additional investments to the COMP scenario. COMP combines HI+NARS+EFF and IRR+WUE investments, or the highest levels of agricultural research and development among the scenarios presented in this report and the highest level of irrigation and water use efficiency investment simulated in the study. COMP2 combines the HI+NARS+EFF and IRREXP-WUE from COMP with the high rural infrastructure investments of the RMM/PHL investment scenario. This study also extended the simulations to the year 2035 to assess hunger outcomes in these two scenarios after 2030.

The results for the total number of hungry people are shown in Table 3.31a, and the share of hungry people in the total population are shown in Table 3.31b. In the COMP scenario, 247 million people are hungry in ADB DMCs in 2030, and the share of hungry people is 5.7%, slightly higher than the 5% threshold in the same year. With continued benefits from investments after 2030, the total number of hungry people is reduced to 196 million, and the share of hungry people is 4.4% by 2035, which is below the threshold for eliminating hunger.

In the COMP2 scenario, the number of hungry people is 180 million in 2030 and 140 million in 2035. The share of hungry people is 4.2% in 2030 and 3.2% in 2035, so the effective zero-hunger threshold is achieved by 2030 for ADB DMCs in total in the COMP2 scenario. Each region except Central and West Asia (11.2%) and Southeast Asia (6.9%) also achieves the threshold level in 2030. Given the progress shown in Tables 3.31a and 3.31b for COMP2, Southeast Asia would reach the 5% threshold by 2038 and Central and West Asia by 2050. Non-agricultural investments such as social safety nets would likely accelerate the progress in these two regions more rapidly than additional agricultural investments.

The total annual investment costs in the reference scenario are \$41.7 billion. The annual incremental costs for COMP are \$21.1 billion, resulting in total annual investment costs in COMP (reference plus incremental costs) of \$62.8 billion. Annual incremental costs of COMP2 are \$36.9 billion, resulting in total annual investment costs in COMP2 (reference plus incremental costs) of \$78.6 billion. The total annual investments of \$78.6 billion is therefore the amount needed to move the total of Asia and the Pacific below the

³⁸ FAO, IFAD, and WFP. 2015. *Achieving Zero Hunger: The Critical Role of Investments in Social Protection and Agriculture*. Rome: FAO. <http://www.fao.org/3/a-i4951e.pdf>.

5% threshold for eliminating hunger to achieve food security. Moving the lagging regions below this level, and further improving the overall results will require policies that must reach out directly to the poor by supporting investments in human capital. Investments in health, nutrition, clean water and sanitation, and education are crucial and essential to address hunger and childhood malnutrition. Moreover, even with rapid economic growth in Asia and the Pacific, some of the poor will be reached slowly if at all and many of them will remain vulnerable to economic reversals. These groups can be reached through income transfers, or through safety nets that will alleviate their nutritional needs and socioeconomic conditions during short-term shocks.

Table 3.31a: Number of Hungry People, by ADB Developing Member Country and Region 2015, 2030, and 2035

Region	COMP			COMP2	
	2015	2030	2035	2030	2035
	(million)				
ADB DMCs	507.0	247.0	196.0	180.0	142.0
PRC	132.0	47.0	24.0	15.0	--
India	193.0	77.0	62.0	61.0	51.0
Central and West Asia	59.0	47.0	42.0	42.0	39.0
East Asia	135.0	48.0	26.0	16.0	2.0
Pacific	1.4	0.5	0.5	0.5	0.4
South Asia	226.0	92.0	74.0	73.0	61.0
Southeast Asia	87.0	59.0	52.0	48.0	41.0

ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, PRC = People's Republic of China.

Source: IMPACT projections.

Table 3.31b: Share of Hungry People in Total Population in Asia, by ADB Developing Member Country and Region 2015, 2015, 2030, and 2035

Region	COMP			COMP2	
	2015	2030	2035	2030	2035
	(%)				
ADB DMCs	13.0	5.7	4.4	4.2	3.2
PRC	9.7	3.4	1.8	1.1	--
India	14.7	5.0	3.9	4.0	3.2
Central and West Asia	19.1	12.4	10.6	11.2	9.6
East Asia	9.5	3.4	1.8	1.1	0.1
Pacific	12.3	3.6	3.0	3.2	2.7
South Asia	14.8	5.2	4.0	4.1	3.3
Southeast Asia	13.9	8.4	7.3	6.9	5.7

ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, DMC = developing member country, PRC = People's Republic of China.

Source: IMPACT projections.

Chapter 4

ECONOMY-WIDE IMPACTS OF ALTERNATIVE INVESTMENT SCENARIOS

4.1. Introduction

In addition to the impact on hunger, it is important to understand how agricultural investments influence economy-wide income. In the context of this research project, a linked modeling system centered on IFPRI's IMPACT tool (Version 3 - footnote 30) is used to analyze alternative medium-run global and regional agricultural investment scenarios up to 2030 in the context of a changing climate with a focus on food security implications for Asia and the Pacific.

One of the components of this model ensemble is the global dynamic computable general equilibrium (CGE) model GLOBE.³⁹ Its role within the analytical framework of the project is to assess the macroeconomic income and welfare effects associated with the alternative pathways for agricultural productivity under the different scenarios and to feed the simulated aggregate income time paths back to IMPACT.

This chapter outlines the methodological approach toward linking GLOBE with IMPACT and presents the main results of the CGE analysis.

Supplementary technical information including the concordances between IMPACT and GLOBE regions and commodities, are provided in Appendix 1.

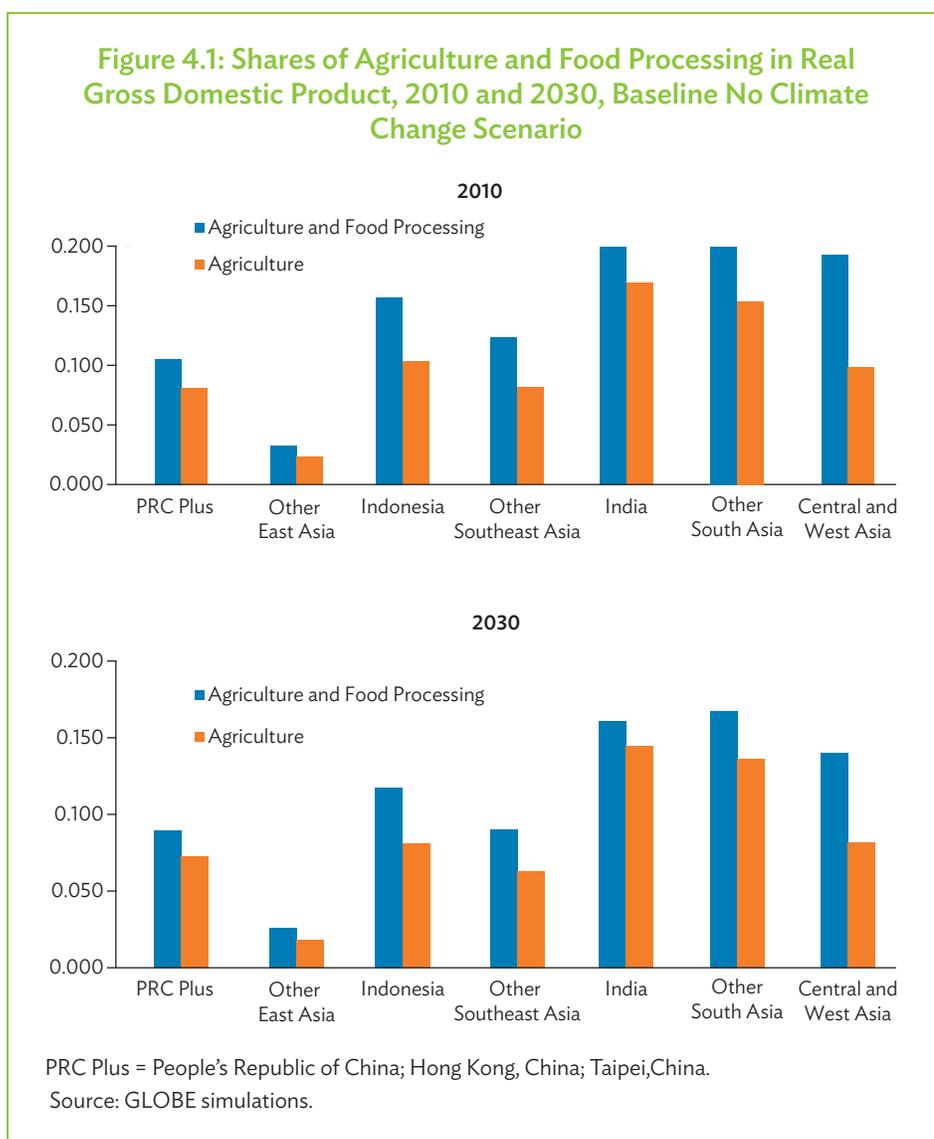
4.2. Methodology

4.2.1. Rationale

In IMPACT, projections for GDP growth by country enter the model as exogenous time series and thus remain invariant to agricultural productivity shocks in scenario simulations. The GDP series in IMPACT drive household food demand and thus serve effectively as a proxy for aggregate disposable household income or aggregate household expenditure. Due to the partial equilibrium nature of IMPACT, feedback effects from productivity change in agriculture to real GDP and hence, disposable household income are necessarily

³⁹ D. Willenbockel. 2015. *The GLOBE CGE Model for Linkage with IMPACT: Technical Description*. Report for the International Food Policy Research Institute under Research Agreement Contract No. 2015X301.IDS.; and D. Willenbockel et al. 2018. *Dynamic Computable General Equilibrium Simulations in Support of Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio: Linking the IMPACT and GLOBE Models*. IFPRI Discussion Paper 01738.

neglected in standalone applications of IMPACT. Ignoring such feedbacks is not particularly problematic for high-income regions where the contribution of agricultural and food processing activities to aggregate GDP is small (Figure 4.1), but for low-income regions with a large share of agriculture in total GDP, the omission of these feedback effects may potentially lead to simulation results that miss an important part of the plot. The linkage of IMPACT with the dynamic CGE model GLOBE serves to address this limitation of partial equilibrium approaches to global food security scenario analysis. Linking IMPACT and GLOBE allows a quantitative analysis of the impact of changes in the agriculture sector on the rest of the economy, including the effects on household income and GDP.⁴⁰



⁴⁰ D. Willenbockel et al. 2016. Climate Policy and the Energy-Water-Food Nexus: A Model Linkage Approach. *EcoMod*2016. 9746. *EcoMod*.

4.2.2. Linking GLOBE and IMPACT

The IMPACT and GLOBE model baseline scenarios are calibrated with respect to agricultural productivity, GDP and prices, and economy-wide GDP. To accomplish this calibration, IMPACT variables including GDP growth, population growth, agricultural land supply, and endogenous agricultural price projections from IMPACT are aggregated to match with the regional and sectoral aggregation structure of the GLOBE model.⁴¹ Once the models are calibrated, to assess the economy-wide general equilibrium and economy-wide effects from any given IMPACT scenario and to evaluate the resulting aggregate income and welfare effects, the agricultural productivity changes simulated in IMPACT are translated into corresponding productivity changes at the GLOBE region and activity level and are then replicated in GLOBE.

For example, climate shocks on agricultural productivity and prices simulated in IMPACT scenarios are transmitted from IMPACT to GLOBE, and GLOBE then simulates the impact on the rest of the economy. An additional iteration is then done to transmit the economy-wide effects on GDP back to IMPACT, so that the income effects on food demand are also captured. The same procedure is followed for investment scenarios.⁴²

A description of the dynamic GLOBE CGE model is presented in Appendix A2b.

4.3. The Transmission of Agricultural Productivity Shocks in a General Equilibrium

This section provides a systematic elaboration of the direct and indirect channels through which agricultural productivity shocks affect aggregate economic performance in the GLOBE model using the climate change impact scenario HGEM as a concrete example. All quantitative results presented here are expressed as percentage deviations from the reference scenario without climate change impacts on agricultural yields, labelled under the NoCC scenario for 2030.

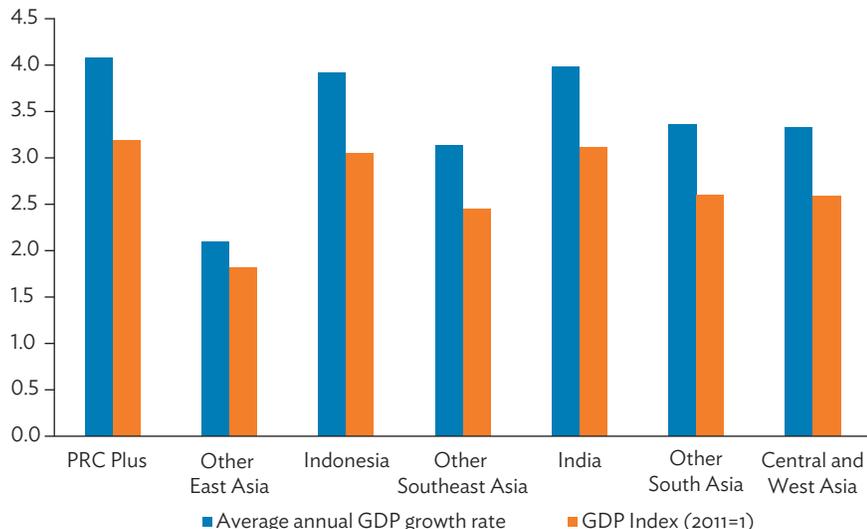
The NoCC and the HGEM climate change scenario considered here cover the period 2011 to 2030 and use the same exogenous Shared Socioeconomic Pathway 2 (SSP2—“middle of the road”⁴³) assumptions about GDP growth (Figure 4.2) and population growth (Figure 4.3). The global population rises from 7.0 billion in 2011 to 8.3 billion in 2030, and a large share of the net increase by 2030 is projected for South Asia (+395 million).

⁴¹ Appendix A2a has the concordances between GLOBE and IMPACT sectors, commodities, and regions.

⁴² D. Willenbockel et al. 2016. Climate Policy and the Energy-Water-Food Nexus: A Model Linkage Approach. *EcoMod2016*. 9746. EcoMod; and D. Willenbockel et al. 2018. Dynamic Computable General Equilibrium Simulations in Support of Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio: Linking the IMPACT and GLOBE Models. *IFPRI Discussion Paper 01738*.

⁴³ B. C. O'Neill et al. 2017. The Roads Ahead: Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century. *Global Environmental Change*. 42. pp. 169–180; and R. Dellink et al. 2017. Long-Term Economic Growth Projections in the Shared Socioeconomic Pathways. *Global Environmental Change*. 42. pp. 200–214.

Figure 4.2: Baseline Gross Domestic Product Growth in Asia and the Pacific, 2011–2030, Shared Socioeconomic Pathway 2



GDP = gross domestic product, PRC Plus = People’s Republic of China; Hong Kong, China; Taipei, China.

Notes:

1. GDP Index 2011 = 1.00.
2. Average annual GDP growth rate for 2011–2030 in percent.

Source: GLOBE simulations.

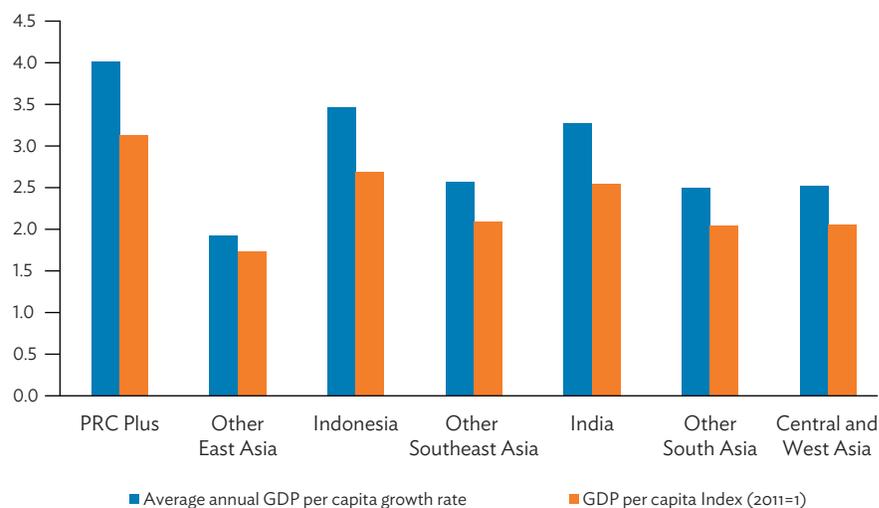
Figure 4.3: Population in Asia and the Pacific, 2011 and 2030, Shared Socioeconomic Pathway 2 (million)



PRC Plus = People’s Republic of China; Hong Kong, China; Taipei, China.

Source: GLOBE simulations.

Figure 4.4: Baseline Gross Domestic Product Per Capita Growth in Asia and the Pacific, 2011–2030, Shared Socioeconomic Pathway 2



GDP = gross domestic product, PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

Notes:

1. GDP per capita Index 2011 = 1.00.
2. Average annual per capita GDP growth rate in 2011–2030 in percent.

Source: GLOBE simulations.

The climate change scenario is based on Representative Concentration Pathway (RCP) 8.5 assumptions about the evolution of greenhouse gas concentration levels in the atmosphere. The global circulation model HadGEM2-ES⁴⁴ has been used to generate regionally disaggregated climate projections for this concentration pathway. These climate change projections have in turn been linked to the DSSAT suite of crop models to generate time series of crop- and region-specific yield impacts.

The agricultural yield shocks considered in the HGEM scenario enter the GLOBE model in the form of shifts of the factor productivity parameters in the agricultural production functions for all regions. These productivity shifts affect aggregate household income primarily via their impact on factor prices. In line with economic theory, equilibrium factor prices in the model are governed by the value of the marginal product of the corresponding factor, i.e., by the additional physical output produced by the last unit of the factor used to evaluate at the output price. Thus, in the case of predominantly negative agricultural productivity shocks—as is the case under HGEM—there are essentially two opposite forces affecting factor prices. On the one hand, the physical marginal products decline due to the adverse climate impacts on yields and this effect drags factor prices down. On the other hand, the resulting supply reductions for agricultural products drive agricultural prices up (Table 4.3) and per se lift factor prices upwards.

⁴⁴ C. D. Jones et al. 2011. The HadGEM2-ES Implementation of CMIP5 Centennial Simulations. *Geoscientific Model Development*. 4 (3). pp. 543–570.

Table 4.1: Impact of Climate Change on International Model for Policy Analysis of Agricultural Commodities and Trade Producer Prices 2030 Under the Hadley Centre Global Environment Model Scenario

(% deviation from 2030 ADB NoCC Scenario)

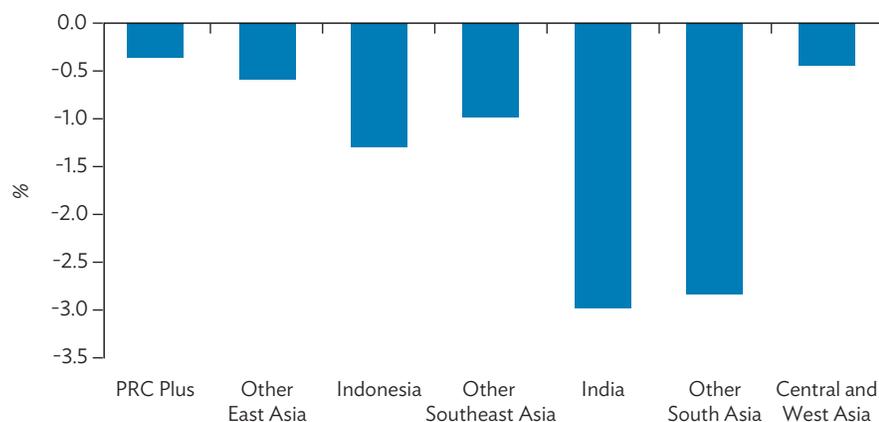
Region	Rice	Wheat	Other Cereals	Oil Seeds	Sugar Cane	Other Crops	Cattle	Other Livestock Products	Vegetable Oils	Sugar
PRC Plus	9.6	1.9	(2.7)	13.8	8.0	5.1	2.7	5.9	2.9	3.2
Other East Asia	9.6	1.9	(1.6)	11.1		4.9	2.8	5.7	2.5	
Indonesia	9.6		(3.8)	9.0	16.0	8.1	2.9	7.6	1.7	3.2
Other Southeast Asia	9.6	1.9	(3.2)	9.8	21.8	7.2	3.2	6.6	1.7	3.2
India	9.6	1.9	5.3	13.2	17.8	6.5	2.8	2.9	3.3	3.2
Other South Asia	9.6	1.9	(1.3)	7.4	10.3	7.2	2.7	3.1	2.9	3.2
Central and West Asia	9.6	1.9	1.6	6.7	6.8	5.8	2.8	2.9	2.8	3.2

(-) = negative, NoCC = no climate change, PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

Source: GLOBE simulations.

For labor wages and returns to capital, the economy-wide net effect is unambiguously negative across all regions, as the marginal productivity effect dominates the output price effect (Figures 4.5–4.6). In the high-income regions, where the share of agriculture in GDP is low (Figure 4.1), the effects on wages and capital returns are very small, whereas in today's low-income regions, where the contribution of agriculture to GDP is still substantial toward 2030, these adverse factor price effects are far more pronounced.

Figure 4.5: Impact of Climate Change on Labor Wage Rates, Hadley Centre Global Environmental Model Scenario

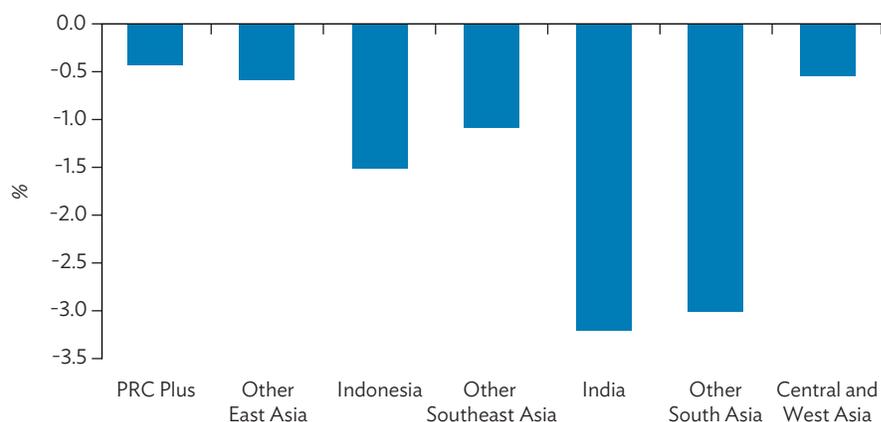


PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

Note: Percentage deviation from 2030 Asian Development Bank No Climate Change Scenario.

Source: GLOBE simulations.

Figure 4.6: Impact of Climate Change on Rates of Return to Capital, Hadley Centre Global Environmental Model Scenario



PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

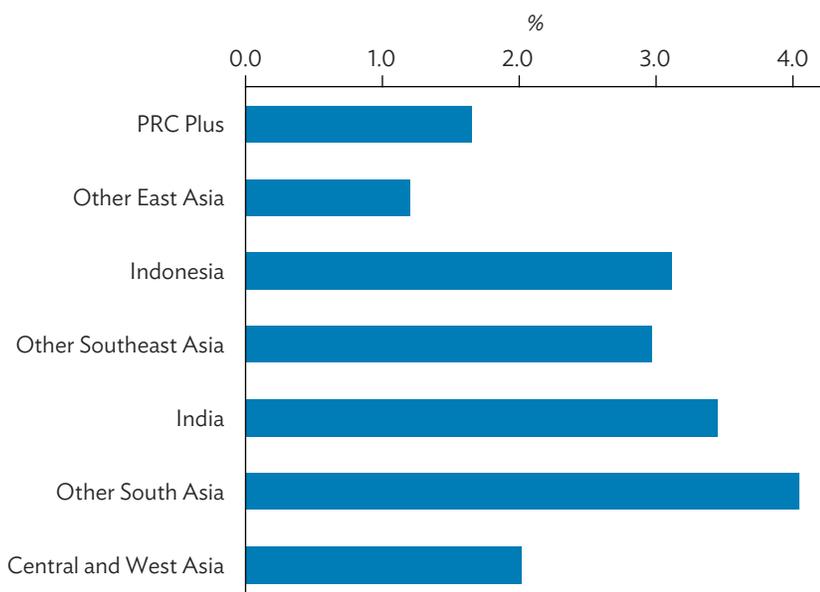
Note: Percentage deviation from the 2030 REF_No Climate Change Scenario.

Source: GLOBE simulations.

In contrast, the global increase in the prices for agricultural commodities drive agricultural land rents significantly upward in all regions except Japan, as the price increases dominate the climate change-induced reductions in the physical marginal productivity of land. The difference in the response of returns to labor versus returns to agricultural land is due to labor being mobile between agricultural and non-agricultural activities, while agricultural land is an agriculture-specific quasi-fixed factor. More precisely, agricultural land can switch across agricultural activities in response to relative price changes in the model, but in contrast to labor, a rise in the prices of agricultural commodities relative to non-agricultural goods cannot pull land from non-agriculture sectors to agriculture. The model allows for endogenous changes in the supply of agricultural land in response to land rent changes, and in the linked IMPACT-GLOBE system, the land supply paths in GLOBE are calibrated to match the aggregate land use projections by region in IMPACT.

To get a full picture of the factor market responses triggered by the agricultural productivity shocks, it is instructive to look at the intersectoral employment reallocation effects. Figure 4.7 shows the simulated changes in employment in agriculture in 2030 relative to the ADB-NoCC baseline for developing regions. In all regions except Japan, agricultural employment expands to some extent in response to the predominantly adverse impacts of climate change on agricultural yields, as additional labor and capital is required to satisfy the demand for food commodities, given that food demand is relatively price-inelastic. In economic terms, the rise in the relative price of food commodities, pulls labor and capital from non-food production to food production.

Figure 4.7: Impact of Climate Change on Agriculture Sector Employment, 2030 ADB–Hadley Centre Global Environmental Model Scenario



ADB = Asian Development Bank, PRC Plus = People’s Republic of China; Hong Kong, China; Taipei, China.

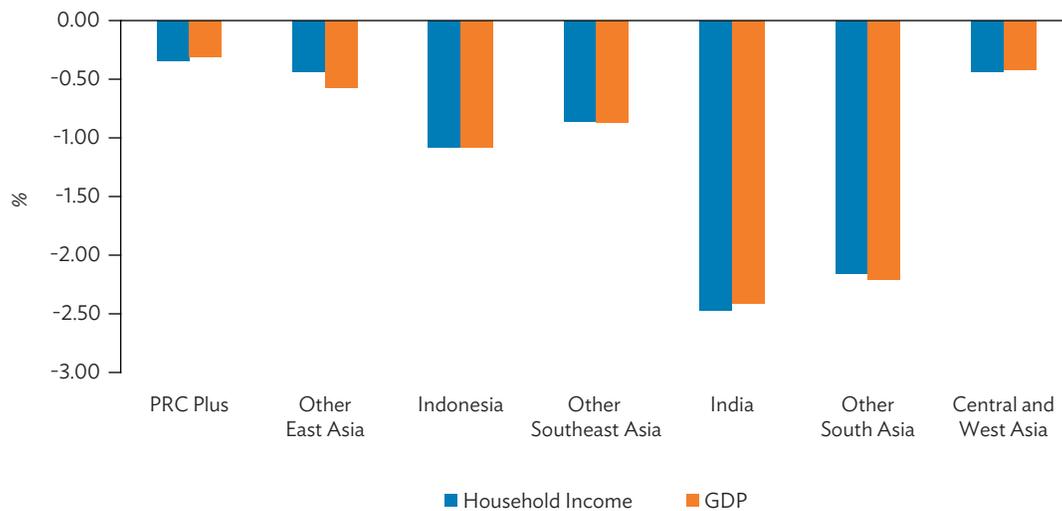
Note: Percentage deviation from the 2030 ADB No Climate Change Scenario.

Source: GLOBE simulations.

However, the net employment reallocation effects reported in Figure 4.8 are also influenced by the international trade effects of climate change, which can either reinforce or diminish this resource pull effect.

The resulting effects on aggregate real household income and GDP is shown in Figure 4.8. As land rents account only for a small fraction of total factor income in all regions, the size orders of the aggregate household income effects are largely determined by the changes in wages and capital returns.

Figure 4.8: Impact of Climate Change on Aggregate Household Income and Gross Domestic Product, 2030 Hadley Centre Global Environmental Model Scenario



PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

Note: Percentage deviation from the 2030 Hadley Centre Global Environmental Model-Climate Change Scenario 2030.

Source: GLOBE simulations.

4.4. Results by Scenario

4.4.1. Overview of Scenarios

The scenarios considered in this study combine three different sets of future climate projections with seven distinct agricultural investment policy scenarios under two alternative assumptions about the geographical coverage of the agricultural investment measures.

The future climates are:

- **NoCC.** No climate change
- **HGEM.** Hadley Centre HadGEM2-ES model projections

The agricultural investment scenarios are:

- No deviation from standard IMPACT baseline
- **Hi-IARCs.** Increased investment in international agricultural research centers for increased productivity growth
- **Hi+NARS.** Increased investment in both international agricultural research centers and national agricultural research systems for increased productivity growth

- **Hi+NARS+EFF.** Increased investment in both international agricultural research centers and national agricultural research systems plus investment in advanced research and breeding techniques for increased productivity growth
- **IRREXP.** Increased investment in irrigation expansion
- **IRREXP-WUE.** Increased investment in irrigation expansion and basin water use efficiency improvements
- **PHL.** Increased infrastructure investment that reduces post-harvest losses, jointly with RMM
- **RMM.** Increased infrastructure investment that reduces marketing margins, jointly with PHL
- **COMP.** Comprehensive scenario combining Hi+NARS+EFF and IRREXP-WUE

The geographical implementation is for ADB regions only, with other regions remaining at reference projections.

4.4.2. Household Income

Table 4.2 displays the real income changes for Asia and the Pacific for 2030 relative to the HGEM-CC baseline scenario. The climate change-related agricultural productivity shifts under the climate change impact scenarios ADB-HGEM are transmitted to aggregate household income primarily via their impact on factor prices. In the high-income regions, where the share of agriculture in GDP is low, the effects on wages and capital returns are small, whereas in today's low-income regions, where the contribution of agriculture to GDP is still substantial toward 2030, these adverse factor price effects are far more pronounced. The real income effects are also affected by aggregate terms-of-trade effects. However, the terms-of-trade impacts for ADB regions remain moderate to small (Table 4.3).

Table 4.2: Change in Household Income 2030 Under Hadley Centre Global Environment Model Scenarios

Regions	HGEM-CC ^a	Hi-IARCs	Hi+NARS	Hi+NARS+EFF	IRREXP	IRREXP-WUE	RMM	PHL	COMP
PRC Plus	(0.3)	0.6	0.7	1.1	(0.1)	0.2	0.4	0.1	1.3
Other East Asia	(0.4)	0.1	0.2	0.3	0	0	0.1	0	0.3
Indonesia	(1.1)	1	1.3	2.1	0.3	0.4	0.3	0	2.4
Other Southeast Asia	(0.9)	0.5	0.7	1	0.1	0.1	0.1	0.1	1.1
India	(2.5)	1.1	1.4	2.2	(0.1)	0.4	0.6	0.4	2.5
Other South Asia	(2.2)	1.2	1.5	2.3	0.3	0.9	0.6	0.2	3.1
Central and West Asia	(0.4)	0.3	0.4	0.6	0.1	0.5	0.2	0.1	1.1
Asia total	(0.9)	0.7	0.9	1.3	0	0.3	0.3	0.1	1.5

() = negative, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, HGEM-CC = Hadley Centre Global Environmental Model climate change scenario, Hi-IARCs = increased investment in IARCs, Hi+NARS = intensified NARS research, Hi+NARS+EFF = investment in advanced technologies for higher research efficiency to Hi+NARS, IRREXP = increased investment in irrigation expansion, IRREXP-WUE = increased investment in irrigation expansion and basin water use efficiency improvements, PHL = post-harvest losses, RMM = increased infrastructure investment that reduces marketing margins, PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

^a Percentage change from NoCC Baseline 2030. Investment scenarios are relative to HGEM-CC.

Source: GLOBE simulations.

Table 4.3: Terms of Trade Impact, by ADB Region, 2030

Regions	HGEM ^a	COMP
PRC Plus	(0.19)	(0.01)
Other East Asia	(0.14)	0.04
Indonesia	(0.04)	(0.31)
Other Southeast Asia	0.0	(0.12)
India	0.34	(0.33)
Other South Asia	(0.30)	0.28
Central and West Asia	(0.26)	0.16

() = negative, ADB = Asian Development Bank, COMP = comprehensive investment scenario that combines the Hi+NARS+EFF and IRREXP-WUE scenarios, HGEM = Hadley Centre Global Environment Model, PRC Plus = People's Republic of China; Hong Kong, China; Taipei, China.

^a Percentage change from NoCC scenario 2030. Investment scenario is relative to HGEM.

Source: GLOBE simulations.

Among the individual investment scenarios, Hi+NARS+EFF shows the strongest positive income impacts for ADB regions, while IRREXP without WUE appears to generate only modest gains at best. For most ADB regions, the yield improvements under the COMP scenarios are sufficiently strong to overcompensate for the negative agriculture-related climate change impacts on aggregate income.

Chapter 5

CONCLUSIONS

5.1. Investment Scenarios for Food Security in Asia and the Pacific

This report uses a global, highly disaggregated, quantitative modeling system—IMPACT, GLOBE, and linked models—to assess the impacts of alternative investments on agricultural area, yield, and production; food prices, demand and trade; and household income and key food and nutrition security indicators in Asia and the Pacific to 2030. The potential to end hunger by 2030 is explored. Three types of agricultural research and investment strategies are analyzed. One set of scenarios increases agricultural productivity through differing levels of investment by IARCs and NARS, with different levels of research efficiency. A second set of scenarios focused on investments to improve water management through expansion in irrigation and increases in basin-level water use efficiency. A third set of scenarios explores infrastructure investments to reduce marketing costs and PHL.

5.2. Highlights from the Results

Key messages from the analysis are as follows.

- (i) Population growth, urbanization, and economic growth in Asia and the Pacific will result in significant increases in the production and demand for food to 2030.

Under the population and economic growth assumptions used in this analysis (SSP2), the population in Asia and the Pacific will reach 4.3 billion by 2030 with a GDP of PPP \$61 trillion, for a per capita GDP of PPP \$14,300 per capita, more than double the per capita GDP in 2015. Population is projected to rise by 18% from 2015 to 2030, with South Asia accounting for two-thirds of the population increase. Rapid urbanization is projected to continue, with the proportion of the population in urban areas increasing from 48% to 55% from 2014 to 2030. The combination of income growth and urbanization will not only increase food demand but will induce diversification of demand and production away from cereals and roots and tubers and into meat, oils, and fruits and vegetables. Cereal production in Asia and the Pacific is projected to increase by 11%, meat production by 26%, production of fruits and vegetables by 28%, oilseeds by 44%, pulses by 16% and roots and tubers by 8% from 2015 to 2030.

- (ii) Under the reference scenario, food and nutrition security are projected to improve slowly over the 2015–2030 period, and climate change reduces food and nutrition security.

Although the negative effects of climate change on agriculture will become much higher after 2030, the detrimental impacts are still felt in 2030. The initial climate shock reduces yields and production, which then induces increases in prices and a partially offsetting increase in production as farmers respond to higher prices. Overall, total crop and livestock production in Asia and the Pacific are 1% lower in 2030 than in the no climate change (NoCC) scenario, which simulates outcomes to 2030 assuming NoCC. Crop prices are 8% higher in 2030 and meat prices are 5% higher, while GDP declines by 1% due to climate change. As a result, for Asia and the Pacific region, the HGEM climate change scenario caused an increase in undernourished people by 38 million and an increase in the number of malnourished by 1 million relative to the NoCC reference scenario. Under the HGEM scenario, the number of undernourished people declines from 507 million in 2015 to 362 million, and the number of malnourished children from 93 million to 76 million, showing relatively slow progress.

- (iii) Increased investment in IARC and NARS agricultural R&D achieves major reductions in hunger and child malnutrition.

Additional investments in agricultural R&D in IARCs and NARS can deliver important achievements in Asia and the Pacific. Each of the three agricultural R&D scenarios reduces hunger and malnutrition through increased food production, lower prices, and higher incomes. As would be expected, the Hi+NARS+EFF scenario, which combines higher investment in international research related to Asia and the Pacific commodities and higher investment in NARS in Asia and the Pacific with increased investment in advanced breeding technology, has the highest impact. For an additional annual investment of \$1.3 billion, this scenario is projected to increase crop production by 5.5% and meat production by 6.4% in 2030. It is because Asia and the Pacific region has such a large agriculture sector within the global economy that these increases in production result in projected decline in world prices of 7% for crops and 6% for meats compared to the HGEM climate change reference scenario. These impacts from additional R&D investment also generate economy-wide impacts that increase total GDP by 1.3%. While this may seem small, it amounts to PPP \$725 billion annually based on the 2015 GDP in Asia and the Pacific, far higher than the investments that generate this income. Because of these production, price, and income effects, this scenario reduces the number of hungry people by an additional 84 million in 2030 compared to the HGEM climate change reference scenario. This large reduction achieves a near-halving of hunger from 2015 to 2030. The impacts on child malnutrition are also important but smaller, with a reduction in the number of stunted children of 2.2 million in 2030, 3% lower than in the reference scenario. Achieving rapid progress in child malnutrition is not as amenable to agricultural investments on their own, but requires more investment in clean water and sanitation, education, and maternal care.

As shown in Chapters 3 and 4, much of the gains in the Hi+NARS+EFF scenario come from investment in improved agricultural R&D efficiency that reduces the lag time from discovery to adoption and increases the productivity impact of research. Investment in advanced R&D technology will generate higher returns by creating efficiencies in the discovery, development, and dissemination of new technologies. Modernization of breeding programs in Asia and the Pacific NARS through investment in enhanced genomics, bio-informatics, and high throughput gene-sequencing would have high payoffs. Gene editing, synthetic biology, and other advanced technologies hold great potential for enhancing agricultural productivity, food security, and resilience to climate change. To fully achieve the gains from advanced technology improves regulatory systems to reduce the time lags for adoption of beneficial technologies is likely to have large positive impacts.

- (iv) Increased investment in improving and modernizing irrigation systems to enhance water use efficiency has substantial, but smaller, impacts on hunger.

The combination of increased investments in irrigation expansion and irrigation modernization to increase water use efficiency (IRREXP-WUE), which costs an additional \$21.3 billion per year over the reference scenario, also improves production and income and reduces hunger, although with smaller benefits than the agricultural R&D scenario. Under this scenario, the number of hungry people is projected to decline by 28 million compared to the 2030 reference scenario. The scenario also has the significant benefit of reducing agricultural water use by 7%. The comprehensive scenario productivity scenario (COMP) incorporating a combination of Hi+NARS+EFF and IRREXP-WUE will further reduce the projected number of hungry people to 247 million in 2030, 115 million less than in the climate change reference scenario and fewer than half of the number of hungry people in 2015.

- (v) Investments in rural infrastructure that reduce marketing margins and post-harvest losses have powerful impacts.

The scenario of increased investment in rural infrastructure costs an additional \$15.8 billion compared to the HGEM reference scenario, generating both lower marketing margins and reduced post-harvest losses. By simultaneously increasing prices for producers and reducing costs to consumers, and reducing food losses in the value chain, the RMM/PHL scenario generates significant reductions in hunger in Asia and the Pacific. Reduced marketing margins result in a projected reduction in the number of hungry people of 16 million in 2030 relative to the reference scenario, while reductions in post-harvest losses have even larger impacts, cutting the number of hungry people by 67 million compared to the reference scenario, driven by reduced commodity prices. Public investment in infrastructure is important both in its direct impact and in inducing private sector participation in value chains. For example, a 2014 paper showed that the rapid growth in cold storage practices in Bihar, India was driven by the improvement of the physical and social infrastructure, which paved the way for producers to have access to profitable technologies.⁴⁵ Not only did governments in the region put in place better public provision services and policy

⁴⁵ B. Minten et al. 2012. The New and Changing Roles of Cold Storages in the Potato Supply Chain in Bihar. *Economic and Political Weekly*. 52 (XLIX). pp. 98–108.

reforms, they have also invested in roads and infrastructure, thereby increasing the ability of farmers in remote areas to have access to markets. Public infrastructure can also be important in providing the enabling conditions for advanced technologies in the value chain, such as sensors that allow full tracking of food from source to final use and monitoring of quality through the chain.

In addition to expanding public investments in agricultural R&D, irrigation, and rural infrastructure, governments should seek funding mechanisms to encourage private investments in these key areas. There is strong evidence that public investment in agricultural R&D stimulates private investment in agricultural R&D, for example when public R&D investment in basic or fundamental science increases the opportunities for applied commercial research (Fuglie 2016). Governments should develop greater funding complementarities in the irrigation and rural infrastructure as well. Funding options include grants and loans guaranteed by governments to reduce the initial risk for private financing, and blended finance, which strategically uses development finance or public funding to mobilize additional resources scaling up private-sector financing (Organisation for Economic Co-operation and Development 2018).

- (vi) Agriculture sector investments of \$78.6 billion per year will end hunger in Asia and the Pacific in 2030, moving the region as a whole below the 5% threshold for share of hungry people.

Increased investments in agricultural productivity growth, irrigation, and water use efficiency, and rural infrastructure are highly effective in improving agricultural production, reducing prices, and raising incomes. The result is large reductions in hunger, and somewhat smaller reductions in child malnutrition. Agricultural R&D and rural infrastructure have particularly large impacts on hunger. Total annual agricultural investments of \$78.6 billion are needed to move the total of Asia and the Pacific below the 5% threshold for eliminating hunger to achieve food security. To move the lagging regions of Central and West Asia and Southeast Asia below this level, and to further improve the overall results will require policies that must reach out directly to the poor by supporting investments in human capital. Investments in health, nutrition, clean water and sanitation, and education are crucial and essential to address hunger and childhood malnutrition. Moreover, even with rapid economic growth in Asia and the Pacific, some of the poor will be reached slowly if at all and many of them will remain vulnerable to economic reversals. These groups can be reached through income transfers, or through safety nets that will alleviate their nutritional needs and socioeconomic conditions during short-term shocks.

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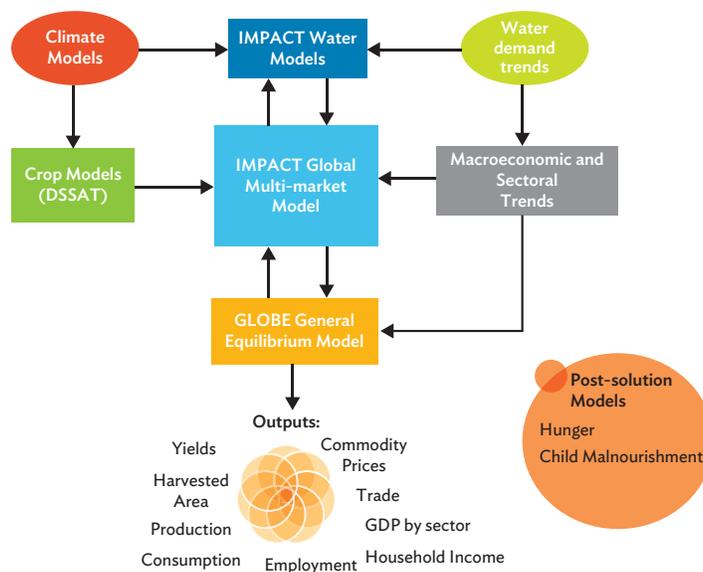
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APPENDIXES

Appendix 1 OVERVIEW OF THE IMPACT MODELING SYSTEM

The International Food Policy Research Institute's (IFPRI's) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is an integrated modeling system that links information from climate models (Earth System Models), crop simulation models (for example, the Decision Support System for Agrotechnology Transfer), and river basin level hydrological and water supply and demand models linked to a core global, partial equilibrium, multimarket model focused on the agriculture sector and a global general equilibrium model, GLOBE. Figure A1.1 provides a summarized schematic of the modeling system. This model system supports longer-term scenario analysis through the integration of these multidisciplinary modules to provide researchers and policymakers with a flexible tool to assess and compare the potential effects of changes in biophysical systems, socioeconomic trends, technologies, and policies. It provides estimates of production, consumption, hunger, and environmental impacts. The model offers a high level of disaggregation with 159 countries, 154 water basins, and 60 commodities.

Figure A1.1: International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade: Exploring Alternative Climate and Investment Futures



DSSAT = Decision Support System for Agrotechnology Transfer, GDP = gross domestic product, IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

Source: Modified from Robinson et al. (2015).

The modeling system is used in this project to assess scenarios that cover a variety of strategies to increase agricultural productivity and resource use efficiency, together with their implications for food security, including an estimation of the investment costs to end hunger in Asia, by using the food security indicators of child malnutrition and the population at-risk of hunger.

A1.1. Modeling Climate Change in IMPACT

The climate and economic scenarios used in IMPACT draw on work developed for IPCC's fifth assessment report. These scenarios are defined by two major components. Shared Socioeconomic Pathways (SSPs) are global pathways that represent alternative futures for economic and population growth (O'Neill et al. 2014; O'Neill et al. 2015). Population growth and gross domestic product (GDP) growth are drawn from SSP2, which is a middle-of-the-road scenario that follows historical trends on economic and demographic growth. The SSP2 rates of population and GDP growth are maintained as the exogenous rates for the alternative investment scenarios. The changes in GDP growth under the different scenarios are endogenous to the specified scenario.

The second component is the Representative Concentration Pathways (RCPs), which represent potential greenhouse gas emission levels in the atmosphere and the subsequent increase in solar energy that would be absorbed (radiative forcing). There are four RCPs, which are named according to the approximate level of radiative forcing in 2100, which ranges from 2.6 watts per square meter (W/m^2) to 8.5 W/m^2 . RCP8.5, which is the strongest climate change scenario, is utilized here as the climate change scenario.

General circulation models (GCM) are utilized to generate projected precipitation, temperatures, and evaporative demand under any RCP. This study utilized the Hadley Centre Global Environment Model, version 2.¹ (HadGEM2-ES or HGEM). The HGEM climate data are downscaled using CMIP and ISI MIP (Warzawski et al. 2014; Rosenzweig et al. 2014; Taylor et al. 2012) and are downscaled for use in the crop models.

The IMPACT hydrology model takes the downscaled precipitation and converts it to runoff in river basins. The linked crop models utilize the information from the downscaled data from HGEM and the hydrology model to simulate crop yields under climate change. These changes are then fed into the IMPACT model and used to simulate the changes in crop productivity growth under climate change. The investment scenarios all assume climate change as well, and the effects of the investment scenarios are presented as changes from the HGEM climate change scenarios.

¹ C. D. Jones et al. 2011. The HadGEM2-ES Implementation of CMIP5 Centennial Simulations. *Geoscientific Model Development*. 4 (3). pp. 543–570.

A1.2. Undernourished Children

The percentage of undernourished children younger than 5 is estimated from the average per capita calorie consumption, female access to secondary education, the quality of maternal and child care, and health and sanitation (Rosegrant et al. 2001). Observed relationships between all of these factors were used to create the semi-log functional mathematical model, allowing an accurate estimate of the number of undernourished children to be derived from data describing the average per capita calorie consumption, female access to secondary education, quality of maternal and child care, and health and sanitation. The precise relationship used to project the percentage of undernourished children is based on a cross-country regression relationship of Smith and Haddad (2000).

The data used in this calculation come from a variety of sources. The base values for undernourished children originally come from the World Bank's World Development Indicators (WDIs) (World Bank 2014). The base values for female–male life expectancy ratio, female secondary school enrollment, and access to safe water come from the WDIs.² The projections of changes in female–male life expectancy come from the United Nations Populations Prospects medium variant (United Nations 2011). The projections of changes in female secondary school enrollment and access to clean water come from the Technogarden Baseline Scenario (MA 2005).

The per capita kilocalorie availability is derived from two sources: (i) the amount of calories obtained from commodities included in the IMPACT-Food model, and (ii) the calories from commodities outside the model (FAO 2015).

After the percentage of undernourished children has been calculated, the total number of undernourished children is calculated as the product of equation 29, with the population of children (0–5 years old) coming from the appropriate SSP scenario (International Institute for Applied Systems Analysis [IIASA] 2013).

A.1.3. Share of At-Risk of Hunger

The share at risk is the percentage of the total population that is at risk of suffering from undernourishment. This calculation is based on a strong empirical correlation between the share of undernourished within the total population and the relative availability of food and is adapted from the work done by Fischer et al. in the International Institute for Applied Systems Analysis (IIASA) World Food System used by IIASA and the Food and Agricultural Organization of the United Nations (FAO) (Fischer et al. 2005). It should be noted that due to the quadratic nature of this equation it is necessary to apply an upper and lower bound to the share at risk. The lower bound is defined as 0, and the upper bound is 100. Developed countries unsurprisingly have low share at-risk, so for simplicity the study treated all countries with less than 4% share at-risk of hunger as if they had 0% share of hunger. The relative availability of food has been bounded to ensure realistic results on the quadratic curve: when the ratio of calories available to calories required, $RelativeKCal$, is greater than 1.7, the study assumed that the share at risk of hunger is effectively 0.

² L. C. Smith and L. Haddad. 2015. Reducing Child Undernutrition: Past Drivers and Priorities for the Post-MDG Era. *World Development*. 68. pp. 180–204.

Appendix 2

GLOBE

A2a. IMPACT-GTAP-GLOBE Concordances

A2a.1 Concordances

The GLOBE-Energy model is calibrated to the Global Trade Analysis Project (GTAP) database. This data set provides a detailed and internally consistent representation of the global economy-wide structure of production, demand and international trade at a regionally and sectorally disaggregated level. GTAP 9, the latest available version of the database at the start of the project, combines detailed bilateral trade and protection data reflecting economic linkages among 140 world regions with individual regional input-output data, which account for intersectoral linkages among 57 production sectors for the benchmark year 2011.

Table A2a.1 displays the mapping from IMPACT countries and regions to GTAP 9 and GLOBE regions, while Tables A2a.2 and A2a.3 report the concordances between GTAP agricultural and matched processed food commodities and sectors on the one hand, and IMPACT activities and IMPACT commodities respectively on the other. The concordances have been constructed by a careful inspection of the detailed GTAP classification particulars where necessary.

Table A2a.1: Concordance between International Model for Policy Analysis of Agricultural Commodities and Trade and Global Trade Analysis Project 9 and GLOBE Regions

IMPACT Name	IMPACT	GTAP 9	GTAP Name	GLOBE-ADB
	cty	reg		r
Afghanistan	AFG	xsa	Rest of South Asia	CWRD
Angola	AGO	xac	South Central Africa	EAfrica
Albania	ALB	alb	Albania	Europe
Argentina	ARG	arg	Argentina	SAmerica
Armenia	ARM	arm	Armenia	CWRD
Australia	AUS	aus	Australia	HIOceania
Austria	AUT	aut	Austria	Europe
Azerbaijan	AZE	aze	Azerbaijan	CWRD
Burundi	BDI	xec	Rest of East Africa	EAfrica

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Table A2a.1 *continued*

IMPACT Name	IMPACT	GTAP 9	GTAP Name	GLOBE-ADB
	cty	reg		r
Benin	BEN	ben	Benin	WAfrica
Burkina Faso	BFA	bfa	Burkina Faso	WAfrica
Bangladesh	BGD	bgd	Bangladesh	OSARD
Bulgaria	BGR	bgr	Bulgaria	Europe
Belarus	BLR	blr	Belarus	OFSU
Baltic States	BLT	est	Estonia	Europe
Baltic States	BLT	ltu	Lithuania	Europe
Baltic States	BLT	lva	Latvia	Europe
Belgium-Luxembourg	BLX	bel	Belgium	Europe
Belgium-Luxembourg	BLX	lux	Luxembourg	Europe
Belize	BLZ	xca	Rest of C'tral America	CAmerica
Bolivia	BOL	bol	Bolivia	SAmerica
Brazil	BRA	bra	Brazil	SAmerica
Bhutan	BTN	xsa	Rest of South Asia	CWRD
Botswana	BWA	bwa	Botswana	SAfrica
Central African Republic	CAF	xcf	Central Africa	EAfrica
Canada	CAN	can	Canada	NAmerica
Chile	CHL	chl	Chile	SAmerica
PRC Plus	CHM	chn	People's Republic of China	PRC Plus
Switzerland Plus	CHP	che	Switzerland	Europe
Ivory Coast	CIV	civ	Ivory Coast	WAfrica
Cameroon	CMR	cmr	Cameroon	WAfrica
Democratic Republic of Congo	COD	xac	South Central Africa	EAfrica
Congo	COG	xcf	Central Africa	EAfrica
Colombia	COL	col	Colombia	SAmerica
Other Caribbean	CRB	xcb	Rest of Caribbean	CAmerica
Costa Rica	CRI	cri	Costa Rica	CAmerica
Cuba	CUB	xcb	Rest of Caribbean	CAmerica
Cyprus	CYP	cyp	Cyprus	Europe
Czech Republic	CZE	cze	Czech Republic	Europe
Germany	DEU	deu	Germany	Europe
Djibouti	DJI	xec	Rest of East Africa	EAfrica
Denmark	DNK	dnk	Denmark	Europe
Dominican Republic	DOM	xcb	Rest of Caribbean	CAmerica

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Table A2a.1 *continued*

IMPACT Name	IMPACT	GTAP 9	GTAP Name	GLOBE-ADB
	cty	reg		r
Algeria	DZA	xfn	Rest of North Africa	MENA
Ecuador	ECU	ecu	Ecuador	SAmerica
Egypt	EGY	egy	Egypt	MENA
Eritrea	ERI	xec	Rest of East Africa	EAfrica
Ethiopia	ETH	eth	Ethiopia	EAfrica
Fiji	FJI	xoc	Rest of Oceania	HIOceania
Finland Plus	FNP	fin	Finland	Europe
France plus	FRP	fra	France	Europe
Gabon	GAB	xcf	Gabon	EAfrica
Georgia	GEO	geo	Georgia	CWRD
Ghana	GHA	gha	Ghana	WAfrica
Guinea	GIN	gin	Guinea	WAfrica
Gambia	GMB	xwf	Rest of West Africa	WAfrica
Guinea-Bissau	GNB	xwf	Rest of West Africa	WAfrica
Equatorial Guinea	GNQ	xcf	Rest of Central Africa	EAfrica
Greece	GRC	grc	Greece	Europe
Greenland	GRL	xna	Rest of North America	NAmerica
Guyanas South America	GSA	xsm	Rest of South America	SAmerica
Guatemala	GTM	gtm	Guatemala	CAmerica
Honduras	HND	hnd	Honduras	CAmerica
Croatia	HRV	hrv	Croatia	Europe
Haiti	HTI	xcb	Rest of Caribbean	CAmerica
Hungary	HUN	hun	Hungary	Europe
Indonesia	IDN	idn	Indonesia	OEastAsia
India	IND	ind	India	India
Ireland	IRL	irl	Ireland	Europe
Iran	IRN	irn	Iran	MENA
Iraq	IRQ	xws	Rest of West Asia	MENA
Iceland	ISL	xef	Iceland	Europe
Israel	ISR	isr	Israel	MENA
Italy plus	ITP	ita	Italy	Europe
Jamaica	JAM	xcb	Rest of Caribbean	CAmerica
Jordan	JOR	xws	Rest of West Asia	MENA
Japan	JPN	jpn	Japan	Japan
Kazakhstan	KAZ	kaz	Kazakhstan	CWRD
Kenya	KEN	ken	Kenya	EAfrica
Kyrgyz Republic	KGZ	kgz	Kyrgyz Republic	CWRD
Cambodia	KHM	khm	Cambodia	OSERD

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Table A2a.1 *continued*

IMPACT Name	IMPACT	GTAP 9	GTAP Name	GLOBE-ADB
	cty	reg		r
Republic of Korea	KOR	kor	Republic of Korea	OEARD
Lao People's Democratic Republic	LAO	lao	Lao People's Democratic Republic	OSERD
Lebanon	LBN	xws	Rest of West Asia	MENA
Liberia	LBR	xwf	Rest of West Africa	WAfrica
Libya	LBY	xnf	Rest of North Africa	MENA
Sri Lanka	LKA	lka	Sri Lanka	OSARD
Lesotho	LSO	xsc	Rest of SACU	SAfrica
Moldova	MDA	xee	Moldova	OFSU
Madagascar	MDG	mdg	Madagascar	EAfrica
Mexico	MEX	mex	Mexico	CAmerica
Mali	MLI	xwf	Rest of West Africa	WAfrica
Myanmar	MMR	xse	Rest of Southeast Asia	OSERD
Mongolia	MNG	mng	Mongolia	OEARD
Morocco	MOR	mar	Morocco	MENA
Mozambique	MOZ	moz	Mozambique	EAfrica
Mauritania	MRT	xwf	Rest of West Africa	WAfrica
Malawi	MWI	mwi	Malawi	EAfrica
Malaysia	MYS	mys	Malaysia	OSERD
Namibia	NAM	nam	Namibia	SAfrica
Niger	NER	xwf	Rest of West Africa	WAfrica
Nigeria	NGA	nga	Nigeria	WAfrica
Nicaragua	NIC	nic	Nicaragua	CAmerica
Netherlands	NLD	nld	Netherlands	Europe
Norway	NOR	nor	Norway	Europe
Nepal	NPL	npl	Nepal	OSARD
New Zealand	NZL	nzl	New Zealand	HIOceania
Other Pacific Ocean	OPO	xoc	Rest of Oceania	HIOceania
Other Southeast Asia	OSA	xse	Rest of Southeast Asia	OEARD
Pakistan	PAK	pak	Pakistan	OSARD
Panama	PAN	pan	Panama	CAmerica
Peru	PER	per	Peru	SAmerica
Philippines	PHL	phl	Philippines	OSERD
Papua New Guinea	PNG	xoc	Rest of Oceania	HIOceania
Poland	POL	pol	Poland	Europe

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Table A2a.1 *continued*

IMPACT Name	IMPACT	GTAP 9	GTAP Name	GLOBE-ADB
	cty	reg		r
Democratic People's Republic of Korea	PRK	xea	Rest of East Asia	OEARD
Portugal	PRT	prt	Portugal	Europe
Paraguay	PRY	pry	Paraguay	SAmerica
Occupied Palestinian Territory	PSE	xws	Rest of West Asia	MENA
Rest of Arab Peninsula	RAP	are	United Arab Emirates	MENA
Romania	ROU	rou	Romania	Europe
Russian Federation	RUS	rus	Russian Federation	OFSU
Rwanda	RWA	rwa	Rwanda	EAfrica
Saudi Arabia	SAU	sau	Saudi Arabia	MENA
Sudan	SDN	xec	Rest of East Africa	EAfrica
Senegal	SEN	sen	Senegal	WAfrica
Solomon Islands	SLB	xse	Rest of Southeast Asia	HIOceania
Sierra Leone	SLE	xwf	Rest of West Africa	WAfrica
El Salvador	SLV	slv	El Salvador	CAmerica
Somalia	SOM	xec	Rest of East Africa	EAfrica
Spain Plus	SPP	esp	Spain	Europe
South Sudan	SSD	xec	Rest of East Africa	EAfrica
Slovakia	SVK	svk	Slovakia	Europe
Slovenia	SVN	svn	Slovenia	Europe
Sweden	SWE	swe	Sweden	Europe
Swaziland	SWZ	xsc	Swaziland	SAfrica
Syria	SYR	xws	Rest of West Asia	MENA
Chad	TCD	xcf	Rest of Central Africa	EAfrica
Togo	TGO	tgo	Togo	WAfrica
Thailand	THA	tha	Thailand	OSERD
Tajikistan	TJK	xsu	Rest of Former SU	CWRD
Turkmenistan	TKM	xsu	Rest of Former SU	CWRD
Timor-Leste	TLS	xse	Rest of Southeast Asia	OSERD
Tunisia	TUN	tun	Tunisia	MENA
Turkey	TUR	tur	Turkey	MENA
Tanzania	TZA	tza	Tanzania	EAfrica
Uganda	UGA	uga	Uganda	EAfrica
United Kingdom Plus	UKP	gbr	United Kingdom	Europe
Ukraine	UKR	ukr	Ukraine	OFSU

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Table A2a.1 *continued*

IMPACT Name	IMPACT	GTAP 9	GTAP Name	GLOBE-ADB
	cty	reg		r
Uruguay	URY	ury	Uruguay	SAmerica
United States	USA	usa	United States	NAmerica
Uzbekistan	UZB	xsu	Rest of Former SU	CWRD
Venezuela	VEN	ven	Venezuela	SAmerica
Viet Nam	VNM	vnm	Viet Nam	OSERD
Vanuatu	VUT	xoc	Rest of Oceania	HIOceania
Yemen	YEM	xws	Rest of West Asia	MENA
South Africa	ZAF	zaf	South Africa	SAfrica
Zambia	ZMB	zmb	Zambia	EAfrica
Zimbabwe	ZWE	zwe	Zimbabwe	EAfrica

Source: Willenbockel et al. (2018) and Willenbockel (2018).

Table A2a.2: Concordance between International Model for Policy Analysis of Agricultural Commodities and Trade Activities and Global Trade Analysis Project 9 Commodities

IMPACT Name	IMPACT	GTAP Name	GTAP
	jj		com
Cattle	jbeef	Bovine cattle, sheep and goats, horses	ctl
Pigs	jpork	Animal products nec	oap
Sheep and Goats	jlamb	Bovine cattle, sheep and goats, horses	ctl
Poultry	jpoul	Animal products nec	oap
Eggs	jeggs	Animal products nec	oap
Dairy	jmilk	Raw milk	rmk
Barley	jbarl	Cereal grains nec	gro
Maize	jmaiz	Cereal grains nec	gro
Millet	jmill	Cereal grains nec	gro
Rice	jrice	Paddy rice	pdr
Sorghum	jsorg	Cereal grains nec	gro
Wheat	jwhea	Wheat	wht
Other Cereals	jocer	Cereal grains nec	gro
Cassava	jcass	Vegetables, fruit, nuts	v_f
Potato	jpota	Vegetables, fruit, nuts	v_f
Sweet Potatoes	jswpt	Vegetables, fruit, nuts	v_f
Yams	yyams	Vegetables, fruit, nuts	v_f
Other Roots and Tubers	jorat	Vegetables, fruit, nuts	v_f
Beans	jbean	Vegetables, fruit, nuts	v_f
Chickpeas	jchkp	Vegetables, fruit, nuts	v_f

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Table A2a.2 continued

IMPACT Name	IMPACT		GTAP
	jj	GTAP Name	com
Cowpeas	jcowp	Vegetables, fruit, nuts	v_f
Lentils	jlent	Vegetables, fruit, nuts	v_f
Pigeonpeas	jpigp	Vegetables, fruit, nuts	v_f
Other Pulses	jopul	Vegetables, fruit, nuts	v_f
Bananas	jbana	Vegetables, fruit, nuts	v_f
Plantains	jplnt	Vegetables, fruit, nuts	v_f
(Sub)-Tropical Fruits	jsubf	Vegetables, fruit, nuts	v_f
Temperate Fruits	jtemf	Vegetables, fruit, nuts	v_f
Vegetables	jvege	Vegetables, fruit, nuts	v_f
Sugarcane	jsugc	Sugar cane, sugar beet	c_b
Sugarbeet	jsugb	Sugar cane, sugar beet	c_b
Cane Sugar	jsugrc	Sugar	sgr
Beet Sugar	jsugrb	Sugar	sgr
Groundnuts	jgrnd	Oil seeds	osd
Groundnuts for Oil	jgdnt	Oil seeds	osd
Rapeseed	jrpsd	Oil seeds	osd
Rapeseed for Oil	jrpn	Oil seeds	osd
Soybeans	jsoyb	Oil seeds	osd
Soybeans for Oil	jsbnt	Oil seeds	osd
Sunflower Seeds	jsnfl	Oil seeds	osd
Sunflower Seeds for Oil	jsfnt	Oil seeds	osd
Oil Palm Fruit	jpalm	Oil seeds	osd
Palm Oil	jplol	Vegetable oils and fats	vol
Palm Kernel	jpkr	Vegetable oils and fats	vol
Palm Kernel Oil	jpkol	Vegetable oils and fats	vol
Total Other Oilseeds	jtols	Oil seeds	osd
Total Other Oilseeds for Oil	jtont	Oil seeds	osd
Groundnut oil from gdnt	jgdoln	Vegetable oils and fats	vol
Rapeseed oil from rpnt	jrpoln	Vegetable oils and fats	vol
Soybean Oil from sbnt	jsboln	Vegetable oils and fats	vol
Sunflower Oil from sfnt	jsfoln	Vegetable oils and fats	vol
Total Other oils from tont	jtooln	Vegetable oils and fats	vol
Groundnut oil from grnd	jgdolt	Vegetable oils and fats	vol
Rapeseed oil from rpsd	jrpol	Vegetable oils and fats	vol
Soybean Oil from soyb	jsbolt	Vegetable oils and fats	vol
Sunflower Oil from snfl	jsfolt	Vegetable oils and fats	vol

continued on next page

Table A2a.2 *continued*

IMPACT Name	IMPACT	GTAP Name	GTAP
	jj		com
Total other oils from tols	jtoolt	Vegetable oils and fats	vol
Cocoa	jcoco	Crops nec	ocr
Coffee	jcafe	Crops nec	ocr
Cotton	jcott	Plant-based fibres	pfb
Tea	jteas	Crops nec	ocr
Other Crops	jothr	Crops nec	ocr
Fodders	jfodr	Crops nec	ocr
Grass	jpstr	Crops nec	ocr

Source: Willenbockel et al. (2018) and Willenbockel (2018).

Table A2a.3: Concordance between International Model for Policy Analysis of Agricultural Commodities and Trade and Global Trade Analysis Project Commodities

IMPACT Name	IMPACT	GTAP Name	GTAP
	cc	com	com
Cattle	cbeef	Bovine cattle, sheep and goats, horses	ctl
Pigs	cpork	Animal products nec	oap
Sheep and Goats	clamb	Bovine cattle, sheep and goats, horses	ctl
Poultry	cpoul	Animal products nec	oap
Eggs	ceggs	Animal products nec	oap
Dairy	cmilk	Raw milk	rmk
Barley	cbarl	Cereal grains nec	gro
Maize	cmaiz	Cereal grains nec	gro
Millet	cmill	Cereal grains nec	gro
Rice	crice	Paddy rice	pdr
Sorghum	csorg	Cereal grains nec	gro
Wheat	cwhea	Wheat	wht
Other Cereals	cocer	Cereal grains nec	gro
Cassava	ccass	Vegetables, fruit, nuts	v_f
Potato	cpota	Vegetables, fruit, nuts	v_f
Sweet Potatoes	cswpt	Vegetables, fruit, nuts	v_f
Yams	cyams	Vegetables, fruit, nuts	v_f
Other Roots & Tubers	corat	Vegetables, fruit, nuts	v_f
Beans	cbean	Vegetables, fruit, nuts	v_f
Chickpeas	cchkp	Vegetables, fruit, nuts	v_f
Cowpeas	ccowp	Vegetables, fruit, nuts	v_f

continued on next page

Table A2a.3 *continued*

IMPACT Name	IMPACT	GTAP Name	GTAP
	cc	com	com
Lentils	clent	Vegetables, fruit, nuts	v_f
Pigeonpeas	cpigp	Vegetables, fruit, nuts	v_f
Other Pulses	copul	Vegetables, fruit, nuts	v_f
Bananas	cbana	Vegetables, fruit, nuts	v_f
Plantains	cplnt	Vegetables, fruit, nuts	v_f
(Sub)-Tropical Fruits	csubf	Vegetables, fruit, nuts	v_f
Temperate Fruits	ctemf	Vegetables, fruit, nuts	v_f
Vegetables	cvege	Vegetables, fruit, nuts	v_f
Sugarcane	csugc	Sugar cane, sugar beet	c_b
Sugarbeet	csugb	Sugar cane, sugar beet	c_b
Sugar	csugr	Sugar	sgr
Groundnuts	cgrnd	Oil seeds	osd
Groundnuts for Oil	cgdnt	Oil seeds	osd
Groundnut Oil	cgdol	Vegetable oils and fats	vol
Groundnut Meal	cgdml	Oil seeds	vol
Rapeseed	crpsd	Oil seeds	osd
Rapeseed for Oil	crpnt	Oil seeds	osd
Rapeseed Oil	crpol	Vegetable oils and fats	vol
Rapeseed Meal	crpml	Vegetable oils and fats	vol
Soybeans	csoyb	Oil seeds	osd
Soybeans for Oil	csbnt	Oil seeds	osd
Soybean Oil	csbol	Vegetable oils and fats	vol
Soybean Meal	csbml	Vegetable oils and fats	vol
Sunflower Seeds	csnfl	Oil seeds	osd
Sunflower Seeds for Oil	csfnt	Oil seeds	osd
Sunflower Oil	csfol	Vegetable oils and fats	vol
Sunflower Meal	csfml	Vegetable oils and fats	vol
Oil Palm Fruit	cpalm	Oil seeds	osd
Palm Oil	cplol	Vegetable oils and fats	vol
Palm Kernel	cpkrl	Vegetable oils and fats	vol
Palm Kernel Oil	cpkol	Vegetable oils and fats	vol
Palm Kernel Meal	cpkml	Vegetable oils and fats	vol
Total Other Oilseeds	ctols	Oil seeds	osd
Total Other Oilseeds for Oil	ctont	Oil seeds	osd
Total Other Oils	ctool	Vegetable oils and fats	vol
Total Other Oilseed Meal	ctoml	Vegetable oils and fats	vol
Cocoa	ccoco	Crops nec	ocr
Coffee	ccafe	Crops nec	ocr
Cotton	ccott	Plant-based fibres	pfb

continued on next page

Table A2a.3 continued

IMPACT Name	IMPACT	GTAP Name	GTAP
	cc	com	com
Tea	cteas	Crops nec	ocr
Other Crops	cothr	Crops nec	ocr
Fodders	cfodr	Crops nec	ocr
Grass	cgrss	Crops nec	ocr

Source: Willenbockel et al. (2018) and Willenbockel (2018).

Table A2a.4: Commodity Group Aggregation of the Global Trade Analysis Project 9 Database

Description	Code	Description	Code
1 Paddy rice	pdr	29 Leather products	lea
2 Wheat	wht	30 Wood products	lum
3 Cereal grains nec	gro	31 Paper products, publishing	ppp
4 Oil seeds	osd	32 Chemical, rubber, plastic products	crp
5 Vegetable oils and fats	vol	33 Petroleum, coal products	p_c
6 Sugar cane, sugar beet	c_b	34 Mineral products nec	nmm
7 Vegetables, fruit, nuts	v_f	35 Ferrous metals	i_s
8 Plant-based fibers	pfb	36 Metals nec	nfm
9 Crops nec	ocr	37 Metal products	fmp
10 Wool, silkworm cocoons	wol	38 Motor vehicles and parts	mvh
11 Cattle, sheep, goats, horses	ctl	39 Transport equipment nec	otn
12 Animal products nec	oap	40 Electronic equipment	ele
13 Raw milk	rmk	41 Machinery and equipment nec	ome
14 Forestry	frs	42 Manufactures nec	omf
15 Fishing	fsh	43 Electricity	ely
16 Coal	coa	44 Gas manufacture, distribution	gdt
17 Oil	oil	45 Water	wtr
18 Gas	gas	46 Construction	cns
19 Minerals nec	omn	47 Trade	trd
20 Processed rice	pcr	48 Transport nec	otp
21 Sugar	sgr	49 Sea transport	wtp
22 Meat: cattle, sheep, goats, horse	cmt	50 Air transport	atp
23 Meat products nec	omt	51 Communication	cmn
24 Dairy products	mil	52 Financial services nec	ofi
25 Food products nec	ofd	53 Insurance	isr
26 Beverages and tobacco products	b_t	54 Business services nec	obs
27 Textiles	tex	55 Recreation and other services	ros
28 Wearing apparel	wap	56 Public administration, defence, health, education	osg
		57 Dwellings	dwe

Source: Willenbockel et al. (2018) and Willenbockel (2018).

Appendix A2b. The Dynamic GLOBE Model

A2b.1. Overview

GLOBE is an extended dynamic version of the comparative-static standard GLOBE model originally developed by McDonald, Thierfelder, and Robinson (2007).¹ Apart from the incorporation of capital accumulation, population growth, labor force growth, and technical progress, the extended model features a stylized representation of the technical substitution possibilities among different energy sources in production using a capital (K), labor, energy, materials (KLEM) technology specification.

The model consists of a set of individual country or region blocs that together provide complete coverage of the global economy and that are linked through international trade and capital flows. The modeling system solves the within country models and between country trade relationships simultaneously to ensure full global consistency among all variables, e.g., the sum of all exports across region matches the sum of all imports across regions for each commodity, and global production matches global demand for each commodity.

Each region bloc represents the whole economy of that region at a sectorally disaggregated level. The economic interactions among producers, consumers, and the government as well as economic transactions with other regions are explicitly captured. Producers in each region combine primary factors (i.e., skilled and unskilled labor, physical capital, land, and other natural resources) and intermediate inputs obtained from the same and other production sectors at home and abroad to produce output. The output is sold to domestic households, the domestic government, to domestic producers (for use as intermediate input or as an addition to the productive capital stock), and to the rest of the world. The production process generates factor income in the form of wages, other in-kind returns to labor, land and natural resource rents, and returns to capital as well as production tax income for the government

The factor income flows to households. Households use their income to pay income taxes, to buy consumer goods, and to save for future consumption. The government receives additional tax revenue from sales taxes including revenue from import duties.

¹ This overview of the GLOBE model is drawn from D. Willenbockel et al. 2016. Climate Policy and the Energy-Water-Food Nexus: A Model Linkage Approach. *EcoMod2016*. 9746. EcoMod; D. Willenbockel, et al. 2018. Dynamic Computable General Equilibrium Simulations in Support of Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio: Linking the IMPACT and GLOBE Models. *IFPRI Discussion Paper 01738*; D. Willenbockel. 2014. Computable General Equilibrium Simulations of the COMESA-EAC-SADC Tripartite Free Trade Agreement. *MPRA Paper 78069*. University Library of Munich, Germany; and C. Ringler et al. 2016. Global Linkages among Energy, Food and Water: An Economic Assessment. *Journal of Environmental Studies and Sciences*. 6. pp. 161–171.

The model share parameters governing household, producer, and government decisions are set in line with observed data for the reference year 2011, so that the model equilibrium in the absence of policy changes or other exogenous shocks exactly replicates the reference year data.

Producer and consumer responses to price changes are modeled in accordance with microeconomic theory, and the parameters governing the responses to changes in input and output prices are based on the available econometric evidence.

In a nutshell, each region bloc of GLOBE is a multisectoral macroeconomic model with microeconomic theoretical foundations. The country models simulate the operation of factor and commodity markets, solving for wages, land and natural resource rents, capital returns, and commodity prices that achieve supply–demand balance in all markets. Each region engages in international trade, supplying exports and demanding imports. The model determines world prices that achieve supply–demand balance in all global commodity markets, simulating the operation of world markets.

The model is initially calibrated to the GTAP 9 database that combines detailed bilateral trade, and protection data reflecting economic linkages among regions with individual country input-output data, which account for intersectoral linkages within regions, for the benchmark year 2011.² The model version employed in the present study distinguishes 22 commodity groups and production sector and 18 geographical regions (Tables 4.1–4.2).

Table A2b.1: GLOBE Sector Aggregation

Short Code	Description	GTAP Sector Code ^a
Rice	Paddy Rice	pdr
Wheat	Wheat	wht
OCereals	Other Cereals	gro
Oilseeds	Oil Seeds	osd
SugarCane	Sugar Cane and Beet	c_b
OCrops	Other Crops	ocr,pfb
Cattle	Bovine cattle, sheep, goats, horses	ctl
OLvstkPrd	Other Livestock Products	wol,oap,rnk
VegOils	Vegetable Oils and Fats	vol
Sugar	Sugar	sgr
PrcRice	Processed Rice	pcr
OPrFood	Other Processed Food	cmt,omt,mil,ofd,b_t
FossFuels	Coal, Crude Oil, Natural Gas	coa, oil, gas, gdt
ONatRes	Other Natural Resources	omn,frs,fsh
Petrol	Refined Petrols	p_c

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² A. Aguiar, B. Narayanan, and R. McDougall. 2016. An Overview of the GTAP 9 Data Base. *Journal of Global Economic Analysis*. 1 (1). pp. 181–208.

Table A2a.1 *continued*

Short Code	Description	GTAP Sector Code ^a
Chemics	Chemicals, Rubber, Plastics	crp
OManuf	Other Manufacturing	nmm, i_s, nfm, fmp, mvh, otn, ele, omc, tex, wap, lea, lum, ppp, omf
Electricity	Electricity	ely
Water	Water Distribution	wtr
Constrc	Construction	cns
TrdTrns	Trade and Transport Services	trd, otp, wtp, atp
OServic	Other Services	cmn, ofi, isr, obs, ros, osg, dwe

Source: Willenbockel et al. (2018) and Willenbockel (2018).

Table A2b.2: Regional Aggregation

Short Code	Description
PRC Plus	People's Republic of China; Hong Kong, China; Taipei, China
OEARD	Other East Asia
CWRD	Central and West Asia
Indonesia	Indonesia
OSERD	Other Southeast Asia
India	India
OSARD	Other South Asia

Notes: Oceania is dropped because this is mainly Australia and New Zealand. Pacific cannot be done independently because of the lack of data for computable general equilibrium (CGE) modeling. Unable to exactly replicate the Asian Development Bank regions because of the lack of availability of detailed data sets for the full economy that are required for the CGE modeling.

Source: Willenbockel et al. (2018) and Willenbockel (2018).

A2b.2. Production, Input Demand, and Factor Markets

Production relationships by activity are characterized by constant returns to scale and specified by nested Constant Elasticity of Substitution (CES) production functions. In the standard version, activity output is a CES composite of an aggregate intermediate input and aggregate value added, where the aggregate intermediate input is a Leontief aggregate of the individual intermediate commodity inputs and aggregate value added is a CES composite of primary factors. The determination of product supply and input demand is based on the assumption of profit maximizing behavior.

For each region bloc, the model allows to adopt either a standard neoclassical factor market closure or a closure with labor underemployment. Under the former closure, factor markets in all regions are characterized by inelastic factor supplies and the model solves for market-clearing factor prices. The primary factors except sector-specific natural resource endowments are mobile across production activities, but immobile across borders. Under the latter closure option, the wage for unskilled labor is fixed relative to the domestic consumer price index and the supply of unskilled labor is perfectly elastic.

A2b.3. Final Domestic Demand by Commodity

The commodity composition of government consumption demand and investment demand is fixed using the observed demand patterns from the benchmark data set, while the determination of the aggregate levels for these final demand components in each region depends on the choice of macro closure. Households are utility maximizers that respond to changes in relative prices and disposable incomes. In this version of the model, the utility functions for private households take the Stone-Geary form and hence, consumer demand by commodity is described by a Linear Expenditure System (LES) specification.

A2b.4. International Trade

Domestically produced commodities are assumed to be imperfect substitutes for traded goods. Import demand is modelled via a series of nested CES functions; imported commodities from different source regions to a destination region are assumed to be imperfect substitutes for each other and are aggregated to form composite import commodities that are assumed to be imperfect substitutes for their counterpart domestic commodities. The composite imported commodities and their counterpart domestic commodities are then combined to produce composite consumption commodities, which are the commodities demanded by domestic agents as intermediate inputs and final demand (private consumption, government, and investment). Export supply is modelled via a series of nested constant elasticity of transformation (CET) functions; the composite export commodities are assumed to be imperfect substitutes for domestically consumed commodities, while the exported commodities from a source region to different destination regions are assumed to be imperfect substitutes for each other. The composite exported commodities and their counterpart domestic commodities are then combined as composite production commodities. The use of nested CET functions for export supply implies that domestic producers adjust their export supply decisions in response to changes in the relative prices of exports and domestic commodities. This specification is desirable in a global model with a mix of developing and developed countries that produce different kinds of traded goods with the same aggregate commodity classification and yields more realistic behavior of international prices than models assuming perfect substitution on the export side.

A2b.5. Macro Closure

Current account balances for all regions are assumed to be fixed at initial benchmark levels in terms of a global numeraire and real exchange rates adjust to maintain external equilibrium. Under the default macro-closure, changes in aggregate absorption are assumed to be shared equally (to maintain the shares from the base data) among private consumption, government, and investment demands. Household and government saving rates adjust residually to establish the macroeconomic saving-investment balance in each region.

Ending Hunger in Asia and the Pacific by 2030

An Assessment of Investment Requirements in Agriculture

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