Future of Rice in Asia: Perspectives and Opportunities, 2050

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1. Introduction

The South and Southeast Asia regions are the world's leading rice producer, accounting for 58% of the global rice production in 2021 [USDA, 2022]. Asian agriculture, especially rice farming, has been facing stagnant yields [Ladha *et al*., 2003], declining productivity of production factors, nutrient deficiencies, or soil degradation [Tripathi and Das, 2017], depleting groundwater, labour scarcity, over-exploitation of natural resources such as water [Humphreys *et al*., 2010] and higher cost of cultivation. In a nutshell, agricultural and food systems' sustainability is at risk. Rice remains closely tied to national and sub-national food security imperatives. Rice production systems in Asia (South Asia and Southeast Asia) in recent years have become increasingly threatened by climate change—such as the increased occurrence of severe weather, including heatwaves, droughts, unpredictable precipitation, increased salinity, rising sea levels, flooding and submergence [Yan *et al*., 2022; Redfern *et al*., 2012]. Asian countries are more primed and vulnerable at the same time to changes in economic progress. In the past two decades, countries in Asia have witnessed faster rates of urbanization, rising wages, more diversity of diets, and increased population density leading to a decreased area in production agriculture [Mishra *et al*., 2022; Mottaleb and Mishra, 2022]. Climate change (increased droughts, extreme weather, flooding, and heat) in Asian countries have played a significant role in food production and thus would have a profound impact on food production, especially rice production. As noted by Furuya and Koyama [2005], Li and Wassmann [2011] and Yan *et al*. [2022], weather variability or climate change can cause a decline in world rice production and yield gaps and have already proven to have negative effects on agricultural production and the socioeconomic conditions of the farmers.

Meanwhile, most of the world is experiencing rapid income growth and urbanization that will profoundly affect food production, crop diversity, food quality, diets, and nutrition. With subsequent lifestyle changes, changes in diets, and the proliferation of fast-food restaurants, households consequently consume relatively more packaged and processed foods. They tend to consume meat, sugar, fats, and oils [Gaiha *et al*., 2013; Pingali, 2007; Mottaleb and Mishra, 2022] and not enough fruits, vegetables, and other healthy foods. Consumption and, therefore, demand for feed grains for other livestock feeds increases. Thus, growing, and evolving food patterns will pressure food production, specifically sustainable food production. However, growth in sustainable food production faces challenges on several fronts, including climate change—higher temperatures and weather

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variability, and increased variability in rainfall. Pingali *et al*. [1997] in their book highlighted slowing yield growth and signs of severe environmental degradation due to increased fertilization and water usage by rice farmers. Additionally, Pandey *et al*. [2010] noted that the food economy is more integrated with other sectors of the global economy, including both energy and financial markets. Women make significant contributions to rice farming, processing, and marketing and play a dominant role in buying rice for consumption [Medagbe *et al*., 2020]. Addressing social considerations with a focus on women and youth is expected to lead to policies and technological changes that promote gender and youth equality in access to productive resources and opportunities that will contribute to household food and nutrition security. Finally, government policies, domestic support, and trade policies alter the supply and demand of rice around the globe. Governments[b,] like the Philippines, have had import restriction policies[c] to protect Filipino farmers from foreign competition and secure lower prices for domestic consumers [Balié and Valera, 2020[d]; Balié *et al*., 2021].

Rice, a staple food for some 4 billion people globally, provides 21 percent of global human per capita energy and 15 percent of per capita protein [United Nations, 2017]. Rice is still the dominant crop in Asia, covering 85% of the arable land. Rice is grown in diverse agroecosystems in South Asia, Southeast Asia, Africa, and Latin America. Asians consume 84% of the world's rice. However, rice production and consumption vary by region [Mishra *et al*., 2022]. Rice farming is associated with poverty in many areas. About 900 million of the world's poor depend on rice as producers or consumers. Mishra *et al*. [2022] notes that about 400 million poor and undernourished people are engaged in rice-based farming systems, mostly on less than 2 ha of landholding. Finally, the authors note that about 144 million farm households, usually small farms, are engaged in rice production for subsistence and employment. Therefore, an abundant and stable supply of affordable rice is critical for reducing poverty and hunger in developing and emerging economies. Figure 1 shows the area, production, and rice yield growth rate from 1962 to 2019 for South and Southeast Asia and the Pacific region. The figure shows the high growth during the Green Revolution (1966-1985), which increased world rice production and yield by 2.5% per year. However, over the past 20 years, land used for rice farming has been declining.

[b] For instance, Tanaka and Hosoe [2011] opposed Japanese government's rice trade liberalization because it would threaten national food security. In India's case, Srinivasan and Jha [2001] note that rice trade liberalization reform would likely increase domestic price variability and increase the costs of price stabilization.

[c] In March 2019, the government of the Philippines promulgated a bill called the Rice Tariffication Law (Republic Act No. 11203). The policy reform abandoned the quantitative restrictions on imports that have been in place for more than thirty years, replacing them with ad valorem tariffs to finally comply with the principles and rules of the World Trade Organization (WTO). Another important aspect of the reform was the elimination of the role of the National Food Authority (NFA) in rice imports. The NFA has long been considered a source of huge inefficiencies and inappropriate interventions in markets [Balié *et al*., 2021].

[d] Replacing import quota with tariffs would decrease domestic production, lower farm and retail prices. Thus, tariff could have beneficial impact on fining inflation in Philippines.

Food security remains fragile despite the economic progress made in the last four decades. The 2008 world food crisis and the recent COVID-19 pandemic reinstate the need to ensure a stable, affordable, quality, and sustainable food supply for the poor. Thus, there is a need to develop a new vision for future rice farming in the context of Asia. The vision is needed to strategically position rice research and technology investments and induce policymakers to design policies that help accelerate policy reforms. Rural-urban migration has increased labour scarcity, rural wages, and feminization[e] and aging of the agricultural labour force. The aging of the rural labour force has many countries worrying about who will grow their food in the coming decades, especially in many countries in Asia.

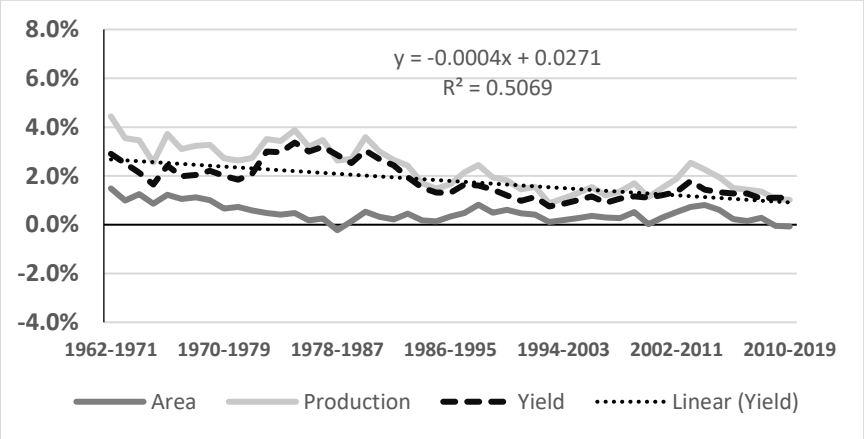


Figure 1: Average growth rate (%) of area (hectares), production (tons), and rice yield (t/ha), 1962-2019 for South Asia, Southeast Asia and the Pacific. Source: Mishra *et al*. [2019]

This chapter presents a perspective and outlines the opportunities for the future of rice farming in Asia. The chapter is forward-looking in the context of major developments in the Asian economy. The chapter has two objectives. First, it documents the current situation and projected status of the rice economy in Asia. The IRRI Global Rice Model (IGRM) is used to assess the direction of supply and demand among rice economies over the next three decades. The outlook of countries with a significant role in the global rice economy will also be discussed. Then it briefly discusses the key lessons from the supply and demand outlook. Second, it will identify and discusses key challenges that countries must address in the intermediate and long-term periods. It also discusses how the design of coherent and coordinated policy actions will meet those challenges.

[e] Factors affecting feminization of rice farming include, out-migration or rural male workers [Radel *et al*., 2012], mechanization and labor-saving technologies [Pandey *et al*., 2012], rice production systems (subsistence farming where women contribute significant amount of labor [Radel *et al.*, 2012]], and sociocultural norms and values [Paris *et al*., 2008].

2. Key Drivers of Rice Supply and Demand

To meet the rice demand by 2050, the International Rice Research Institute (IRRI) estimates that an extra 75 million tons of rice will need to be produced worldwide compared to 2020. This represents a substantial leap forward when rice yields are plateauing in most countries. Asia's ongoing demographic transformation is expected to affect future rice production and consumption [Bhandari and Mishra, 2018].[f] Several factors are likely to drive the supply response. On the supply side, major factors include growth in the actual area planted, rice cropping intensity and rice yields through the adoption of high-yielding varieties, aging farmers, out-migration, and off-farm income opportunities [Bhandari and Mishra, 2018]. Rural out-migration affects rice farming by influencing the farming population, labour supply, and geographic shifting of rice demand. The aging of farmers is a matter of concern because it affects the farming population and the adequate amount of food to feed the growing population. Other effects of the aging farm population on agriculture and rice farming are labour market, land market, land use, production practices, farming intensification and commercialization, technology adoption, livelihood strategies, food and nutrition security, poverty, and farm consolidation. Rice production growth can be accomplished by adopting new technologies and sustainable practices, improving access to credit, increasing investment in agriculture research and development, repurposing the policy support from the national government and redesigning national and international trade policies.

Meanwhile, the drivers of rice demand include population growth, income, family size, household labour reallocation, urbanization [Mottaleb *et al*., 2018], and changing consumers preference. Bhandari and Mishra [2018] predicted that the urban population will surpass the rural population for the first time in history in 2025. Empirical studies demonstrate that with the increase in income and urbanization, people diversify their food consumption from cereal to more high-value-added items [Huang and David, 1993; Huang and Bouis, 1996; Pingali, 2007; Timsina *et al*., 2016]. In addition, in Bangladesh, Mottaleb *et al*. [2017] argue that with rising income and urbanization, consumers will be demanding more high-quality rice—long grain and fragrant rice. Indeed, one would recognize a similar pattern across East and Southeast Asian countries.

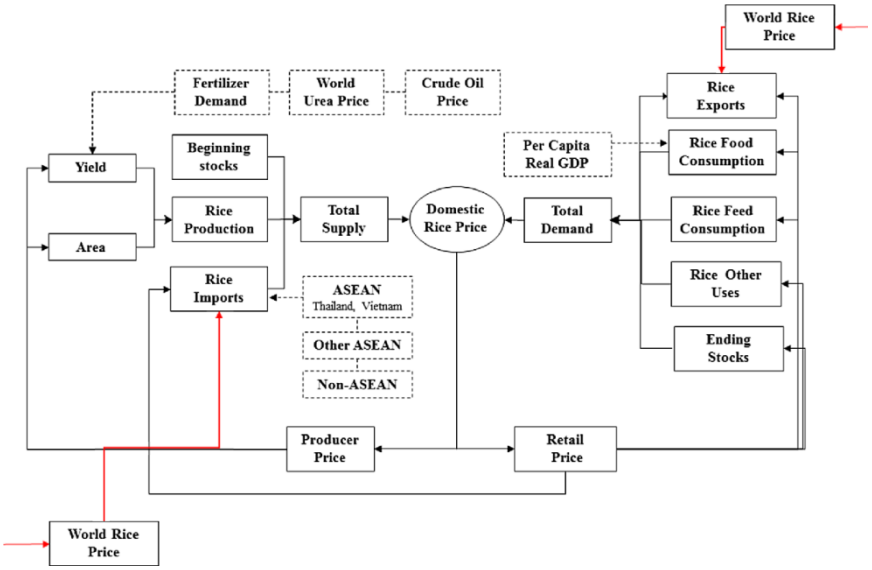
To meet the demand for quality rice and rice with attributes (like smell, taste, texture, grain shape, and other characteristics), rice value chains are rapidly changing in many parts of the world. Since rapid urbanization is occurring in Asia, rice value chains will attempt to tap into growing market opportunities by tailoring their products to the increasingly demanding taste of urban consumers, who spend more on food per person than rural consumers. However, food represents a

[f] Asian population is projected to reach 4.6 billion in 2050.

lower share of their total expenditures [Mottaleb *et al*., 2016]. Thus, the above supply and demand drivers will shape the rice sector's transformation. Other factors include mechanization, feminization, land consolidation, branding, quality upgrading, healthier, more nutritious products, and globalization.

2.1 The global rice supply and demand outlook using IGRM

In this chapter, a long-term supply and demand outlook is developed using the IRRI Global Rice Model[g] (IGRM) managed by researchers at IRRI. This model has been extensively used for policy analyses in the Philippines and other parts of the world [Hoang and Meyers, 2015; Balié and Valera, 2020]. Figure 2 shows the representative country model[h] that includes supply, demand, trade and market equilibrium conditions. The supply comprises production, beginning stocks, and imports. Demand is composed of domestic consumption, ending stock, and exports. The model's representation of the global rice market comprises 25 countries and four regional aggregates. Those countries account for about 90% of



[g] IGRM is a dynamic partial equilibrium framework with a structure similar to the well-established Arkansas Global Rice Model (AGRM) of the University of Arkansas [Wailes and Chavez, 2011]. IGRM has been used as an analytical framework for rice trade liberalization studies in the Southeast Asian rice markets [[Hoang and Myers, 2015; Balié and Valera, 2020; Balié *et al*., 2021].

[h] IGRM representative country model for the Philippines employed in the rice tariffication policy simulation [Balié and Valera, 2020].

Figure 2: IGRM model structure. Source: Balié and Valera [2020].

worldwide rice consumption and production. The world reference price for the model is the Thai FOB 5% broken price. The Thai 5% broken price is solved to close the model such that Thailand's net exports equal the sum of the net trade of the remaining countries.

On the supply side, the rice area is specified as a function of the previous year's harvested area and expected gross returns or prices received by producers for rice and competing crops. In general, partial adjustment expectations of the prior year are the most representative, but there are some variations in specific variations by country. The model specified yield as a function of expected output, input prices, and R&D expenditures or trend assumptions to capture technological change. On the demand side, per capita food consumption is estimated based on real per capita income and real retail prices of rice and substitute food.

2.2 Global rice outlook

In this chapter, we develop long-term baseline deterministic estimates of global supply and demand for rice between 2022 and 2050. The estimates are generated under a set of assumptions regarding population, income, exchange rate, and other macroeconomic indicators. In addition, the estimates assume a continuation of existing rice sector policies and average weather conditions. Before presenting our long-term baseline estimates, it is worthwhile to mention some key developments in the Asian rice market. In 2020-2021, for example, there was a record production in the rice market fundamentals in Asia along with high levels of global stocks, which were well above the levels observed in 2008 and 2011 when the global rice market experienced a surge in prices. While key rice exporters in the region, such as Vietnam, Cambodia, and Myanmar, abandoned the rice trade restrictions at the initial stage of the Covid-19 pandemic, India imposed a ban on the export of broken rice and a 20-percent export tax on other rice grades in September 2022. The rice export restrictions are mainly imposed to protect the domestic rice market and food security. The baseline estimates we developed did not account for India's recent rice trade restrictions.

As shown in Table 1, the IGRM model estimates that the world rice area will increase by 2 percent between 2022 and 2050. However, rice yield would increase by 10.6 percent during the same period. World rice consumption would increase by 11.2 percent and net trade in rice would increase by about 17 percent during the 2022-2050 period. For Asia, our analysis for the 2022 to 2050 period reveals that the rice area would only increase by 0.2 percent between 2022 and 2050. However, rice yield would increase by nearly 8 percent, perhaps due to technological changes in rice production,

during the same period. Asian rice consumption would increase by 4.6 percent, well below the yield increase, and as a result, net trade in rice would increase by about 51 percent during the 2022-2050 period (Table 1).

The rice outlook in Africa is quite different. For instance, our analysis using IGRM shows that Africa's rice area would increase by 18.3 percent between 2022 and 2050. However, rice yield would increase by three folds compared to rice area—by 55.3 percent during the same period. Interestingly, African rice consumption would grow at a faster rate. Our analysis reveals that African rice consumption between 2022 and 2050 would increase by about 83 percent. Thus, African countries would have to import much of the rice from Asia and the rest of the world (the United States and others) to meet the consumption demand. Import of rice (net trade negative) would have to increase by about 65 percent during the 2020-2050 period.

Next, Table 1 also shows the rice situation in the Americas. The IGRM baseline projections show that the America's rice area would increase by only 2.3 percent between 2022 and 2050. However, rice yield would increase ten folds compared to rice area—by 20.5 percent during the same period. Interestingly, America's rice consumption would grow at a slower rate. Our analysis reveals that America's rice consumption between 2022 and 2050 would increase by about 12.7 percent. Finally, the bottom part of Table 1 shows the long-term outlook on rice in the European Union. The IGRM baseline projections show that the rice area in this region would increase by 18.7 percent between 2022 and 2050. Rice yield is expected to increase by 21.4 percent during the same period. European Union's rice consumption is expected to grow much faster—by 20.4 percent between 2022 and 2050. Accordingly, rice imports of the European Union would increase by 31.6% during the same period.

Table 1. Rice supply and use in selected years: World, Asia, Africa, and Americas

	Unit	2021	2022	2025	2030	2040	2050	Growth rate
World								
Area	1000HA	163,304	162,332	163,559	165,315	166,833	165,656	2.05
Yield	MT/HA	4.60	4.61	4.70	4.78	4.94	5.10	10.58
Milled Production	1000MT	503,101	501,604	514,924	528,919	550,400	564,098	12.46
Beginning Stocks	1000MT	188,087	185,049	179,304	179,516	181,269	184,704	-0.19
Consumption	1000MT	515,733	517,687	525,738	539,848	561,654	575,573	11.18
Ending Stocks	1000MT	185,049	179,462	179,191	179,608	181,512	185,019	3.10
Total Trade	1000MT	40,650	40,312	40,729	40,997	42,523	47,186	17.05
Asia								
Area	1000HA	140,613	139,748	140,551	141,518	141,790	139,981	0.17
Yield	MT/HA	4.76	4.79	4.86	4.92	5.04	5.17	7.97
Milled Production	1000MT	449,110	448,809	458,237	466,593	478,098	484,082	7.86
Beginning Stocks	1000MT	177,057	173,824	168,565	168,729	169,999	172,248	-0.91
Consumption	1000MT	434,296	434,890	439,174	447,033	455,524	454,846	4.59
Ending Stocks	1000MT	173,824	168,553	168,491	168,789	170,185	172,496	2.34
Net Trade	1000MT	18,047	19,190	19,137	19,500	22,388	28,989	51.06
Africa								
Area	1000HA	15,562	15,562	15,810	16,454	17,606	18,403	18.26
Yield	MT/HA	2.34	2.32	2.48	2.75	3.20	3.60	55.31
Milled Production	1000MT	23,677	23,410	25,485	29,314	36,562	42,902	83.26
Beginning Stocks	1000MT	4,280	4,308	3,787	3,631	3,669	3,826	-11.19
Consumption	1000MT	41,149	42,110	45,127	50,381	61,316	73,164	73.74
Ending Stocks	1000MT	4,308	3,985	3,721	3,623	3,680	3,845	-3.51

Net Trade	1000MT	-17,500	-18,377	-19,576	-21,059	-24,765	-30,281	64.78
Americas								
Area	1000HA	5,501	5,448	5,531	5,650	5,735	5,571	2.26
Yield	MT/HA	6.44	6.36	6.57	6.77	7.21	7.66	20.51
Milled Production	1000MT	24,091	23,546	24,707	26,023	28,070	28,974	23.05
Beginning Stocks	1000MT	4,279	4,038	3,908	4,023	4,376	4,790	18.62
Consumption	1000MT	24,527	24,585	25,025	25,590	26,688	27,716	12.73
Ending Stocks	1000MT	4,038	3,901	3,916	4,048	4,414	4,827	23.73
Net Trade	1000MT	-195	-902	-327	409	1,344	1,221	-235.32
European Union-28								
Area	1000HA	403	357	409	419	424	424	18.67
Yield	MT/HA	6.53	5.84	6.51	6.83	7.15	7.10	21.44
Milled Production	1000MT	1,713	2,087	2,666	2,862	3,031	3,007	44.11
Beginning Stocks	1000MT	663	737	603	632	620	1,134	53.83
Consumption	1000MT	3,500	3,559	3,655	3,770	4,145	4,684	31.60
Ending Stocks	1000MT	737	615	609	635	619	1,134	84.38
Net Trade	1000MT	-1,861	-2,101	-1,953	-1,941	-2,203	-2,758	31.29

Source: IRRI Global Rice Model (IGRM) 2022 version prepared for the book on Food Security Issues in Asia.

2.3 Asian rice sector outlook

USDA (2021) reports that globally 503.17 MT of rice is produced, where China has 29.5% of the total, followed by India (23.8%), Bangladesh (7.0%), Indonesia (6.9%), Vietnam (5.4%), and Thailand (3.7%) [Al Mamun *et al*., 2021]. Using the IGRM model, we also projected the outlook of the rice industry in selected Asian countries (see Table 2). These countries represent high producers, exporters, and rice consumers (about 74% of global trade[i]). We explore in depth the outlook for rice in several of the major rice growing countries in the sections which follow.

2.3.1 Bangladesh

The top panel of Table 2 shows the area, yield, consumption, per capita consumption, net trade, and farm and retail rice prices in Bangladesh. Bangladesh's rice production heavily depends on rainfall and has three growing seasons (Aman, Aus and Boro). Rice is also the staple food in Bangladesh and accounts for approximately 78 percent of the country's total net cropped areas in cultivation. The IGRM baseline projections show that Bangladesh's rice area and yield would increase by nearly 8 percent between 2022 and 2050 (Table 2). Although the total consumption would increase by 13.4 percent, per capita consumption would decrease by 1.1 percent during the same period—perhaps due to the high population growth rate. To meet rice demand, Bangladesh would have to increase rice imports by 1 percent from 2022 to 2050.

2.3.2 China

China is the world's largest producer of rice, with an average yield of about 6.5 tons per hectare, among the highest in Asia. More than 90% of China's rice is irrigated, and, in some parts of China, two harvests per year can be grown. The IGRM baseline projections show that China's rice area would decrease by about 4.8 percent between 2022 and 2050 (Table 2). This may be due to increased urbanization and higher demand for land for other activities. However, rice yield would increase by about 2.7 percent during the same period. Interestingly, our baseline projections show that total and per capita rice consumption would decrease by about 6.9 percent and 3.9 percent, respectively, during the same period. This may be due to the increased consumption of other types of food and the westernization of Chinese diets. As a result, China will be able to reduce its rice imports.

2.3.3 India

Rice is a staple food for most Indians. Rice farming is directly and indirectly linked to poverty, food security, and economic, social, cultural, political, and environmental aspects of Indians.

[i] India exports about 37.5% of rice to the world market, followed by Thailand, 13%, Pakistan, 8.4%, Vietnam 7.7%, China, 3.3%, Myanmar 2.1% and Cambodia about 1.6%.

India accounts for over 23% of overall global rice production. India, the second world's biggest rice consumer after China, has a market share of more than 40% of the global rice trade. India exports rice to more than 150 countries. The IGRM baseline projections show that India's rice area would increase by about 1.9 percent between 2022 and 2050 (Table 2). However, rice yield would increase significantly by about 11.3 percent during the same period. This may be accomplished by increased use of modern rice technologies like hybrid rice and water management techniques. Our results show that total and per capita rice consumption would increase by 14.3 percent and decrease by 1.8 percent, respectively, during the same period. This may be due to a slower rate of population growth and the westernization of Indian diets. Rice export from India would also increase by 5.4 percent during 2022-2050.

Table 2. Rice supply and use in Selected Asian countries, IGRM model, selected years, 2022-2050.

	Unit	2021	2022	2025	2030	2040	2050	Growth rate
Bangladesh								
Area	1000HA	8,410	8,323	8,461	8,673	8,920	9,004	8.18
Yield	MT/HA	4.51	4.53	4.58	4.65	4.77	4.89	7.91
Milled Production	1000MT	25,299	25,154	25,845	26,866	28,393	29,365	16.74
Beginning Stocks	1000MT	1,461	2,101	1,552	1,539	1,559	1,621	-22.85
Per capita consumption	KG/Year	219.48	219.20	219.00	216.57	215.05	216.78	-1.10
Consumption	1000MT	36,500	36,801	37,756	38,765	40,518	41,745	13.44
Ending Stocks	1000MT	2,101	1,542	1,548	1,538	1,563	1,629	5.64
Net Trade	1000MT	-1,290	-592	-1,205	-879	-632	-598	0.89
China								
Area	1000HA	29,921	30,000	30,004	29,793	29,236	28,576	-4.75
Yield	MT/HA	7.11	7.10	7.19	7.21	7.25	7.28	2.67
Milled Production	1000MT	148,990	149,000	151,044	150,341	148,291	145,719	-2.20
Beginning Stocks	1000MT	116,500	113,000	108,985	108,854	108,809	109,048	-3.50
Per capita consumption	KG/Year	107.61	107.52	105.49	104.78	103.87	103.36	-3.87
Consumption	1000MT	156,290	156,631	154,690	154,353	151,436	145,864	-6.87
Ending Stocks	1000MT	113,000	108,993	108,956	108,828	108,823	109,081	0.08
Net Trade	1000MT	-3,800	-3,625	-3,618	-3,986	-3,159	-178	-95.09
India								
Area	1000HA	47,000	45,999	46,412	46,561	46,734	46,852	1.85
Yield	MT/HA	4.14	4.19	4.27	4.36	4.50	4.66	11.28
Milled Production	1000MT	129,660	128,500	132,099	135,229	140,295	145,652	13.35
Beginning Stocks	1000MT	37,000	36,500	36,201	36,550	37,072	37,723	3.35
Per capita consumption	KG/Year	77.80	76.49	76.38	76.17	75.70	75.08	-1.84

Consumption	1000MT	108,410	107,592	110,365	114,526	120,571	123,070	14.38
Ending Stocks	1000MT	36,500	36,050	36,271	36,605	37,131	37,793	4.84
Net Trade	1000MT	21,750	21,358	21,664	20,647	19,664	22,512	5.40
Indonesia								
Area	1000HA	11,600	11,650	11,672	11,674	11,658	11,620	-0.26
Yield	MT/HA	4.67	4.68	4.74	4.83	5.02	5.20	11.21
Milled Production	1000MT	34,400	34,600	35,143	35,835	37,136	38,378	10.92
Beginning Stocks	1000MT	3,060	2,860	3,142	3,269	3,487	3,707	29.62
Per capita consumption	KG/Year	127.19	125.39	124.80	123.81	121.48	118.29	-5.66
Consumption	1000MT	35,150	35,001	35,828	37,044	38,710	39,143	11.83
Ending Stocks	1000MT	2,860	3,011	3,172	3,290	3,509	3,729	23.85
Net Trade	1000MT	-550	-552	-715	-1,231	-1,595	-788	42.68
Philippines								
Area	1000HA	4,800	4,800	4,885	4,997	5,143	5,209	8.53
Yield	MT/HA	4.17	4.10	4.28	4.28	4.29	4.29	4.43
Milled Production	1000MT	12,600	12,411	13,172	13,481	13,885	14,067	13.34
Beginning Stocks	1000MT	3,763	4,513	4,494	4,491	4,499	4,521	0.18
Per capita consumption	KG/Year	138.68	138.64	137.85	136.70	131.92	128.64	-7.21
Consumption	1000MT	15,400	15,598	16,105	16,910	17,890	18,588	19.16
Ending Stocks	1000MT	4,513	4,424	4,492	4,490	4,500	4,524	2.25
Net Trade	1000MT	-3,550	-3,099	-2,931	-3,427	-4,007	-4,523	45.97
Thailand								
Area	1000HA	10,587	10,700	10,619	10,848	10,890	10,421	-2.60
Yield	MT/HA	2.81	2.80	2.85	2.93	3.09	3.24	15.56
Milled Production	1000MT	19,650	19,800	19,965	20,991	22,213	22,285	12.55
Beginning Stocks	1000MT	4,280	3,930	3,037	3,120	3,530	3,869	-1.55

Per capita consumption	KG/Year	185.84	187.02	186.08	182.91	179.45	179.55	-4.00
Consumption	1000MT	13,000	13,106	13,087	12,867	12,383	11,840	-9.66
Ending Stocks	1000MT	3,930	3,334	2,995	3,159	3,566	3,896	16.83
Net Trade	1000MT	7,000	7,289	6,921	8,084	9,794	10,418	42.93
Vietnam								
Area	1000HA	7,285	7,290	7,313	7,385	7,440	7,399	1.49
Yield	MT/HA	5.95	6.01	6.10	6.21	6.45	6.68	11.10
Milled Production	1000MT	27,069	27,400	27,868	28,683	29,985	30,896	12.76
Beginning Stocks	1000MT	2,639	2,808	2,931	2,812	2,866	3,294	17.33
Per capita consumption	KG/Year	219.01	219.29	218.37	216.13	211.64	207.57	-5.35
Consumption	1000MT	21,500	21,700	22,079	22,512	22,813	22,751	4.84
Ending Stocks	1000MT	2,808	2,910	2,892	2,797	2,893	3,351	15.17
Net Trade	1000MT	5,400	5,598	5,828	6,185	7,144	8,089	44.50

Source: IRRI Global Rice Model (IGRM) 2022 version prepared for the book on Food Security Issues in Asia.

2.3.4 Indonesia

Indonesia is the third-largest producer of rice and one of the top five importers of rice. Indonesia imports rice mainly from Thailand, Vietnam, and India. Indonesia's rice consumption will likely increase because of the growing population. Table 2 shows the baseline projection for Indonesia's rice area would decrease by 0.3 percent. In contrast, rice yield would increase significantly by about 11 percent during the same period. This may be accomplished by the increased use of modern rice technologies. Our analysis shows that total and per capita, rice consumption would increase by 11.8 percent and decrease by 5.7 percent, respectively, during the same period. Rice imports would increase by 43 percent during 2022-2050.

2.3.5 Philippines

In the Philippines, rice is the national staple and a political crop. It is a primary source of income for millions of farmers. Rice represents almost 23% of the total consumption of poor households and 10% of non-poor. The contribution of the rice sector to GDP is low, about 0.7%. Our baseline projections show that the Philippines' rice area would increase by about 8.5 percent between 2022 and 2050 (Table 2). However, rice yield would increase by about 4.6 percent during the same period. The results further show that total and per capita rice consumption would increase by 19 percent and decrease by 7.2 percent during the same period. Indeed, as Balié and Valera [2020] pointed out, it is unsurprising that this pattern conforms to the literature that indicates an increase in global rice consumption due to population growth. Rice imports would increase by 46 percent during 2022-2050.

2.3.6 Thailand

Rice has long been Thailand's traditional food crop and main export product. Thailand remains the world's second-largest rice exporter after India. According to the UN Food and Agriculture Organization's Rice Market Monitor, Rice occupies about 55% of the total arable land, and over 80% of the Thai population eats rice as their main meal. The annual per capita consumption is about 100.8 kg. Table 2 shows that Thailand's rice area would decrease by about 2.6 percent between 2022 and 2050 (Table 2). This is because of climate change and rising sea levels that have made arable land inoperable because of salinity and flooding [Kawasaki, 2010]. The USDA reports that a decline in output is likely due to reduced area of off-season rice as reservoirs are at critically low levels and the government restricts irrigation for rice production. Production costs have risen over the past decade due to rising fertilizer and fuel prices. These issues are only exacerbated by the more recent energy crisis resulting from Russia's invasion of Ukraine. Meanwhile, rice yield would increase considerably by about 15 percent during the same period. Our baseline projections show that total, and per capita rice consumption would decrease by 9.7 percent and 4.0 percent during the same period. Rice exports would increase by 43 percent during 2022-2050.

2.3.7 Vietnam

Rice is Vietnam's leading staple food, and total rice output ranks fifth in global production, behind China, India, Indonesia, and Bangladesh. The Mekong River Delta and the Red River Delta cover approximately 70 percent of the total rice area in Vietnam. Rice is essentially cultivated year-round. However, seasonal weather drives planting cycles phased into three planting periods, Lua Mua (Winter), Winter-Spring, and Summer-Autumn. Our analysis using the IGRM baseline projection shows that Vietnam's rice area would increase by about 1.5 percent between 2022 and 2050 (Table 2). However, rice yield would increase significantly, ten times more (about 11.1 percent) during the same period. This may be accomplished by increasing production area, using modern rice technologies like hybrid rice and improved water management techniques, and the government's decision to make the rice sector low carbon in the next 10 years. Our baseline projections show that total, and per capita rice consumption would increase by 4.8 percent and decrease by 5.4 percent during the same period. When it comes to trade, Vietnam has the upper hand. For instance, in 2022 the EU-Vietnam Free Trade Agreement (EVFTA) came into effect. According to EVFTA, the European Union provides Vietnam with 80,000 tons of rice for export at a 0% tax rate annually (including 30,000 tons of milled rice, 20,000 tons of unmilled rice, and 30,000 tons of aromatic rice. Table 2 shows that rice export from Vietnam would increase by 44.5 percent during 2022-2050.

Note that the findings reported in the preceding paragraphs are based on a 5-year time horizon of the IGRM baseline projection from 2022 to 2026. The performance of the model is validated by comparing projection results of 2022 with the USDA's 2022 actual production, consumption and trade data.

3. Tradeoffs between Food and Nutrition Security and Opportunities

The above outlook of the rice sector globally and regionally (Asia) assumes that the prevailing paradigm of feeding the world is one with abundant and cheap agricultural produce out of sustained intensification.

3.1 Food versus nutrition security

However, in the recent decade, the paradigm of agricultural research, including rice research, has been shifting to incorporate food systems thinking about economic, social, and environmental sustainability and food and nutrition security under a climate change imperative. As a result, funding for technological development and other innovations in the food system has shifted to focus on healthy, affordable, nutritious, and sustainably produced food, particularly nutritious rice [Balié, 2020]. In other words, we have enough food to eat, but the population in developing and emerging economies

lacks diet diversity leading to micronutrient deficiencies [Palanog *et al*., 2019]. Iron deficiency anemia and zinc deficiency are two severe nutritional problems. Thus, future opportunities in the rice sector would have to focus on developing nutritional rice variety, low glycemic index rice, high-zinc rice, high-iron rice and rice with high protein content. In the Philippines, the government[j] has proactively initiated various programs and policies to address micronutrient deficiencies, particularly fortifying essential food commodities. Thus, developing rice varieties with high micronutrient concentrations within rice grains is a cost-effective and sustainable strategy to address micronutrient needs among populations unable to access a healthy and diverse diet [Stein *et al*., 2005].

3.2 Opportunities to address the rice complex

3.2.1 Addressing production issues

Regarding the future of the rice sector, national rice research institutions in countries and/or the International Rice Research Institute (IRRI) need to strengthen their capacity to deal with more diverse and complex topics that relate to rice production with complementary, holistic views that deal with significant problems such as climate change, nutrition, and environmental sustainability as well as the prosperity of rice growers and the communities around them. Soil, water and other environmental issues, as well as farming households' resilience to shocks, require that rice research in Asia and globally increasingly focus on sustainable farming practices, soil fertility, regeneration and conservation practices, efficient water management and conservation technologies as well as water pricing policies in rice cultivation. Research on short-duration, high-yielding, and stress-tolerant rice varieties and the benefits of direct seeded rice and mechanized transplanting on zero-tilled/un-puddled fields can improve the input use efficiency in rice cultivation under medium–heavy-textured soils. By the same token, more research is warranted on developing and replacing varieties to adapt to rapidly evolving stress conditions for rice cultivation.

3.2.2 Improving market intelligence

Other opportunities that have yet to be explored in the Asian rice sector include consumer-based market intelligence-driven varietal development, contract farming, and using futures markets to manage commodity risk. Commodity growers, including rice farmers, in Asian countries[k] could benefit tremendously from creating market intelligence centres (MICs). The centres would forecast market conditions (supply and demand) and market prices and anticipate the emergence of new

[j] Currently, only two biofortified rice varieties, Zn rice, NSIC Rc460, and Fe rice, NSIC Rc172 (MS13), are commercially available for production and multiplication.

[k] Developed countries already have government agencies that provide this information. For example, US Department of Agriculture (USDA) and its several services (Agricultural Marketing Service, Economic Research Service, Foreign Agriculture Service.

market segments driven by fast-evolving consumer preferences. The centre would also develop a commodity market outlook and provide commodity market research and services for traders, investors, and other value chain stakeholders. The centres would also provide information on export procedures, post-harvest technologies, good management practices, and infrastructure development (rail, storage, cold chain, warehousing, ports, etc.). The centres can accelerate information delivery to accelerate the adoption of improved rice varieties by providing timely and appropriate market intelligence information to guide the development of new rice varieties. Examples of such centres have started to emerge. For instance, India has established centres called "Networking of Agricultural Market Intelligence Centres," comprising university researchers, private companies, and the central government. The One-CGIAR has recently launched a new initiative called 'Market Intelligence' which aims to maximize CGIAR and partners' returns on investment in breeding, seed systems, and other Initiatives based on reliable and timely market intelligence, enables stronger demand orientation and strengthens co-ownership and co-implementation by CGIAR and partners.[l]

3.2.3 Farming modalities

Contract farming has emerged as a popular vertical coordination mechanism for smallholders to diversify risk and receive higher product prices [Otsuka *et al*., 2016]. Production contracts can shift farming risk and provide smallholders with transportation, storage, and capital needs. Smallholders producing both high-value and low-value crops in many Asian countries have used contract farming arrangements. Empirical evidence [Meemken and Bellemare, 2020; Mishra *et al*., 2016, 2017, 2018a, 2018b, 2018c] from Africa and Asia shows that contract farming positively impacts growers' profit, yield, and technical efficiency. Finally, governments in Asia should start exploring the use and potential benefits of futures markets for rice trading. Both consumers and rice producers can manage price risk by purchasing and selling rice futures.[m] The futures contract would enable rice growers to obtain greater security for the sale of their harvest, locking in prices at acceptable levels. For instance, the Dojima Rice Exchange in Japan started in 1967. It is a commodity futures exchange specializing in rice. In the futures market, buyers (smallholders in our case) could purchase rice at predetermined prices, eliminating the risk of sudden price increases and securing valuable rice supplies ahead of time. The risk management benefits of an active Asian rice futures contract could be significant. Public/state agencies and private market firms could use the futures market to lock in or fix the price they buy/sell rice months in advance – removing the risk associated with price spikes.

[l] More information about the Market intelligence Initiative are available at https://www.cgiar.org/initiative/05-market-intelligence-for-more-equitable-and-impactful-genetic-innovation/

[m] For example, rice producers could employ short hedge to lock in selling price for their rice. Businesses that require rice could use long hedge to secure a purchase price for the rice.

4. Concluding remarks

The Asian rice market fundamentals in 2020–2021 indicated record production and high levels of global stocks. These production and stock levels were much higher than in 2008 and 2011. At the onset of the COVID pandemic, many rice exporting countries such as Vietnam, Cambodia, and Myanmar restricted exports for food security reasons in their own country, thus, pushing international rice prices higher. Since then, global reference prices for rice, based on Thai 5% broken rice, have declined significantly. Additionally, the rice exporting countries rolled back their export restrictions because of the influx of Indian rice in the global market. However, India recently imposed a ban on the export of broken rice and a 20-percent export tax on other rice grades to lower domestic prices and ensure enough local rice supply for Indians. The global rice economy could see a dramatic shift or tightening quickly if India continues to restrict rice exports and experiences a bad monsoon season. The global rice market will be in peril if rice-exporting countries like Vietnam, Cambodia, Myanmar, and Thailand follow the Indian philosophy of export ban.

Considering the vital role played by Asia in tackling the challenge of eradicating hunger and improving food security, this chapter provides a long-term outlook for the region and global rice market, assuming average weather and non-imposition of India's recent rice export restrictions and a continuation of current policies in other countries. The baseline projections presented in this book chapter indicate that global rice output, consumption, stocks, and trade can be expected to grow. The growth in rice yield in Asia is expected to be much slower than in Africa, where yield is projected to increase by 55 percent between 2022 and 2050. Over the long run, total rice consumption in Asia and Africa is projected to rise by 5% and 73%, respectively. To meet the rice consumption demand in Africa, the region would have to import much of the rice from Asia and the rest of the world. The baseline projections further indicate a decline in per capita rice consumption over the long run. The decline in per capita rice consumption in many Asian countries is being offset by a rise in rice consumption in Africa.

Lastly, for the yield improvement and food security of billions of Asians, policymakers need to focus on addressing natural and man-made challenges such as climate change, nutrition, environmental sustainability, efficient water management, soil fertility, sustainable farming practices, and prosperity of rice growers. We argue that a significant amount of resources should be devoted to developing varieties that can grow in unfavorable environments. To this end, it is not surprising that scientists and policymakers have been forward-looking and joined the cause. They have been working relentlessly to develop stress-tolerant varieties that can withstand submergence, drought, and salinity and climate-smart technologies that can reduce input usage.

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