Policy Paper 51

The Future of Food in India
A 2050 Perspective

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Preface

India's ambitious aim to attain developed nation status by 2047 presents both opportunities and challenges for its agri-food system. The country's rapid economic growth and urbanization are anticipated to significantly boost the demand for a diverse range of food products. However, fulfilling this increasing demand will necessitate a substantial transformation of India's agricultural sector. The agri-food system will encounter a confluence of several biotic and abiotic pressures to produce the necessary quantity of food.

This study projects food demand and supply under various economic growth scenarios to assess whether India can produce sufficient food and to evaluate the associated environmental consequences. The research offers critical insights for policymakers, industry leaders, and academics. These findings can be instrumental in formulating strategic, evidence-based plans to address the significant challenges and leverage the opportunities in food system transformation.

The study received funding from Bioversity International, Rome, Italy, with the International Food Policy Research Institute (IFPRI) serving as a knowledge partner. The authors extend their appreciation to both institutions. Additionally, the authors express their gratitude to Keith Wiebe of IFPRI for his valuable suggestions throughout the course of this study. We also thank Dr. Devender Pratap, Senior Fellow at the National Council of Applied Economic Research, New Delhi, and Dr. P. Shinoj, Principal Scientist at the ICAR-Central Marine Fisheries Research Institute, Kochi, for their excellent comments and suggestions on the earlier draft.

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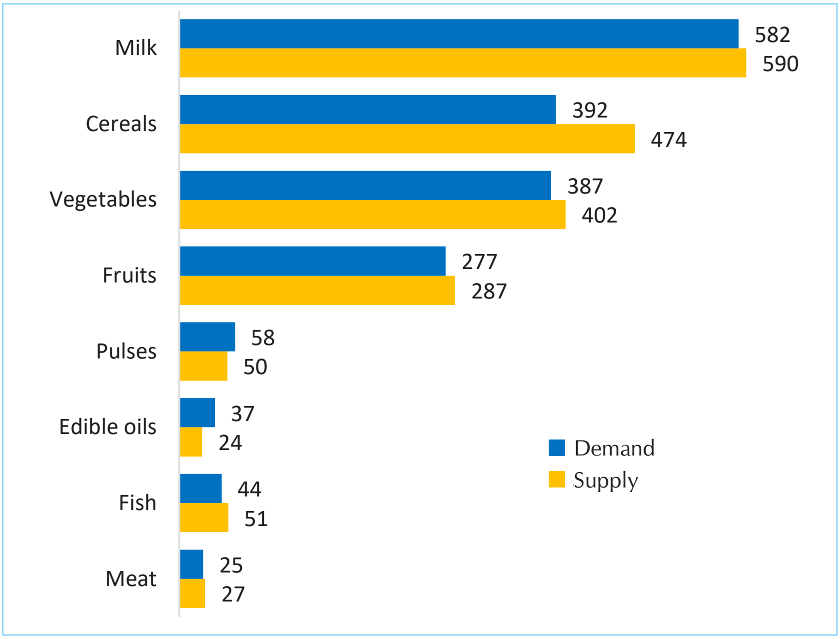
Executive Summary

India's agri-food system is poised for a significant transformation driven by its potential for rapid economic growth and increasing globalization. As these forces reshape consumer preferences, there is a growing demand for nutrition-rich foods. This shift presents a unique opportunity for India to reimagine its agri-food system over the next quarter-century, aligning it with evolving consumer needs while addressing persistent nutritional challenges.

However, this transformation of the food system faces significant challenges related to the quantitative and qualitative degradation of land, labor, and energy resources. As India moves forward, it will need to balance the demands of a changing food landscape with the imperative for resource conservation and sustainable agricultural practices. This balancing act is crucial in ensuring food security, improving nutritional outcomes, and fostering economic growth within the constraints of available resources.

Planning for a sustainable, equitable and efficient agri-food system should be based on a comprehensive understanding of the future food demand and supply, as well as their responses to factors such as investments in infrastructure, agricultural research, and climate mitigation and adaptation. This study projects food demand and supply by 2050, under three distinct economic scenarios, and their potential impacts on the agri-food system. These scenarios are: progressive, aggressive, and retreating growth scenarios. The progressive and aggressive growth scenarios paint optimistic pictures, with increased innovation, higher female labor participation, and successful adaptation to climate change driving economic expansion. In contrast, the regressive scenario highlights the potential risks and challenges that could hinder India's progress towards achieving status of a developed nation. The figure below displays the projected demand and supply for key food items/groups by 2050, as projected under the aggressive growth scenario. Considering these diverse outcomes, policymakers and stakeholders can better prepare for a range of possibilities and develop strategies to mitigate potential risks while capitalizing on opportunities for sustainable growth in the agricultural sector.

Figure 1. Food demand and supply projections by 2050
(million tons, aggressive growth scenario)



The key findings are as follows.

- With the right development strategies, India could potentially achieve the status of a developed country by 2050. By then, its GDP per capita is projected to reach US$ 12,631, bringing it significantly closer to the high-income benchmark of US$ 13,935.
- By 2050, the combination of rising disposable income and a growing population is expected to significantly boost household food demand: fruits by 116-200%, vegetables by 98-151%, milk by 136-188%, and meat and fish by 200-292%, all compared to their 2022 levels.
- By 2050, the total demand for food, including that required for food processing and consumption associated with industrial and service sector activities, is expected to rise by 53-58% for cereals, 92-123% for pulses, 52-76% for edible oil, 50-75% for sugar, 99-166% for fruits, 69-108% for vegetables, 125-180% for milk, and 171-229% for meat and fish.
- By 2050, India is projected to have a significant cereal surplus, with 33-72 million tons of rice and 13-30 million tons of wheat. However, there will be a shortfall in pulses, necessitating imports of 7-14 million tons. Additionally, India will continue to import 13–15 million tons of edible oils. Overall, the production of fruits and vegetables is expected to satisfy domestic demand.

- Intensive agriculture degrades natural resources and the environment. The expansion of sugarcane, rice, maize, wheat, and soybean cultivation requires substantial amounts of water resources. Milk and meat production also contribute significantly to the water demand. Within the agricultural sector, milk production remains the predominant source of greenhouse gas (GHG) emissions, followed by rice cultivation.

While India's agri-food system faces significant challenges in meeting future food demands, technological innovations and policy reforms offer promising solutions to boost productivity, improve resource efficiency, and ensure food security for a growing population.

- The emerging demand-supply balance for various food commodities in India indicates a pressing need for agricultural diversification. Although rice production has historically been a cornerstone of Indian agriculture, shifting consumer preferences and nutritional requirements necessitates a more varied approach. Pulses, oilseeds, nutri-cereals, fruits, and vegetables are increasingly important for meeting evolving dietary needs and reducing dependence on foreign sources.
- India's endowment of natural resources, especially groundwater, is insufficient to support the expansion of water-intensive crops, such as rice. Rice cultivation is also a significant contributor to greenhouse gas (GHG) emissions. Projections of carbon and water footprints highlight the necessity for more efficient resource management and the encouragement of innovative solutions.
- Livestock production is also not environmentally friendly because both the water and carbon footprints are considerably high. Therefore, by improving feeding strategies, optimizing manure management, and enhancing pasture quality, methane emissions from enteric fermentation and manure decomposition can be significantly reduced.

In summary, scaling up actions and strategies that drive the transformation toward a sustainable food system should be a priority. Improved food system governance, which fosters effective negotiations among diverse stakeholders, could be instrumental in this process.

1 Background

Globally, agri-food systems face a dual challenge: meeting the growing demand for diverse food and non-food commodities while simultaneously conserving natural resources and fulfilling the aspirations of farming communities. Over the past two decades, trends in food system indicators have underscored the complexity of this challenge, with approximately half showing positive changes and the remainder requiring governance intervention (Schneider et al. 2025). This situation underscores the necessity for a thorough reassessment of current agricultural practices and policies, urging governance actions to revisit existing policy frameworks and consider the socio-political, economic and environmental implications of inaction (Resnick and Swinnen 2023).

In the absence of governance, the process of transforming the food system may face challenges, particularly when economic projections suggest a less favorable future outlook. For instance, economic growth, a crucial driver of transformation, appears to be insufficient to support future development amid policy uncertainties, trade instability, geopolitical tensions, and climate-related natural disasters. The per capita incomes of emerging markets and developing economies (EMDEs) are projected to converge with those of developed economies at a significantly slower rate. Projections indicate that most low-income countries are unlikely to achieve middle-income status by the mid-21st century (World Bank 2025a).

The slowdown in growth may have significant implications for global food security and hunger, particularly in Africa and Asia. It is important to note that while hunger is increasing in Africa, it is not decreasing in Asia, which accounts for over half of the world's hungry population (FAO, IFAD, UNICEF, WFP, and WHO 2024). Climate change can potentially exacerbate this crisis. In the absence of climate change, projections indicate that global food demand may increase by 35–56% from 2010 to 2050. When considering climate change, the upper bound of food demand is projected to rise by 62%, with the risk of hunger increasing by 30% (van Dijk et al. 2021). In low-income and middle-income countries, 40% and 22% of the disposable income is allocated to food, respectively. These challenges necessitate large-scale efforts to promote growth and to adapt to climate change.

South Asia is home to a substantial population of individuals who face poverty and malnutrition. The region's agricultural systems, predominantly centered on cereal crops, face challenges of overextraction of groundwater resources and climate change. Projections suggest a shift in irrigation sources, with meltwater and groundwater expected to play an increasing role in supporting irrigated agriculture (Lutz et al. 2022). Unlike other regions, South Asia is expected to experience significant economic growth in the near future.

India is the largest economy in South Asia and is distinguished by its diverse and rapidly expanding market. Its economic growth has consistently surpassed that of most of the other countries in the region. India's economic influence extends beyond its borders, serving as a major trading partner for other South Asian countries and playing a pivotal role in regional economic cooperation. Nevertheless, India continues to face challenges, such as income inequality, infrastructure bottlenecks, and suboptimal nutritional and health outcomes. Advancing economic reforms remains crucial for sustaining its growth trajectory and fully realizing its potential as a regional economic powerhouse.

During the past five decades, India's agri-food system has undergone a substantial transformation. The consumption of nutrient-rich animal-source foods, fruits, and vegetables has significantly increased (GoI 2024a). Concurrently, the consumption of ultra-processed foods such as chocolates, sugar confectioneries, salty snacks, beverages, ready-to-eat meals, and breakfast cereals has increased. Following cereals and milk, snacks and prepared foods have the largest share of food expenditure. The share of the food budget allocated to highly processed packaged foods nearly doubled from 6.5 to 12 percent between 2015 and 2019 (IFPRI 2024). Such a shift in dietary patterns impedes government efforts to improve health outcomes.

Malnutrition has evolved from a dual-burden issue to a triple-burden challenge, now including micronutrient deficiencies, undernutrition, overnutrition, and obesity (Meenakshi 2016). The rising prevalence of overweight individuals has become a major public health issue, even in rural areas, while anemia has remained an unresolved problem for years. However, the nutritional quality of food remains inadequate. Individuals with limited financial resources may find it challenging to maintain a diet rich in fruits, vegetables, dairy products, and meat, as the cost per calorie of these foods has increased more rapidly than that of cereals.

Nutritional challenges have significant implications for agri-food system transformation. Over time, India's agri-food production system has transitioned from cereals to more diverse products including fruits, vegetables, milk, meat, and fish. This diversification not only enhanced farm income but also contributed to the reduction of poverty and malnutrition (Pal et al. 2020). Currently, the agricultural sector accounts for approximately 15% of the gross value added (GVA), with crops accounting for more than half (54%). Livestock and fisheries also have a substantial share (GoI 2024a). Between 2012-13 and 2022-23, the crop subsector experienced a modest annual growth rate of 2.1%, whereas livestock and fisheries achieved impressive growth rates of 7.6% and 8.9%, respectively. A significant proportion of the food produced is utilized in the food processing industry, with processed foods accounting for approximately 12% of the manufacturing value added (Grant Thornton 2024).

India's food system faces significant uncertainty. Crop yields of several staple crops, including coarse cereals, pulses, and oilseeds, remain significantly below the global average (GoI 2024b). Natural resources have been overexploited in several regions and efforts to address this issue have been largely unsuccessful. For example, approximately 25% of groundwater assessment units are classified as overexploited, critical, or semi-critical (GoI 2023), with the majority located in northwestern and southern parts of the country. Although numerous policy initiatives have been taken to regulate groundwater usage in the Green Revolution states of Punjab and Haryana, these measures have largely been ineffective (Kishore et al. 2024; Rosencranz et al. 2021).

Climate change poses a substantial threat to agricultural productivity. Since 1980-81, climate-related risks have reduced India's agricultural growth by 25% (Birthal et al. 2021a). Projections indicate that temperatures in India could increase by 1.1–5.1 °C by 2100, resulting in yield reductions in various crops ranging from 7 to 23% (Kumar et al. 2023; Birthal et al. 2021b)[1]. From a developmental perspective, sustained income growth is expected

[1] Temperature projections are based on the SSP5-8.5 scenario, while yield reductions are assessed using the RCP 8.5 scenario. Shared Socioeconomic Pathways (SSPs) explore potential global changes in societal, demographic, and economic dimensions over the next century. By the year 2100, five distinct pathways are envisaged. SSP1 represents minimal challenges in addressing socio-economic issues. SSP2 indicates moderate challenges, whereas SSP3 presents significant challenges in this regard. In SSP4, mitigation of challenges is relatively straightforward, but adaptation proves difficult, whereas in SSP5, the situation is reversed. Representative Concentration Pathways (RCPs) are climate change scenarios that delineate various potential future trajectories of greenhouse gas (GHG) concentrations and radiative forcing. The four principal RCPs are RCP2.6, RCP4.5, RCP6, and RCP8.5. RCP8.5 represents the highest emission scenario, which is projected to result in a global mean temperature increase exceeding 4 °C by 2100, characterized by escalating radiative forcing throughout the century. Conversely, RCP2.6 is the most optimistic scenario, endeavouring to restrict global warming to well below 2 °C above pre-industrial levels. RCP4.5, anticipates a stabilization of radiative forcing around 2040, with a global mean temperature increase of approximately 2 °C by 2100. RCP6 envisions the stabilization of radiative forcing after 2100, although it may involve temporary overshoots beyond 2 °C warming.

to increase India's per capita greenhouse gas emissions by 40% by 2030, thereby further affecting crop productivity (Karstensen et al. 2020).

The necessity to reform current food systems is evident, as implied by the hidden costs, amounting to US$ 1.5 trillion as reported by the FSEC (2023), arising from a combination of nutritional deficiencies and unsustainable agricultural practices. By enhancing labor productivity through healthier diets, minimizing environmental impacts, and reducing greenhouse gas emissions, these costs can be reduced by 25%, or approximately US$ 300 billion annually. Improving dietary habits by incorporating more fruits and vegetables could lead to better health outcomes, potentially reducing healthcare costs and increasing labor productivity. This transition could also stimulate job creation in the agricultural sector with an estimated 17 million new jobs in fruit and vegetable production. Furthermore, adopting more sustainable production practices could mitigate environmental impacts, including the reduction of greenhouse gas emissions from agriculture.

Understanding future food demand and supply is essential for shaping the future of the food, land, and water systems. This study addresses this need by offering comprehensive projections of India's food demand, differentiating between household and industrial demand across various economic growth scenarios: progressive, aggressive, and retreating. It also projects the production of various food commodities, considering climate change and technological advancements. The examination of trade potential in selected crops and the evaluation of environmental impacts, such as carbon and water footprints, highlight its importance in promoting a sustainable and resilient food system.

The remainder of this paper is organized as follows. Chapter 2 reviews recent advancements in India's agri-food systems and examines the developments from a resource perspective. Chapter 3 provides detailed projections of household and industrial (including service sectors) food demand by 2050, while Chapter 4 focuses on supply projections. Chapter 5 assesses the likely impacts of the carbon and water footprints. The concluding section summarizes the key findings and discusses governance and policy issues related to the transformation of the food, land, and water systems.

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2 Agriculture and Food System in India

Over the past two decades, food consumption patterns in India have undergone significant transformation. Consistent with Engle's and Bennett's laws, the increase in income levels and population growth has resulted in a reduction in household expenditure on food, and concurrently, there has been a growing preference for higher-value foods, including fruits, vegetables, dairy products, meat, fish, beverages, and processed foods. On the supply side, the agricultural sector effectively adjusted to this change in demand. The traditional farming system, which primarily focused on staple crops, has transformed into a diversified and export-oriented production system. Although agricultural exports have consistently exceeded imports, reliance on foreign sources for pulses and edible oils remains a significant challenge. Furthermore, from the perspective of consumption, production, and trade, resource management in the context of future climatic conditions remains a critical challenge for agricultural sustainability.

2.1 The shift in food demand

Staple foods, traditionally considered cost-effective sources of calories, are being increasingly replaced by nutrient-dense fruits, vegetables, and other alternatives. From 2000 to 2024, the share of food expenditure in total spending fell from 59% to 47% in rural areas, and from 48% to 40% in urban areas (GoI 2024c). The trend in cereal expenditures is particularly striking. In 2000, rural households spend 22% of their total budget on cereals, which dropped to 5% by 2024. In urban India, this share decreased from 12% to 4%.

Within the food basket, the proportion of expenditure on foodgrains, including cereals and pulses has declined in both rural and urban regions (Figure 2&3). While spending on edible oils, spices, sugar, salt, and dairy products has increased slightly, significant shifts have occurred in other high-value food items. The share of meat, fish, and eggs in total food spending increased from 6% to 10% in rural India and from 7% to 9% in urban India. Notably, spending on beverages and processed foods tripled from 7% to 21% in rural areas, and has more than doubled from 13% to 28% in urban areas. Notable changes were also observed in the consumption of fruit and vegetables.

Figure 2. Food expenditure shares on different items
(Rural India, 1999-00 -vs- 2023-24, %)

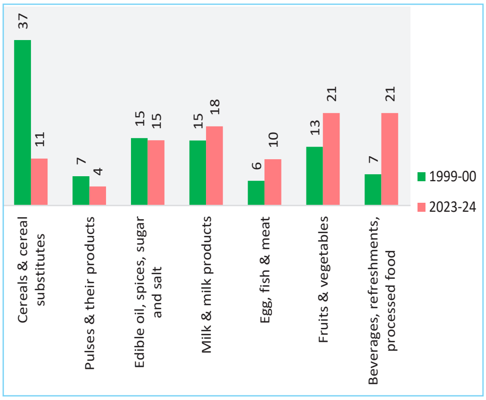
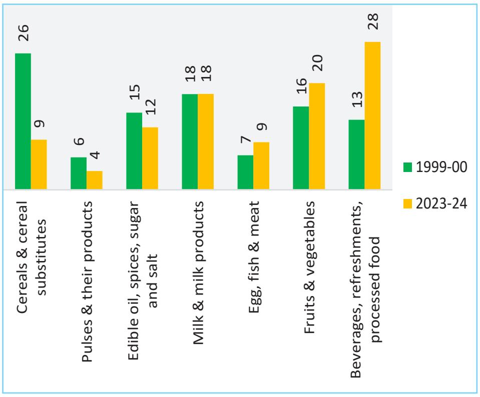


Figure 3. Food expenditure shares on different items
(Urban India, 1999-00 -vs- 2023-24, %)



With anticipated income and population growth in the coming years, the composition of food expenditure could further shift towards these high-value commodities. Meeting this demand would necessitate adjustments to food production, supply, and trade systems, potentially affecting the land and water systems in the future.

2.1.1 Two key drivers

Changes in food preferences can be largely attributed to rising income levels and population growth. In the early 1990s, India initiated a series of economic reforms, including trade liberalization by reducing import barriers and customs tariffs, currency devaluation, and opening domestic markets by minimizing licensing requirements for private sector investments, easing regulations, lowering corporate taxes, and dismantling public-sector monopolies. Consequently, the Indian economy embarked on a path toward higher and more sustainable growth. These reforms significantly accelerated economic growth to 6.3% per annum compared to the previously modest rate of approximately 3% (Figure 4).

Figure 4. Decadal growth in GDP (India, %, 1964-2023)

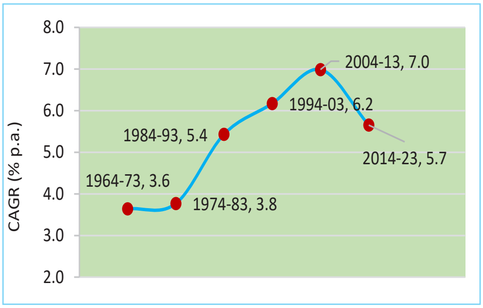
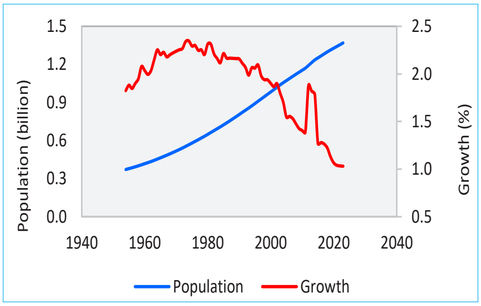


Figure 5. Population growth deceleration (1954-2023)



Population growth is another critical factor that contributes to increased food demand. At the time of independence, the population was 0.36 billion. By 1965, with the onset of the Green Revolution, it had risen to 0.47 billion. The spread of the Green Revolution and the subsequent increase in food supply led to further population growth (Figure 5). Between 1965 and 1990, the population grew at an annual rate of 2.2%. However, following the economic reforms, population growth began to decline. From 1991 to 2005, the growth rate decreased to 1.9%, and further to 1.3% during 2006 to 2023. In the last two years, the growth rate was only 1%. By 2023, the country's total population reached 1.4 billion. Projections suggest the population could reach 1.8 billion by 2050 with high fertility rates, or 1.7 billion with current fertility levels (UNDESAPD 2022). Meeting the food demand at this population level could be a formidable challenge.

2.1.2 Effect on food imports

The rising demand for food fueled by both income and population growth has led to a substantial increase in imports, even with improvements in agricultural productivity. The value of agricultural imports was Rs. 12 billion in 1991. Over the next decade, this figure surged tenfold to Rs. 121 billion in 2001, and further climbed to Rs. 511 billion by 2011. In TE 2023-24, agricultural imports are estimated at Rs. 2,481 billion. Table 1 presents the principal import items, along with their respective shares in total agricultural imports.

Table 1. Composition of agricultural imports, TE 2023-24

Item	Rs. billion	%
Vegetable oils	1,396	56.2
Pulses	208	8.4
Fresh fruits	198	8.0
Cashew	116	4.7
Spices	105	4.2
Alcoholic beverages	73	2.9
Cotton (raw incld. waste)	67	2.7
Sugar	66	2.7
Others	253	10.2
All	2,481	100.0

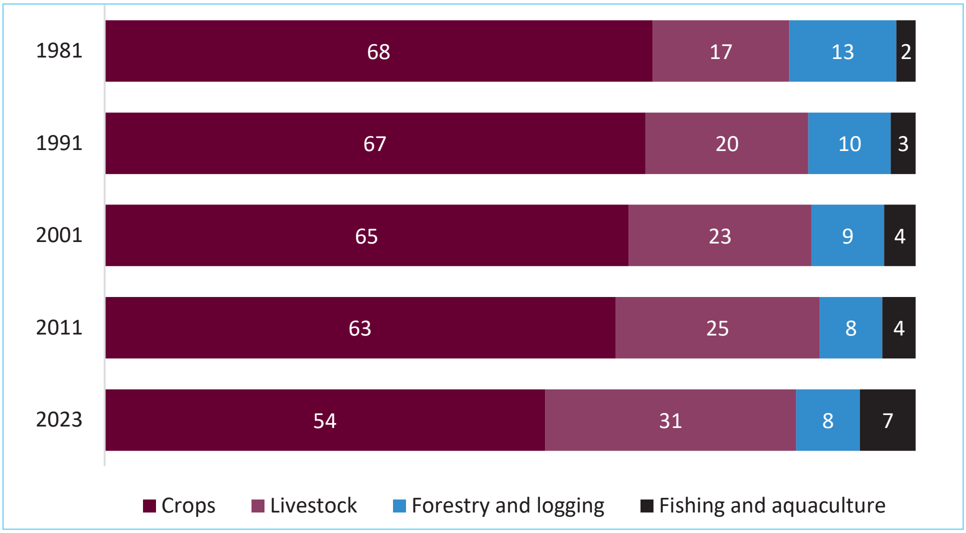
Source: Balaji & Saxena (2025).

Imports are concentrated in a few commodities, specifically vegetable oils, pulses, and fresh fruits (see Table 1). In TE 2023-24, vegetable oil imports reached Rs. 1,396 billion, accounting for over 56% of agricultural imports. Evidence indicates that tariff reduction has minimal influence on enhancing domestic oilseed production, thereby underscoring the necessity for more investment in agricultural research (Balaji et al. 2022). In TE 2023-24, pulses and fresh fruits were the other major imported products, costing Rs. 208 billion and Rs. 198 billion, respectively.

2.2 Agriculture's supply response

The agricultural sector has undergone significant changes since the Green Revolution, which has led to a rapid increase in food production. The success of the Green Revolution spurred similar transformative changes in the dairy industry, known as the "White Revolution," and in the fisheries subsector, referred to as the "Blue Revolution." Poultry farming has experienced substantial economic growth. Together, these revolutions have had a profound impact, driving the country into food self-sufficiency by the late 1980s and enhancing its ability to address unexpected threats to food security.

Figure 6. Sectoral composition of agricultural output (%), 1981-2023

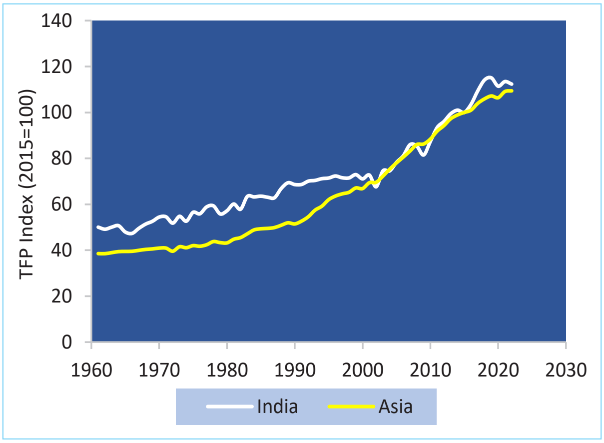


There has been a noticeable shift in agricultural production systems towards livestock and fisheries (Figure 6). The share of crops in the total value-added from agriculture decreased from 68% to 54% between 1981 and 2023. In contrast, the share of livestock nearly doubled from 17% to 31%. An analysis of growth patterns over the past decade (2012-13 to 2022-23) reveals a dynamic transformation within the agricultural sector. The crop subsector has experienced a modest annual growth rate of 2.1%. In contrast, livestock and fisheries showed remarkable growth rates of 7.6% and 8.9% per annum, respectively. Robust growth in livestock and fisheries can be attributed to factors, such as changing dietary preferences that favor protein-rich foods.

2.2.1 Driver of agricultural supply

Technological advancements have played a crucial role in boosting India's agricultural growth. Initially, the benefits of the Green Revolution were mainly observed in the northern regions, before spreading to other areas. Since then, productivity has been the main driver of holistic agricultural growth, with a significant shift from cereals to high-value crops in India's less-productive regions. Since the 1980s, two-thirds of agricultural productivity growth has been attributed to Total Factor Productivity (TFP) (Rada and Schimmelpfennig 2016; Dholakia and Dholakia 1993). Over the past two decades, TFP growth has accelerated compared with the earlier period (Figure 7).

Figure 7. Total Factor Productivity trend in Indian agriculture (1961-2022)



A closer examination reveals that crop yield growth was the primary contributor to growth in the 1980s, whereas diversification and terms of trade became more important in the 1990s (Joshi et al. 2006). Birthal et al. (2025a) observed that the contribution of prices to agriculture has significantly surpassed the contribution of technologies in the recent past. Balaji and Saxena (2025) show that the livestock subsector has contributed 47% of agricultural growth, and fruits and vegetables have contributed 40% of crop subsector output growth between 2012-13 and 2022-23.

2.2.2 A net-food exporter

Continuous improvement in agricultural productivity driven by technological advancements has significantly improved India's capacity to export food commodities. At the beginning of the economic reforms, the country exported agricultural commodities worth Rs. 60 billion in 1991. Today, this figure soared to Rs. 4.3 trillion. Key export items include marine products, rice (basmati and non-basmati), sugar, spices, and buffalo meat. India has adapted to the shift in global food demand (Table 2). In 2009-10, Indian basmati rice was in the highest demand, followed by marine products such as shrimp, raw cotton, oil meals, and spices. By 2022-23, exports of marine products surpassed those of basmati rice. The export of non-basmati rice exceeded that of basmati rice, influenced by the Covid-

19 pandemic and Russia-Ukraine conflict. Globally, sugar is the third most demanded commodity.

Table 2. Top-5 export destinations of selected agricultural commodities

Commodity	Export destinations	
	2009-10	**2023-24**
Non-basmati rice	Saudi Arabia (14%)	Benin (11%)
	Maldives (12%)	Guinea (8.2%)
	UAE (11%)	Togo (6.1%)
	Malaysia (10%)	Vietnam (5.8%)
	Nepal (8.5%)	Cote D Ivoire (5.4%)
Sugar	Malaysia (19%)	Sudan (18%)
	Maldives (17%)	Sri Lanka (8.8%)
	Sri Lanka (15%)	Libya (8.2%)
	USA (5.9%)	Somalia (7.1%)
	UAE (5.8%)	Djibouti (7.0%)
Pulses	Pakistan (23%)	Bangladesh (24%)
	Sri Lanka (14%)	UAE (12%)
	Algeria (12%)	China (9.3%)
	Turkey (11%)	USA (9.0%)
	UAE (8.9)	Sri Lanka (5.1%)

Source: GoI (2024d).

India has also broadened its range of export destinations. Table 2 lists the export destinations of the selected commodities. In 2009-10, Asian countries, including Saudi Arabia, the Maldives, the UAE, Malaysia, and Nepal, were the primary markets for non-basmati rice exports. Currently, the trend has shifted towards African countries, such as Benin, Guinea, and Togo. Similarly, sugar exports have increasingly targeted African countries including Sudan, Libya, Somalia, and Djibouti. While pulses were predominantly exported to Pakistan and Sri Lanka, recent trends have indicated a focus on Bangladesh and the UAE. Similar trends were observed for the other commodities.

2.3 Labor market transition

Changes in food demand and the corresponding adjustments in food supply have significantly shaped the composition of both farm and nonfarm labor markets. According to population census estimates, 70% of the workforce was engaged in agriculture in 1951 (Table 3). This proportion remained stable for the next two decades but declined to 61% in 1981, 59% in 1991, and 55% in 2011. By 2024, this figure had further decreased to 46%.

Table 3. Shift in farm-nonfarm labor market composition in India, 1951-2024

Year	Workforce (%)			Farm labor market (%)		
	Farm sector	Nonfarm sector	Total	Farmers	Laborers	Total
1951	70	30	100	72	28	100
1961	69	31	100	76	24	100
1971	70	30	100	62	38	100
1981	61	39	100	63	38	100
1991	59	41	100	60	40	100
2001	58	42	100	54	46	100
2011	55	45	100	45	55	100
2024*	46	54	100	46	54	100

Source: Estimated based on GoI (2024b).
Note: Estimates for 2024 are based on GoI (2024e).

Within the farm sector, there was a marked shift towards casualization among cultivators and agricultural laborers. In 1951, approximately 72% of agricultural workers were landowning farmers, while only 28% were wage laborers. The 1950s was the only decade that saw an increase in the proportion of farmers, reaching 76% by 1961, with less than one-fourth being wage laborers. However, the share of farmers has declined, reaching 46% by 2024.

The transition from agricultural to non-agricultural employment is a hallmark of structural transformation. However, the sustained decrease in the proportion of individuals engaged in farming over several decades suggests the role of push factors within the agricultural sector, such as drought and low economic returns. However, agricultural productivity continues to increase. Balaji and Babu (2020) reported that over 52 million workers exited agriculture between 2006 and 2016, without adversely affecting agricultural output due to productivity gains. They further observed that the inter-sectoral labor shift increasingly contributes to economic growth.

Nonetheless, a significant challenge persists, as there remains a surplus of labor in agriculture, particularly among small-farm families, and employment guarantee programs have had limited success in addressing underemployment (Sekhar and Thapa 2023). Wages in agriculture have increased, particularly as both farmers and workers move away from the agricultural sector, leading to a gap between productivity and wages (Balaji and Pal 2021). In summary, wages in the agricultural sector surpass labor productivity, which is further intensified by the prolonged increase in labor demand within the construction industry. The disparity between productivity and wages, in conjunction with an excess of labor, reduces the benefits derived from agricultural activities.

2.4 Challenges to food production

The transformation of food systems is impeded by structural factors that subsequently exert pressure on both natural and human resources, thereby influencing agricultural growth. In India, the productivity of several key crops, including staples, coarse cereals, pulses, and oilseeds, remains below the global average (GoI 2024b). Among natural resources, land, water, and energy are particularly critical, especially considering the projected future demand for food. Climate change and trade instability – global factors – necessitate efficient management of these resources.

2.4.1 The land constraint

Land use statistics indicate that the proportion of agricultural land in the total reported area has remained relatively stable over several decades at approximately 60% (GoI 2024f). This implies a limited scope for farmland expansion. Nevertheless, the proportion of net cropped area in the agricultural land has increased marginally from 83.19% in 1970-71 to 85.68% in 2022-23. Projections indicate that agricultural land can decrease by 4 million hectares and the net sown area by 3 million hectares by 2047-48, from 2022-23 levels (Birthal et al. 2025a).

This situation necessitates more intensive farming. Of the 141 million hectares sown in 2022-23, 56% were cultivated more than once, resulting in a cropping intensity of 156%. Concurrently, the increase in the farming population has led to a reduction in the average size of cultivated land, thereby constraining investment and mechanization. The average size of landholdings in India has decreased from 2.28 hectares in 1970-71 to 1.08 hectares currently, with approximately 70% of these holdings being less than one hectare. By 2047-48, average size of landholding is projected to decline to 0.6 hectare (Birthal et al. 2025a).

Securing stable income for smallholder farmers will continue to be a significant challenge. Between 2012-13 and 2018-19, farmers' income rose by 3% annually in real terms (Chand et al. 2015; Saxena et al. 2023). Regional income disparities persist across states and districts (Balaji and Gopinath 2023). However, farm income, which includes both crops and livestock, has converged across districts in recent years, albeit at a much lower rate (<1%), especially among low-income farmers. The main factors that drive convergence are irrigation, agricultural diversification, and market access. Notably, farmers in the middle of income hierarchy tend to benefit more from these trends than the wealthiest and poorest farmers (Balaji and Gopinath 2023).

Nevertheless, when evaluated in terms of labor productivity, this trend is not reflected because of the greater pressure of employment on small farms (Balaji and Pal 2014). Farmers have diversified their income sources in response to the land constraints. The slow growth in farm income, coupled with the small farm size, has led many farm households to increasingly rely on wage labor. Consequently, wage earnings now constitute 40% of farmers' total income, surpassing income from crops (37%) and livestock (15.5%).

2.4.2 The water constraint

Globally, the effective management of irrigation water remains a crucial issue for advancing agriculture (Lele 2021). In India, since independence, significant investments have been made in irrigation coverage, with irrigated land expanding from 23 million hectares in 1951 to 120 million hectares by 2022. In the 1950s and the 1960s, canals and tanks were the primary sources of irrigation, with canals designed to supply water to a single crop annually (Mukherji 2022). Investment in irrigation facilitates multiple cropping systems. Over time, canals have been insufficient to fully meet irrigation water demands because of their inadequate maintenance.

The late 1960s and the 1970s saw a shift from public to private irrigation with groundwater emerging as the predominant source. The proportion of net irrigated areas using groundwater increased from 34% in 1967 to 60% in 2022. Groundwater is used for irrigation in several regions. Approximately 25% of the assessment units are classified as overexploited, critical, or semi-critical (GoI 2023), primarily in the northwestern and southern regions. Overexploitation disrupts ecological balances and imposes financial burdens on farmers, leading to socioeconomic disparities in distribution (Sarkar 2011). Projections show that the irrigation water demand could be higher by 18% in 2047-48 over the present level. However, evidence indicates that irrigation development is unsustainable. Climate change is expected to further impact India's hydroclimatic system in the coming decades (Shah 2013). As 55% of the cultivated area is dependent on rainfall, the complexity of irrigation management has increased.

Achieving sustainability requires balancing the irrigation water supply and demand through technological and policy interventions. Sprinkler irrigation can conserve 15-20% of water, whereas drip irrigation saves 40-60% compared to traditional flood irrigation. Micro-irrigation also conserves fertilizers, enhances productivity, expands irrigated areas, promotes crop diversification, and increases incomes. However, the adoption of micro-irrigation systems remains limited, with significant variations across states. In 2023, only 17.6% of the potential area was covered by micro-irrigation.

2.4.3 Energy requirement

Energy is an essential component of groundwater management. There is a strong push to shift towards renewable energy sources, with a particular focus on solar energy, to power irrigation pumps. The implementation of solar-powered irrigation systems can enhance economic access to irrigation, lessen dependence on subsidies, and aid decarbonization. Currently, solar energy is underutilized in micro-irrigation, accounting for only 2.6% of the irrigation energy mix. Both micro-irrigation and conversion of diesel/electric wells to solar power have the potential to reduce greenhouse gas emissions.

At present, micro-irrigation conserves 11.22 BCM of groundwater, and with an annual growth rate of 7%, its full potential can be achieved by 2049, leading to the conservation of 65 BCM of groundwater. This would enable the irrigation of an additional 33 million hectares. Similarly, converting diesel/electric wells to solar power reduces CO_2 emissions by 1.05 million tons annually. This reduction could increase to 45 million tons if all such wells were solarized, requiring an annual growth of 14.9% in solar pump adoption by 2050 (Srivastava et al. 2024).

2.4.4 Climate change

Climate-smart agricultural practices offer considerable potential for mitigating the production risks encountered by farmers, with evidence indicating a reduction of 12–25% (Pal et al. 2022). Measures such as crop diversification, improved water management, and soil conservation not only help farmers adapt to climate change but also contribute to the reduction of greenhouse gas emissions. Importantly, the bundled application of these methods has a more significant impact on productivity and resilience (Birthal et al. 2021c). Additionally, a national crop insurance program has been established that currently provides coverage for only one-third of the cultivated area.

The widespread adoption of climate-smart practices and insurance has been hindered by the farmers' limited access to financial resources. Evidence has shown that financial access is crucial for enhancing productivity and resilience in agriculture (Birthal et al. 2025b). While irrigation boosts agricultural productivity and resilience, declining groundwater levels, especially in Punjab and Haryana, raise significant concerns about the long-term sustainability of water resources. Indeed, the benefits of irrigation have slowed (Birthal et al. 2015; Birthal et al. 2021d). Despite various policy initiatives aimed at regulating groundwater use, these efforts have been ineffective (Kishore et al. 2024; Rosencranz et al. 2021).

2.4.5 Food trade and geopolitical risks

Trade policies significantly affect global crop yields, production, and consumption, varying by region. Wiebe et al. (2015) note that while the effects of climate change on agricultural outcomes are consistent across shared socioeconomic pathways worldwide, they differ when trade policy changes are factored in. India's food trade with other countries is often considered unstable. To control inflation, India frequently imposes export bans on key commodities, such as rice, wheat, sugar, and onion.

For instance, on September 8, 2022, India banned the export of broken rice in order to curb food inflation. Following heavy rainfall and crop damage, it prohibited non-basmati white rice exports in July 2023, and levied a 20% duty on parboiled rice shipments in August 2023. In September 2024, a minimum export price (MEP) of Rs 42,679/mt (US$490) was set for non-basmati white rice owing to overflowing granaries and an expected bumper harvest from the upcoming *Kharif* crop.

These restrictions often disrupt stable trade policies and worsen food insecurity in importing countries. Before these restrictions were imposed, African countries secured nearly half of their rice imports from India. In 2022, Indian rice accounted for over 60% of rice imports in 17 African countries and exceeded 80% in nine of these nations. Africa accounted for 65% of India's non-basmati white rice exports (excluding parboiled rice), and 75% of its parboiled rice exports. From September 2022 to August 2023, India's rice exports to Africa fell by 5.3 million tons, a 43% drop compared to the previous year, making up 75% of the total global reduction in India's rice exports. This supply disruption and the resulting price increase in importing countries significantly affects food security, especially in poor countries. Although stable trade policies can be beneficial in the long term, their unpredictable effects can hinder the transition of food systems, particularly if adequate measures are not implemented. External conflicts, such as the Russia-Ukraine war, further destabilize agri-food systems, especially in developing countries, including India (Arndt et al. 2023).

♦♦♦

3 What India will Consume and How Much?

The demand for 40 distinct food commodities or groups was projected. These include cereals, pulses, edible oils, fruits, vegetables, milk, meat, and fish, with each group including essential food items[2]. Food demand is calculated as the sum of the demand for each commodity from two sources: (i) households, and (ii) the rest of the economy, which includes demand from processed foods, other manufacturing industries, restaurants, and service sectors, including public administration. The first stage involves projecting household food demand, which requires projections of the population and income per capita until 2050. Population projections were sourced from the United Nations World Population Prospects 2022 (UNDESAPD 2022), while income per capita estimates were derived using the standard neoclassical growth model. In the second stage, household-level demand estimates are incorporated into a Social Accounting Matrix (SAM)-based multiplier framework.

3.1 Growth scenarios

Projections of per capita income growth and the corresponding household and total food demand estimates were developed for three distinct economic growth scenarios: progressive, aggressive, and retreating.

The progressive growth (PR) scenario assumes that the economy continues to grow, building on past momentum, and remains resilient to climate change, trade, and geopolitical disruptions. Physical and human capital are expected to increase steadily, fostering an environment that is conducive to innovation. Population growth is projected to decelerate with a medium fertility rate, and the labor market is expected to provide ample employment opportunities, particularly for women.

In the aggressive growth (AG) scenario, economic growth is expected to accelerate and deviate from past trends. The economy is presumed to adapt to and manage external and internal shocks. Investment rates are anticipated to be higher than those in the PR scenario, thereby ensuring

[2] Projections reported are for TE 2050 (including supply and trade). For simplicity, it is referred as 2050 throughout the study.

greater economic growth. Innovation is anticipated to fuel economic expansion by increasing investment in human capital and maintaining population growth at low fertility rates. The labor market is presumed to approach full employment, with higher participation rates for women.

Table 4. Assumptions on general features of future income

Growth Scenarios		
Progressive growth (PR)	**Aggressive growth (AG)**	**Retreating growth (RT)**
The economy experiences gradual and consistent growth, demonstrating resilience against both internal and external disruptions, which fosters stable investments.	The economy experiences more robust and rapid growth, effectively adapting to and managing disruptions. Investor confidence surges, leading to a higher rate of investment.	The economy becomes susceptible to both external and internal shocks, making it difficult to maintain consistent growth. Investment levels decline as growth becomes less predictable.
Investment ecosystem attracts both physical and human resources sustainably, creating a more favorable environment for innovation.	Private investors engage actively, channelling funds into advanced technologies and high-skill human resources. Innovation serves as a catalyst for growth.	Households reduce their spending on goods and services, opting to save more money instead. Private entrepreneurs hesitate to invest due to a decrease in demand.
Population growth occurs at a slower pace, maintaining a moderate fertility rate. The labor market improves, offering better employment opportunities, and there is an increase in female participation in the workforce.	Population growth decelerates and turns negative. The labor market approaches full employment, with women actively participating in the workforce.	The population increases as fertility rates rise, driven by the hope of securing income. The labor market attracts fewer workers and utilizes less capital, while skill development declines.

The regressive growth (RT) state is characterized by a deceleration in growth. In contrast to previous scenarios, we posit that global and domestic shocks related to climate, trade, and geopolitics impede growth progress, resulting in a slowdown. Consequently, private investment levels are expected to decline and household spending is anticipated to decrease due to income uncertainty. A constant fertility rate is presumed to drive population growth and unemployment is expected to be prevalent.

These behavioral traits are captured in the parameters determining income per capita growth, and scenario-specific parameters are integrated into the growth model to reflect these assumptions. Table 4 lists the general characteristics of the three scenarios. The parameters specific to each scenario that form the basis for the per capita growth projections (discussed in Section 3.2.1) are displayed in Appendix I.

3.2 Method for estimation of demand

3.2.1 Income per capita projections

The present study follows the specification mentioned in Loayza and Pennings (2022) to project the income per capita in 2050. A standard neoclassical growth model of the following form was used:

$$Y_t = A_t K_t^{1-\beta}(h_t L_t)^{\beta} \quad \text{----------- (1)}$$

where Y_t is GDP, A_t is total factor productivity, K_t is capital stock, and $h_t L_t$ is *effective* labor used in production, which can be decomposed as h_t human capital per worker and number of workers. L_t can be decomposed further into $L_t = \rho_t \omega_t N_t$, where ρ_t is the labor market participation rate, and ω_t is the worker population rate. β is the labor share.

Following the above, GDP per worker can be written as

$$y_t = A_t \rho_t \omega_t k_t^{1-\beta} h_t^{\beta} \quad \text{----------- (2)}$$

and GDP growth per worker as

$$\frac{y_{t+1}}{y_t} = \frac{A_{t+1}}{A_t}\left[\frac{k_{t+1}}{k_t}\right]^{1-\beta}\left[\frac{h_{t+1}}{h_t}\right]^{\beta} \quad \text{----------- (3)}$$

Rewriting in terms of growth, GDP per capita growth is estimated as

$$1 + g_{y,t+1}^{pc} = [1 + g_{w,t+1}][1 + g_{\rho,t+1}][1 + g_{y,t+1}] \quad \text{-------- (4)}$$

Using 2022 as a reference year, for which most data points are available, projections for income per capita growth are projected for 2050. A comprehensive explanation of the neoclassical specifications provided in Appendix II.

3.2.2 Household food demand

Using the projected per capita income (section 3.2.1) and the population growth (UNDESAPD 2022), household food demand is estimated by multiplying the change in income per capita by the commodity-specific expenditure elasticities of demand. The commodity-specific household food demand is modelled as

$$D_{c,t+1} = D_{c,t} * N_t\left(1 + \frac{y_{t+1}^{pc}}{y_t^{pc}} * e_c\right) \quad \text{----------- (5)}$$

where $D_{c,t+1}$ is the demand *D* for commodity *c* in year *t+1*, N_t is the population in year *t*, y_{t+1}^{pc}/y_t^{pc} is income (GDP) percapita growth between

$t+1$ and t, and e_c is the income elasticity of demand for commodity c. Elasticities were obtained from studies listed in the GoI (2024g). Additional methodological details are provided in Appendix III, and the elasticities selected for this study are presented in Appendix IV.

3.2.3 Total food demand

A Social Accounting Matrix (SAM)-based multiplier analysis is used to project food demand. This study employed the SAM developed by the International Food Policy Research Institute (IFPRI), which adopts a nexus approach (IFPRI 2021). The matrix corresponds to 2019. It encompasses 39 sectors related to agriculture and allied activities, 18 sectors for agro-processing, four sectors for mining, 24 sectors for manufacturing, four sectors for construction and utilities, and 23 sectors for services. The primary inputs include land, labor, and capital, with labor and capital further divided into eight and four types, respectively[3]. Households in rural areas were categorized as either farm or non-farm, whereas urban households were identified separately. Each household type was further subdivided into five categories based on per capita expenditures quintiles.

The household food demand projections obtained earlier are introduced as exogenous shocks in the final demand vector. The total demand for each food item or group is estimated using:

$$\Delta X = (I - M)^{-1} * \Delta H \text{ ---------- (6)}$$

where ΔX is the change in total amount of output that must be produced by 2050, ΔH is the change in household food demand between 2022 and 2050 in real terms, and M is the coefficient matrix capturing the linkage effects. Appendix V provides the foundational principles of the circular economy model and a comprehensive explanation of the multiplier approach.

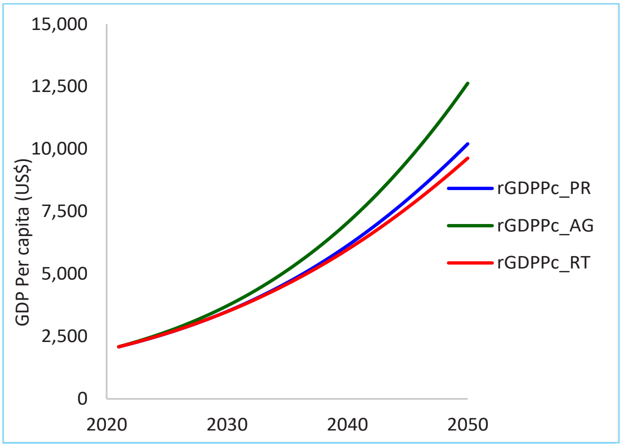
3.3 Income per capita in 2050

India could be closer to attaining the status of a developed nation by 2050 if it adopted an aggressive growth strategy. A nation is classified as developed (high-income) when its gross national income (GNI) per capita is more than US$ 13,935 (World Bank 2024a). Our projections indicate that India's GDP per capita will reach US$ 12,631, close to the benchmark (Figure 8). Achieving

[3] Total labor is classified under eight categories based on their literacy levels and state of residence viz., rural uneducated, rural primary, rural secondary, rural tertiary, urban uneducated, urban primary, urban secondary, and urban tertiary. Total capital is classified as crops, livestock, mining, and others.

this milestone requires pursuing an aggressive growth trajectory, focusing on investment rates, technological advancement, human capital, and employment, as detailed in Appendix I. However, if the economy follows a more moderate growth path, it may achieve a per capita income of US$ 10,207. If economic growth is hindered by challenges such as climate shocks, trade, and geopolitical risks, projections indicate that per capita income could fall to US$ 9,634.

Figure 8. Income per capita projections (2022-2050)



Note: rGDPPc is real GDP per capita (at constant 2015 US$); PR, AG, and RT are the progressive, aggressive, and retreating growth scenarios, respectively.

The World Bank (2025b) projected that India's estimated GNI per capita by 2047 should be US$ 20,000 under an accelerated reforms scenario in current prices, which, in real terms, is equal to US$ 15,406. The deviations of our estimates from those of the World Bank are due to differences in the growth model's assumptions. Similarly, Behera et al. (2023) provided a roadmap for India attaining a developed country status by 2047-48, considering factors such as labor hours and quality, Information and Communication Technology (ICT), non-ICT, and TFP, and projects real GDP growth paths until 2047-48. Our growth projections are supported by international and domestic estimates; further details are available in Appendix VI.

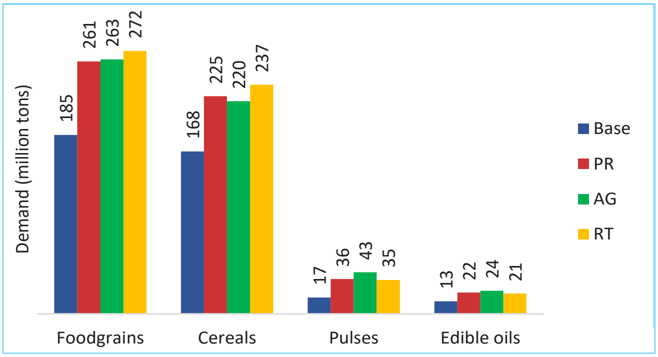
3.4 Household food demand to 2050

3.4.1 Foodgrains and edible oils

In 2022, household demand for food grains was estimated to be 185 million tons (Figure 9). Of these, 91% were cereals, with rice and wheat accounting for 93% of total cereal demand. Specifically, the demand for cereals, rice, and wheat was 168, 86, and 71 million tons, respectively (Table 5). The household demand for pulses was 17 million tons. If the economy experiences progressive growth, the demand for food grains is expected to increase to 261 million tons by 2050. In a scenario of aggressive growth, demand is projected to be slightly higher, at 263 million tons. Conversely, in the retreating growth state, the projected demand is higher than in the progressive and aggressive states, reaching 272 million tons.

Income effects largely explain the reduced demand for cereals during periods of rapid growth and the increased demand during slower growth states. In the former situation, as household incomes rise significantly, there is a tendency to consume more nutritious, high-value foods such as fruits, vegetables, milk, meat, and fish. Conversely, in the latter situation, with slower income growth, the opposite holds true. This shift is clearly reflected in the projected demand for rice and wheat, which are the primary staples.

Figure 9. Projected household demand for food grains & edible oils in 2050



Note: PR, AG, and RT are as mentioned in Figure 8.

The demand for pulses is expected to rise significantly by 2050, with projections indicating an increase from 106% to 153% compared to 2022. Specifically, the anticipated demand growth for Bengal grams, red grams, black grams, green grams, and lentils is 148%, 140%, 150%, 138%, and 145%, respectively. This suggests a strong future demand for pulses, primarily to fulfill protein requirements, as current consumption levels do not meet the recommended standards. In a scenario where the country still relies on imports for pulses, particularly lentils, the projected surge in household demand necessitates appropriate policy intervention.

Table 5. Projections of household demand for specific items of foodgrains, edible oils, and sugar in 2050 under various growth scenarios (million tons)

S.N.	Food item	Household demand, 2050			
		2022	PR	AG	RT
1	Rice	86.0	115.0	112.0	124.0
2	Wheat	71.0	95.0	93.0	102.0
3	Sorghum	2.8	3.8	4.1	3.7
4	Pearl millet	3.0	4.0	4.3	4.0
5	Corn	1.4	1.9	2.0	1.8
6	Bengal gram	2.5	5.4	6.2	5.2
7	Red gram	5.0	11.0	12.0	10.0
8	Black gram	1.8	3.9	4.5	3.7
9	Green gram	2.1	4.3	5.0	4.2
10	Lentils	2.2	4.7	5.4	4.5
11	Groundnut oil	0.9	1.6	1.8	1.5
12	Mustard oil	5.1	8.5	10.0	8.3
13	Soybean + Sunflower oil	5.0	8.4	9.4	8.2
14	Sugar	12.0	20.0	23.0	19.0

Note: PR, AG, and RT are as mentioned in Figure 8.

Projections suggest that the demand for edible oil increases with increasing income levels and declines if income decreases. Households consumed 13 million tons of edible oil in 2022 (Figure 9). Mustard oil constituted 39% of household demand, while soybean and sunflower oils together accounted for another 38%. Groundnut oil, another significant edible oil, accounts for 7% of the demand. By 2050, the household demand for edible oil will increase by 69% over 2022 in PR, 85%, and 62% in the AG, and RT growth scenarios, respectively. The highest demand growth for different types of edible oils is projected in AG: 100% for groundnut oil, 96% for mustard oil, and 88% for soybean and sunflower oils.

3.4.2 Sugar

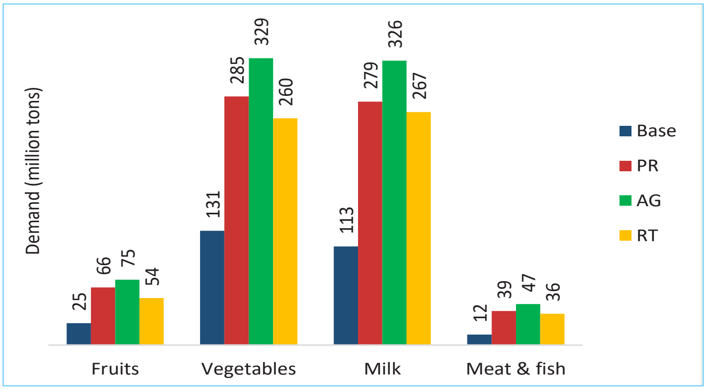
By 2050, household demand for sugar is projected to increase by 58% to 92%. In 2022, the estimated household demand for sugar was 12 million tons. This demand is anticipated to rise to 20 million tons under the progressive growth scenario, to 23 million tons under the aggressive growth scenario, and to 19 million tons under the regressive growth scenario.

3.4.3 High-value foods

The household demand for fruits and vegetables is expected to increase considerably. In 2022, it was estimated to be 25 million tons for fruits (Figure 10), which is projected to increase by 2050 to 66 million tons in PR, 75 million tons in AG, and 54 million tons in the RT growth scenarios. These figures represent increases of 164%, 200%, and 116%, respectively, over the 2022 levels. The projected demand for individual fruits is presented in Table 6.

The household demand for vegetables was 131 million tons in 2022. The projections for 2050 are 285 million tons in the PR, 329 million tons in the AG, and 260 million tons in the RT scenario. Potatoes, onions, and tomatoes are

Figure 10. Projected household demand for high-value food-groups in 2050



Note: PR, AG, and RT are as mentioned in Figure 8.

essential vegetables, and their demand in 2022 were estimated at 33, 18, and 11 million tons, respectively. Projections suggest that demand could reach 85 million tons for potatoes, 66 million tons for onions, and 20 million tons for tomatoes.

The household demand for milk in 2022 was 113 million tons. By 2050, this demand is expected to rise to 279, 326, and 267 million tons under the PR, AG, and RT growth scenarios, respectively. The demand for meat, including chicken, mutton, and beef, was estimated 5.3 million tons in 2022. Specifically, households demanded 3.6 million tons of chicken and 1.7 million tons of mutton and beef. Projections indicate that the demand for chicken will reach 13 million tons in PR, 16 million tons in AG, and 12 million tons in the RT growth scenarios. For beef and mutton, the projected estimates were 4.0, 5.3, and 3.9 million tons, respectively.

Table 6. Projections of household demand for specific high-value food items in 2050 under various growth scenarios (million tons)

S.N.	Food item	Household demand, 2050			
		2022	PR	AG	RT
1	Banana	12.0	25.0	28.0	21.0
2	Mango	3.6	10.0	11.0	7.7
3	Orange	2.5	6.5	7.5	5.3
4	Lemon	3.3	4.7	5.1	4.3
5	Potato	33.0	63.0	85.0	58.0
6	Onion	18.0	56.0	66.0	49.0
7	Tomato	11.0	18.0	20.0	17.0
8	Egg plant	6.7	8.9	9.4	8.5
9	Cauliflower	5.6	12.0	14.0	11.0
10	Milk	113	279.0	326.0	267.0
11	Fish + prawn	6.7	22.0	26.0	20.0
12	Mutton	0.9	2.2	2.9	2.1
13	Chicken	3.6	13.0	16.0	12.0
14	Beef	0.8	1.8	2.4	1.8

Note: PR, AG, and RT are as mentioned in Figure 8.

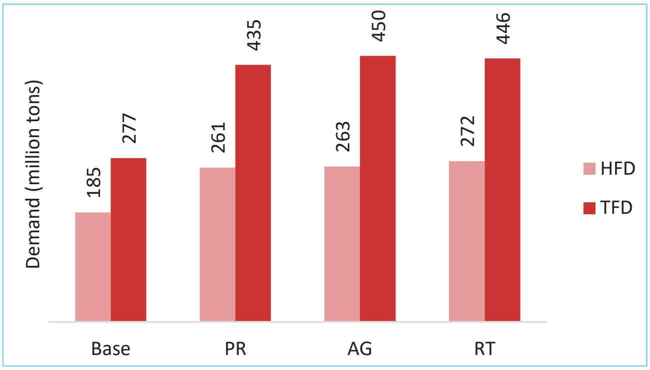
The combined household demand for fish and prawns was estimated at 6.7 million tons in 2022. It is projected to increase to 22 million tons by 2050 under the PR scenario, 26 million tons under the AG scenario, and 20 million tons under the RT scenario. In short, compared to cereals, pulses, and edible oils, household demand would be considerably higher for fruits, vegetables, milk, meat, and fish, in principle, through Engle's and Bennett's laws, triggered by the increase in population and income growth.

3.5 Total food demand by 2050

3.5.1 Foodgrains

By 2050, the total demand (TFD) for foodgrains is anticipated to reach 435 million tons under the PR scenario (Figure 11). Household demand (HFD) is expected to constitute 60% of this total, with the remainder arising from the industrial and service sectors and excluding exports. Under the AG scenario, total demand will increase by an additional 15 million tons. Conversely, if economic growth decelerates (RT), demand could increase by 11 million tons above the level projected under the PR scenario. In the AG and RT scenarios, household consumption is expected to account for 58% and 61% of the total demand, respectively.

Figure 11. Projected total demand for foodgrains in 2050

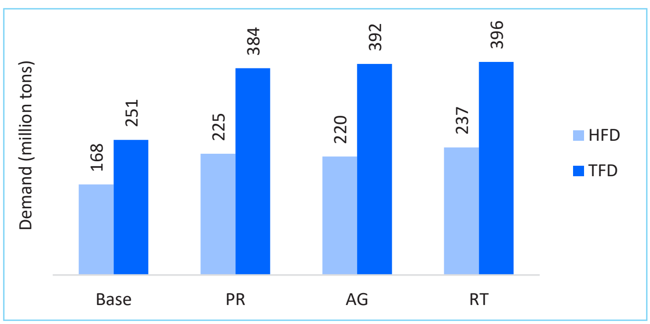


Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are household and total food demands, respectively.

3.5.2 Cereals

By 2050, the total demand for cereals is projected to reach 384 million tons under the PR scenario, 392 million tons under the AG scenario, and 396 million tons under the RT scenario (Figure 12). The total demand for rice is anticipated to be 124 million tons in the PR scenario, 122 million tons in the AG scenario, and 135 million tons in the RT scenario (Table 7). The total demand for wheat is expected to be 130, 115, and 126 million tons, respectively. Consequently, rice's share of total cereal demand could range from 31% to 34%, whereas wheat's share is expected to range from 29% to 34% of the total cereal demand.

Figure 12. Projected total demand for cereals in 2050

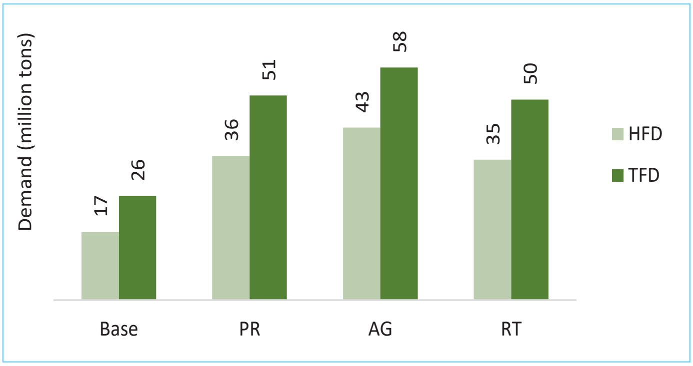


Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

3.5.3 Pulses

By 2050, the total demand for pulses is expected to double the current level (Figure 13). Under the PR scenario, the country will require approximately 51 million tons of pulses. However, if growth accelerates, demand may increase by an additional seven million tons, whereas a slowdown in growth could result in a decrease of one million tons. Pulses are anticipated to constitute 11%–13% of the total foodgrain demand. The relatively stable ratio of cereals to pulses in the overall foodgrain demand indicates a need for further examination of protein intake levels in relation to recommended standards.

Figure 13. Projected total demand for pulses in 2050

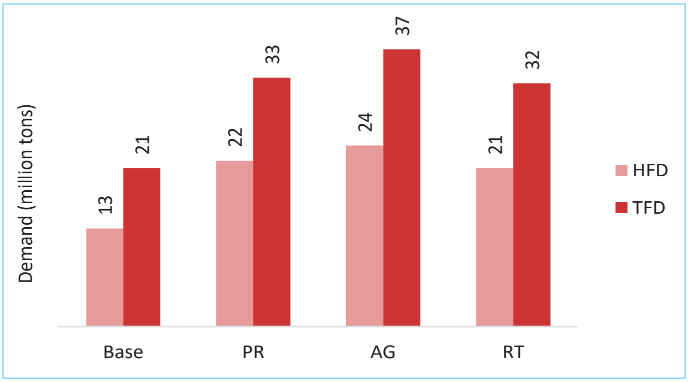


Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

3.5.4 Edible oils

By 2050, the total demand for edible oils is projected to reach 37 million tons under the AG scenario, signifying a 76% increase from the 2022 level (Figure 14). Mustard oil is expected to comprise 39% of the total demand, whereas soybean and sunflower oils collectively account for an additional 38%. The remaining demand is expected to be met by groundnut and palm oil. It is noteworthy that households consume 65% of the total edible oil, with the remainder utilized by industries.

Figure 14. Projected total demand for edible oils in 2050



Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

In 2022, households accounted for 62% of the total consumption of edible oils. This proportion is predicted to increase to 67% by 2050 under the PR scenario and 65% under the AG and RT scenarios.

Table 7. Projections of total demand for specific items of foodgrains, edible oils, and sugar in 2050 under various growth scenarios (million tons)

S.N.	Food item	Total demand, 2050			
		2022	PR	AG	RT
1	Rice	104.0	124.0	122.0	135.0
2	Wheat	101.0	130.0	115.0	126.0
3	Sorghum	4.0	6.3	6.8	6.2
4	Pearl millet	4.3	6.8	7.3	6.7
5	Corn	27.0	93.0	118.0	91.0
6	Bengal gram	3.5	7.6	8.5	7.3
7	Reg gram	7.1	15.0	17.0	15.0
8	Black gram	2.8	5.4	6.1	5.3
9	Green gram	3.0	6.3	7.2	6.2
10	Lentils	3.1	6.6	7.5	6.4
11	Groundnut oil	1.5	2.3	2.6	2.3
12	Mustard oil	8.2	12.9	14.4	12.6
13	Soybean + Sunflower oil	8.1	12.7	14.2	12.4
14	Sugar	28.0	47.0	49.0	42.0

Note: PR, AG, and RT are as mentioned in Figure 8.

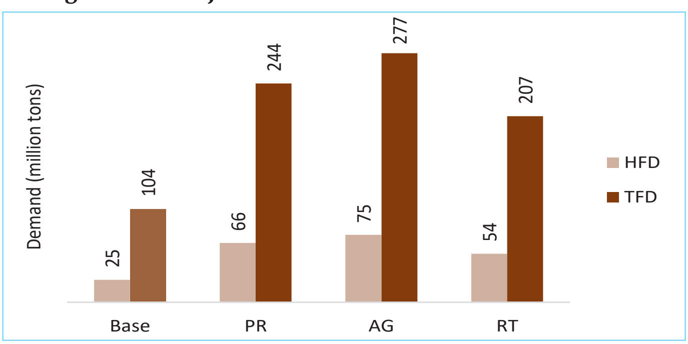
3.5.5 Sugar

In 2022, the total demand for sugar was estimated at 28 million tons. This demand is projected to increase to 47, 49, and 42 million tons in the PR, AG, and RT scenarios, respectively. In 2022, the non-household segment accounted for 57% of total sugar demand. While this proportion is expected to remain unchanged in 2050 under the PR scenario, it may decrease to 53% in the AG scenario and 55% in the RT scenario.

3.5.6 High-value foods

By 2050, the demand for both fresh and dried fruits is projected to rise to 244 million tons under the PR scenario (Figure 15). In 2022, the total demand for fruits, including those used industrially, was just

Figure 15. Projected total demand for fruits in 2050

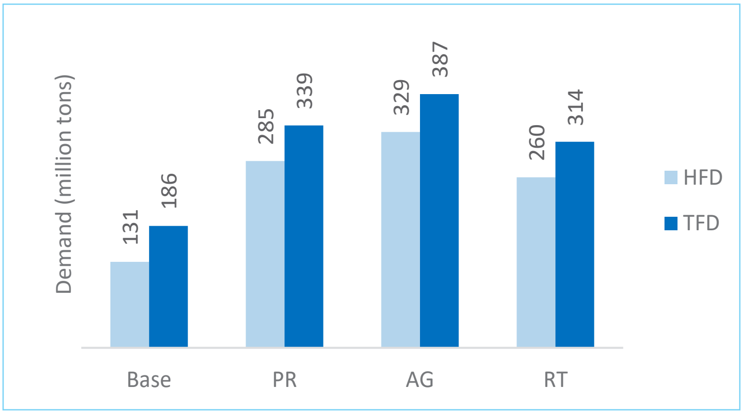


Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

104 million tons. This anticipated growth underscores a strong consumer preference for fruits as per capita income increases. An additional 33 million tons are expected owing to rapid economic expansion. Nonetheless, the gradual transition from fresh to processed fruit consumption is likely to persist. Projections indicate that household consumption accounts for as little as 27% of overall fruit demand.

Mangoes and bananas are anticipated to make up a large share of the fruit demand. By 2050, mango demand is projected to reach 29 million tons in the PR scenario, 33 million tons in the AG scenario, and 25 million tons in the RT scenario. For bananas, the expected demand is 34 million tons in the PR scenario, 39 million tons in the AG scenario, and 29 million tons in the RT scenario. The demand for oranges is estimated to fall between 10 and 14 million tons, while lemons are predicted to range from 4.6 to 6.1 million tons.

Figure 16. Projected total demand for vegetables in 2050



Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

The total demand for vegetables is likely to reach 339 million tons in the PR scenario (Figure 16). In the AG scenario, the demand is projected to be more than 387 million tons, whereas in the RT scenario, it is estimated to be 314 million tons. Unlike fruits, a substantial portion (84%) of vegetables are consumed fresh. Among the primary vegetables, the demand for potatoes is projected to be 82 million tons by 2050 under the PR scenario, 93 million tons under the AG scenario, and 75 million tons under the RT scenario. The estimated demand for onions in the respective scenarios is 45, 51, and 41 million tons. In comparison, the estimated production figures for tomatoes are 27, 31, and 25 million tons, respectively.

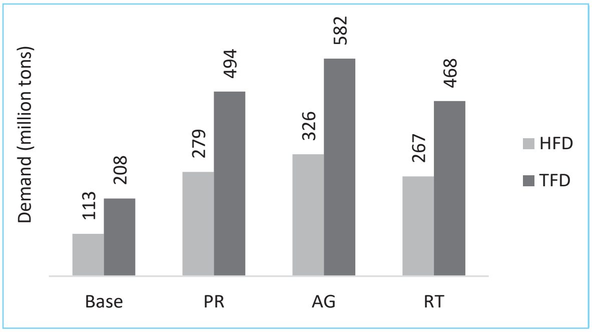
Table 8. Projections of total demand for specific high-value food items in 2050 under various growth scenarios (million tons)

S.N.	Food item	Total demand, 2050			
		2022	PR	AG	RT
1	Banana	27.0	34.0	39.0	29.0
2	Mango	25.0	29.0	33.0	25.0
3	Orange	10.0	12.0	14.0	10.0
4	Lemon	4.6	5.4	6.1	4.6
5	Potato	39.0	82.0	93.0	75.0
6	Onion	21.0	45.0	51.0	41.0
7	Tomato	13.0	27.0	31.0	25.0
8	Egg plant	7.9	17.0	20.0	16.0
9	Cauliflower	6.6	15.0	17.0	13.0
10	Milk	208.0	494.0	582.0	468.0
11	Fish+prawn	13.0	40.0	44.0	38.0
12	Mutton	1.3	2.4	2.8	2.3
13	Chicken	5.1	17.0	20.0	15.0
14	Beef	1.1	2.2	2.5	2.1

Note: PR, AG, and RT are as mentioned in Figure 8.

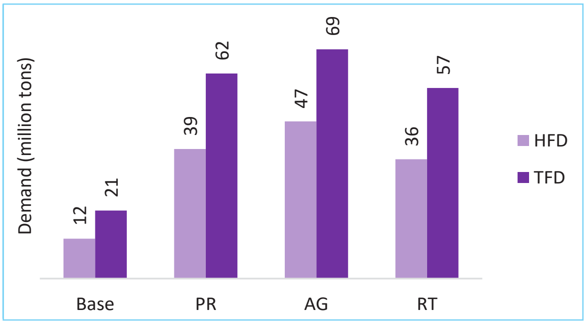
Projections indicate that by 2050, the total demand for milk will increase to 494 million tons, assuming a steady economic growth (Figure 17). In a scenario of rapid economic expansion, the demand is projected to increase to 582 million tons, whereas a scenario of economic decline projects a demand of 468 million tons. The proportion of milk consumed by households is anticipated to remain consistent *i.e.* 56%.

Figure 17. Projected total demand for milk in 2050



Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

Figure 18. Projected total demand for meat and fish in 2050



Note: PR, AG, and RT are as mentioned in Figure 8; HFD and TFD are as mentioned in Figure 11.

Under the PR scenario, the total demand for meat and fish is anticipated to reach 62 million tons by 2050 (Figure 18). In the context of accelerated growth, this demand is projected to increase by an additional seven million tons, culminating in a total of 69 million tons. Conversely, with decelerated growth, demand is expected to be limited to 57 million tons. The share of fresh meat and fish is predicted to decrease. Furthermore, the share of demand for meat and fish by the household is projected to rise to 68% in the AG scenario from 57% in 2022.

By 2050, the estimated overall demand for fish and prawns is expected to reach 40 million tons in the PR scenario, 44 million tons in the AG scenario, and 38 million tons in the RT scenario, all of which signify a notable rise from the 2022 levels. As for other meats, the demand for chicken is projected to increase from five million tons in 2022 to 17 million tons in the PR scenario, 20 million tons in the AG scenario, and 15 million tons in the RT scenario. The demand for mutton is anticipated to be between 2.3 and 2.8 million tons, while beef demand is expected to range from 2.1 to 2.5 million tons.

The projections for both household and total food demand in the current study align closely with the estimates presented in the GoI (2024g) for most food items and groups. This concordance supports the reliability of the estimates obtained in the present study. The tables comparing the results under various scenarios are provided in Appendix VII. Additional references include Jose and Gulati (2023) and the GoI (2018).

♦♦♦

4 Will Domestic Production be Sufficient?

Projections for crops and crop groups are based on area and yield projections. The historical growth in yield and area is assumed to be shaped by technological advancements and climate variations. A trend variable was included to account for technological progress, and temperature and rainfall estimates were used to assess the impact of climate change on the historical area and yield. To address uncertainties in future climatic conditions, area and yield projections were developed using the temperature and climate variables corresponding to scenarios SSP1, SSP2, SSP3, and SSP5 (Riahi et al. 2017). These yield projections were further refined by narrowing the yield gap to reflect potential advancements in production technology, along with the continuation of historical trends.

Data on area and yield were sourced from the Ministry of Agriculture and Farmers' Welfare, Government of India (GoI 2024h). For field crops, these statistics are available from 1965 to 2022, while for horticultural crops, they are available from 1991 onwards. This production series was used to project milk, meat, and fish production. Both historical and future climate variable projections were compiled by the World Bank (2024b). Past area and yield estimates were smoothed using two-year moving averages. Initially, each series was analyzed using the seven regression equations listed below:

$$S_t = \alpha + \beta t + e_t \quad (1)$$

$$S_t = \alpha + \beta_1 t + \beta_2 Rf + \beta_3 Rf^2 + e_t \quad (2)$$

$$S_t = \alpha + \beta_1 t + \beta_2 Rf + \beta_3 Rf^2 + \gamma T_{avg} + e_t \quad (3)$$

$$S_t = \alpha + \beta_1 t + \beta_2 Rf + \beta_3 Rf^2 + \gamma_1 T_{max} + \gamma_2 T_{min} + e_t \quad (4)$$

$$S_t = \alpha + \beta_1 Rf + \beta_2 Rf^2 + e_t \quad (5)$$

$$S_t = \alpha + \beta_1 Rf + \beta_2 Rf^2 + \gamma T_{avg} + e_t \quad (6)$$

$$S_t = \alpha + \beta_1 Rf + \beta_2 Rf^2 + \gamma_1 T_{max} + \gamma_2 T_{min} + e_t \quad (7)$$

In the equations mentioned above, S represents the area/yield series, and t indicates the time trend. The variables Rf and Rf^2 account for rainfall in absolute and squared forms, respectively. T_{avg}, T_{max}, and T_{min} correspond to the average, maximum, and minimum temperatures, respectively, within a given SSP scenario. In the first stage, seven distinct series of projections were generated using coefficients derived from the ordinary least squares (OLS) method for each crop or crop group. Most models demonstrated satisfactory performance, as evidenced by the significance of the coefficients and the model fitness coefficients (coefficient of determination). Subsequently, the average of all the seven models was calculated and used as the basic projection series till 2050.

These projections do not consider future technological advancements, because they assume the continuation of past technology growth trends. To incorporate technological improvements, yield estimates were adjusted to reflect higher productivity growth by addressing the current yield gaps. That is, the yield of a given crop in 2050 was assumed to be the sum of present yield rate with the product of rate of reduction in yield gap (i.e., 50%) and the difference between actual and potential yield in the present. Both national and global yield gaps were considered. Potential yields at the national level were obtained from GoI (2024i&j) and their previous reports, and at the global level were from GoI (2024g). Various scenarios have been explored to bridge the yield gap, such as reducing it by 50%, 75%, and 90% from current levels, with future yield estimates based on current national and global figures. The following six scenarios were assumed.

1. Reduction in the national crop yield gap by 50% by 2050
2. Reduction in the national crop yield gap by 75% by 2050
3. Reduction in the national crop yield gap by 90% by 2050
4. Reduction in the global crop yield gap by 50% by 2050
5. Reduction in the global crop yield gap by 75% by 2050
6. Reduction in the global crop yield gap by 90% by 2050

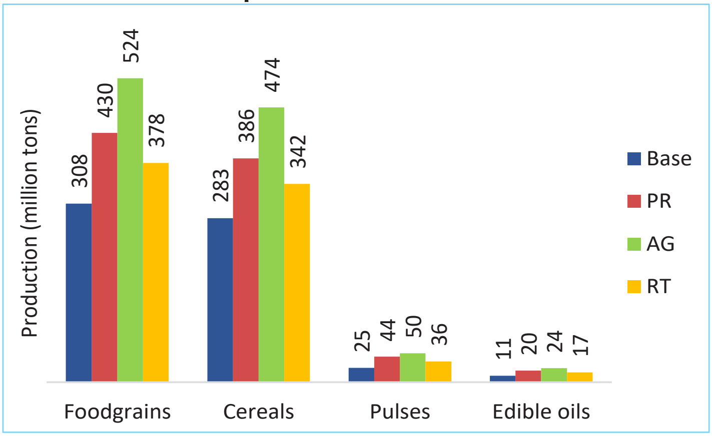
The area estimates for 2050 projected earlier were then employed to determine different production levels. For each SSP scenario, this method generated six additional series of domestic supplies for each crop or crop group (seven projections for each crop and crop group). This exercise was replicated with temperature and precipitation associated with SSP-1.26, SSP-2.45, SSP-3.7, and SSP-5.85, resulting in additional 28 projection figures for each food item or group (35 projection series for each crop group). The most accurate estimates for a specific food item or group were selected for various growth scenarios based on their variability both within and across specific climate scenarios. For instance, the estimates of SSP-1.26 were utilized for the progressive growth scenario, whereas SSP-2.45 was applied to the aggressive growth scenario. Note that the effect of temperature can be further decomposed to account for the roles of the global and idiosyncratic components (Berg et al. 2024). However, this was not considered in the present study.

4.1 Food supply projections for 2050

4.1.1 Foodgrains

Figure 19 illustrates the production projections for the selected crop categories for 2050. Foodgrain production may reach 430 million tons in a steady growth scenario and 524 million tons with rapid economic expansion or 378 million tons if growth slows. It is crucial to highlight that while household demand for food grains is anticipated to rise in a slow growth scenario and decline in a rapid-growth scenario, the supply estimates indicate the opposite pattern: food grain production is expected to grow in a rapid growth scenario and diminish in a slow-growth scenario. This is because of the beneficial effects of technology and climate factors, as explained in the growth scenario section, as well as behavioral factors.

Figure 19. Projected foodgrain and edible oil production in 2050



Note: PR, AG, and RT are as mentioned in Figure 8.

Cereal production is projected to reach 386 million tons by 2050 under conditions of steady growth (PR). Under the AG scenario, production could increase to 474 million tons, whereas in the slow growth scenario, it might reach 342 million tons. Rice production is likely to be 37 million tons higher in the AG scenario than in the PR scenario, increasing from 157 to 194 million tons (Table 9). The increase in wheat production is expected to be relatively modest, with an increase of 2 million tons. The adequate production of rice and wheat suggests that India will likely continue exporting these crops in the coming decade, as it currently does. However, there may be constraints related to the sustainability of natural resources such as irrigation water and fertilizer use.

Table 9. Projections for specific items of foodgrains, edible oils, and sugar production in 2050 under various growth scenarios (million tons)

S.N.	Food item	Production, 2050			
		2022	PR	AG	RT
1	Rice	124.0	157.0	194.0	138.0
2	Wheat	108.0	143.0	145.0	134.0
3	Jowar	4.6	5.1	5.2	4.8
4	Bajra	10.0	7.9	8.8	8.6
5	Maize	31.0	95.0	119.0	84.0
6	Gram	12.0	16.0	19.0	14.0
7	Arhar	4.1	7.3	9.1	5.6
8	Urad	2.4	2.8	3.0	2.6
9	Moong	2.9	3.3	3.4	3.1
10	Masur	1.3	3.2	3.4	2.9
11	Groundnut oil	2.5	3.1	3.9	2.5
12	Mustard oil	2.9	9.4	10.4	8.4
13	Soybean + Sunflower oil	2.2	6.1	6.6	5.1
14	Sugar	41.0	62.0	70.0	53.0

Note: PR, AG, and RT are as mentioned in Figure 8.

Maize production is anticipated to increase substantially, reaching approximately 95 million tons by 2050. This growth is attributed to the government's Ethanol Blending Program and the consequent rise in the demand for maize as a feedstock. Under the AG scenario, production can potentially reach 119 million tons. Although this study does not model the production response to government interventions in green energy policy, the projected increase in production may result from a stable policy framework in the green energy sector in the future.

While sorghum production is projected to improve slightly from the present level, projections suggest that pearl millet production could fall from the current levels. Therefore, effective production enhancement strategies are required. Ex-ante research suggests that transitioning cropland from staple crops, such as rice and wheat, to nutrient-rich cereals, such as sorghum and pearl millet, can not only decrease farm subsidies, but also help reduce greenhouse gas (GHG) emissions if farmers switch to millet-based cropping systems (Balaji 2024). It is projected that if households reverted to pearl millet consumption levels in the early 1990s, the government could save as much as US$ 75 million. This suggests that these savings could be redirected toward agriculture to support climate adaptation and mitigation efforts, thereby fostering a more sustainable food system. Moreover, the shift to nutri-cereals could lead to a decrease in net GHG emissions by 3.3–3.6 million tons of CO_2-equivalent (CO_2eq), thereby promoting both environmental sustainability and food security.

Pulse production is anticipated to reach 44 million tons by 2050 under the PR. However, production is expected to double from the current 25 million tons to 50 million tons in the AG scenario and reach 36 million tons in the RT scenario. A significant increase in production is projected for arhar under the PR and AG scenarios. Compared to the base year production level (2022), arhar production is projected to increase by 78% and 122% under these scenarios. Gram, another major pulse crop, are projected to experience only a 58% increase in production, even with accelerated growth.

4.1.2 Oilseeds and edible oils

Oilseeds are predominantly cultivated under rainfed conditions. By 2050, the total oilseed production is projected to increase from 36 million tons in 2022 to 88 million tons, assuming steady economic growth, and potentially reaching 104 million tons under the AG scenario. Notably, soybean and rapeseed & mustard are anticipated to demonstrate significant growth. Soybean production is expected to more than double, reaching 41 million tons under the AG scenario. Similarly, rapeseed and mustard production is projected to increase from 10 million tons in 2022 to 34 million tons by 2050. Groundnut production is expected to expand at a moderate pace.

Consequently, the total production of edible oils is expected to double by 2050. India, the world's leading importer of edible oil, currently imports approximately 57% of its domestic edible oil requirements (GoI 2024k). Projections suggest that this supply deficit may persist until 2050, with edible oil production expected to reach only 20 million tons under PR, and 24 million tons under AG. These figures fall significantly short of the total demand.

Approximately 12 million hectares of land used for rice cultivation remain fallow in the following season. Bringing this land under the cultivation of pulses and oilseeds is an opportunity to reduce dependence on imports. The preference for pro-liberalization policies over self-reliance strategies is often cited as a significant factor in India's huge imports. If the current low-tariff regime continues, India is expected to remain a significant importer of edible oils. Interestingly, evidence suggests that, even with increased tariffs on edible oil, the impact on imports may be minimal and unlikely to significantly boost oilseed production (Balaji et al. 2022; Balaji et al. 2021). This finding highlights the critical role of technological innovation in enhancing production.

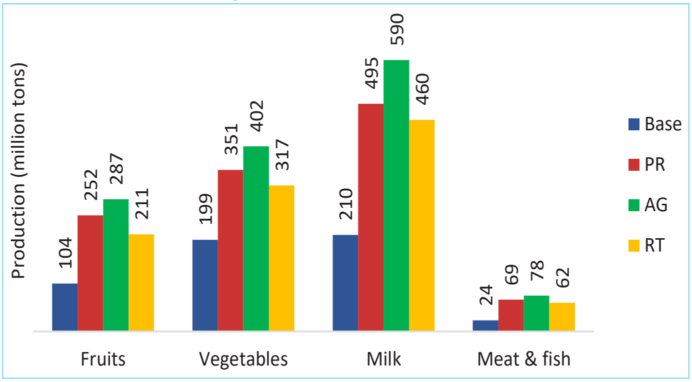
4.1.3 Sugar

Sugar production is anticipated to rise to 62 million tons in the PR scenario and 70 million tons in the AG scenario. These figures represent increases of 51% and 71%, respectively, compared with the 2022 levels. Furthermore, the supply estimates are slightly higher than total demand, thereby presenting opportunities for exports.

4.1.4 High-value foods

By 2050, the production of fruits and vegetables is projected to reach 252 and 351 million tons, respectively, under the PR scenario (Figure 20). In contrast, under the AG scenario, these estimates increase to 287 million tons for fruits and 402 million tons for vegetables.

Figure 20. Projected fruits, vegetables, milk, meat & fish production in 2050



Note: PR, AG, and RT are as mentioned in Figure 8.

Specifically, mango production is expected to rise from 20 million tons in 2022 to 30 million tons in the PR scenario and 34 million tons in the AG scenario (Table 10). Furthermore, the production of major vegetables, including potatoes, onions, and tomatoes, is anticipated to increase by 65%, 100%, and 33%, respectively, from 2022 levels in the PR scenario, and by 87%, 132%, and 52%, respectively, in the AG scenario.

Table 10. Projections for specific high-value food items production in 2050 under various growth scenarios (million tons)

S.N.	Food item/group	Production, 2050			
		2022	PR	AG	RT
1	Banana	33.0	38.0	45.0	32.0
2	Mango	20.0	30.0	34.0	25.0
3	Orange	10.0	12.0	15.0	10.0
4	Lemon	3.7	5.7	6.5	4.8
5	Potato	54.0	89.0	101.0	80.0
6	Onion	28.0	56.0	65.0	51.0
7	Tomato	21.0	28.0	32.0	25.0
8	Brinjal	13.0	17.0	21.0	16.0
9	Cauliflower	9.2	15.0	17.0	13.0
10	Milk	210.0	495.0	590.0	460.0
11	Fish+prawn	15.0	47.0	51.0	43.0
12	Meat (mutton, chicken, beef)	8.9	22.0	27.0	19.0

Note: PR, AG, and RT are as mentioned in Figure 8.

A similar trend is expected for milk, meat, and fish. Milk production is expected to increase from 210 million tons in 2022 to 495 million tons in 2050 under the PR scenario, and to 590 million tons in the AG scenario. Meat and fish are anticipated to experience significant increases in their production. Between 2022 and 2050, meat production is projected to increase by 200%, and fish/prawn production by 240% under the AG growth scenario. The estimates presented here align closely with those reported in the GoI (2024g) (see Appendix VIII).

4.2 Trade impacts

Section 3.5 outlined the projected total food demand in India by 2050, covering the needs of the household, industry, and service sectors. Section 4.1 highlighted the potential for agricultural production to meet this demand. The gap between the projected demand and supply offers insights into the potential for exports or imports. The potential for exporting key food items is shown in Table 11.

Rice is expected to remain a significant exportable commodity with a gap of 33 million tons between demand and supply under the steady growth trajectory. If the growth accelerates, an additional 39 million tons of rice may be exported. Furthermore, even if growth slows in the coming decades, there may still be scope to export rice. Wheat has a relatively low potential. Under steady growth conditions, wheat exports can reach up to 13 million tons. With aggressive economic growth, there are opportunities to export 30 million tons of wheat annually.

Table 11. Export projections in different growth scenarios by 2050 (million tons)

S.N.	Food item	Exports, 2050		
		PR	AG	RT
1	Rice	33.0	72.0	3.0
2	Wheat	13.0	30.0	8.4
3	Fruits	8.8	10.0	3.9
4	Banana	3.8	5.9	3.5
5	Mango	0.9	1.5	0.6
6	Vegetables	12.0	15.0	2.7
7	Potato	7.3	8.2	4.9
8	Onion	11.0	14.0	10.0
9	Tomato	0.52	0.85	0.46
10	Sugar	16.0	21.0	11.0

Note: PR, AG, and RT are as mentioned in Figure 8.

Pulses offer limited opportunities for future export. Observing the demand-supply differences, one can note that India might import 7-14 million tons of pulses by 2050. However, projections suggest that Bengal gram production might surpass the demand. Other types, such as red gram, black gram, green gram, and lentil, might require imports.

The potential for fruit export is expected to range from 4 to 10 million tons. By 2050, India is expected to export approximately 1.5 million tons of mangoes and six million tons of bananas. Vegetable exports are expected to slightly exceed those of fruits. The production of potatoes, onions, and tomatoes is projected to surpass domestic demand, thereby presenting opportunities for export.

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5 What will be the Environmental Implications of Food System Transformation?

The environmental impacts of food production were assessed using two primary metrics: water footprint, which quantifies the volume of freshwater utilized in the production of a specific commodity, and carbon footprint, which evaluates the amount of greenhouse gases released into the atmosphere during the production process.

Total water footprint of commodity c was estimated as

$$W_C^G = WF_C^G * S_C^{2050}$$

$$W_C^B = WF_C^B * S_C^{2050}$$

$$W_C^R = WF_C^R * S_C^{2050}$$

$$W_C = W_C^G + W_C^B + W_C^R$$

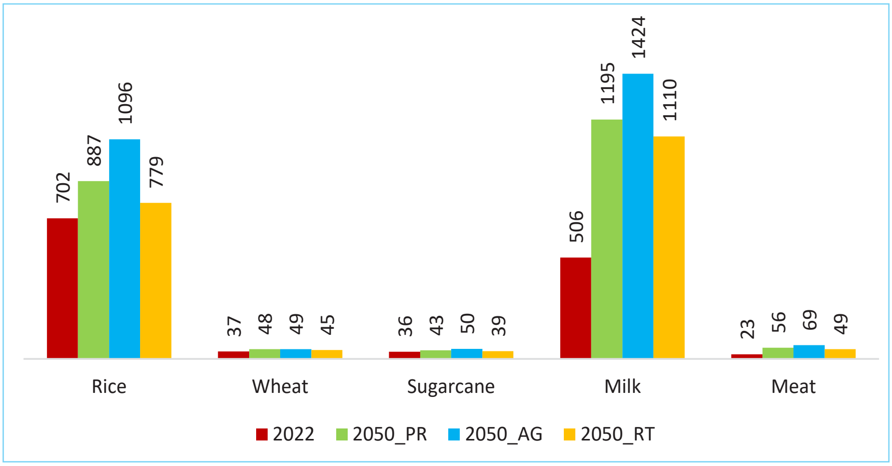
where W_C^G is the *green water* component associated with producing commodity c; W_C^B is the *blue water* component, and W_C^R is the *grey water* component. W_C is the sum of all three components, capturing the total water use associated with commodity production. WF_C^G is the green water footprint, WF_C^B is the blue water footprint, and WF_C^R is the grey water footprint of producing commodity c. S_C^{2050} is commodity c's projected supply in 2050. Further, the carbon footprint of commodity c was measured as

$$CF_C = CEF_C * S_C^{2050}$$

where CF_C is the carbon footprint of producing commodity C and CEF_C is the *carbon emission factor*. The total water footprint W_C and carbon footprint CF_C associated with commodity C were estimated using the coefficients reported by Kashyap and Agarwal (2020).

Rice is expected to continue one of the largest source of greenhouse gas (GHG) emissions (Figure 21). In 2022, rice farming released 702 million tons of CO_2, and this figure is anticipated to increase by 56% to 1,096 million tons by 2050 under the AG scenario. However, GHG emissions from rice production are projected to be lower than those from milk production. Milk production may release 1,424 million tons of CO_2, which is 918 million tons more than that in 2022.

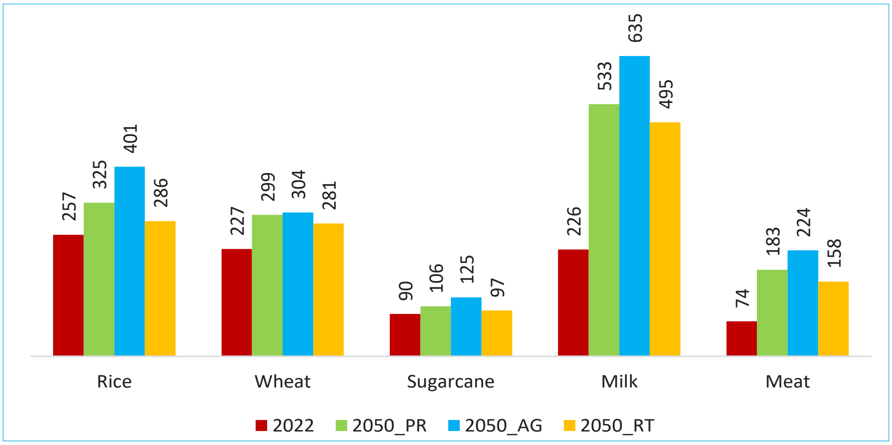
Figure 21. Carbon footprint projections for selected commodities in 2050



Estimates represent carbon footprint in Mt CO_2 eq; Note: PR, AG, and RT are as mentioned in Figure 8.

Figure 22 shows the projected water footprints. Milk is estimated to require 635 billion cubic meters of fresh water, highest in the total agriculture and allied sector. Among the crops, rice cultivation has the largest water footprint, necessitating approximately 401 billion cubic meters of freshwater in the AG scenario. Other crops with high water demand include wheat, and sugarcane which are estimated to require 304 and 125 billion cubic meters of freshwater by 2050.

Figure 22. Water footprint projections for selected commodities in 2050



Estimates represent water footprint in billion m^3; Note: PR, AG, and RT are as mentioned in Figure 8.

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6 Space for Governance for Food System Transformation

The “food system” encompasses the entire process from production to consumption. Our projections indicate no shortage of staple crops. Rice is expected to be in significant surplus, with wheat following the suit. These projections are contingent on continued policy support for agriculture. The projected surplus of staple crops presents a significant opportunity for India to strengthen its position as a key player in global food security. By exporting excess rice and wheat to food-insecure nations in Africa and Asia, India can alleviate hunger and malnutrition in these regions. This export potential not only benefits recipient countries, but also bolsters India’s economic and diplomatic ties. The current list of countries receiving Indian rice exports, including several African nations and Asian neighbors, demonstrates the existing framework for such international food trade relationships.

Achieving self-sufficiency in pulses necessitates efforts to enhance the domestic production. Recent trends indicate an increase in imports, with 2.7 million tons in 2021-22 and 4.7 million tons in 2023-24 (GoI 2024l). The majority of this demand has been fulfilled by Australia, Canada, Myanmar, Mozambique, Tanzania, Sudan, Malawi, and Brazil. Recently, Russia emerged as a significant supplier of lentils and yellow peas. It is imperative to focus on boosting domestic production, as the current yield levels remain below the global average. Furthermore, average yields across states, when compared to potential yields, are 33% lower for Bengal gram, 24% lower for lentil, 41% lower for red gram, 31% lower for black gram, and over 49% lower for green gram (GoI 2024i&j). Addressing these yield gaps could significantly aid a country in meeting its demand.

A similar strategy could be implemented to increase oilseed production. From 2014-15 to 2023-24, oilseed production increased from 27 to 40 million tons. In addition, the import of edible oils has also increased. Over the last three years, from 2019-20 to 2022-23, imports have increased from 13 million tons to 16.5 million tons (SEA 2024). It is anticipated that, as income continues to grow, the demand for imported edible oils will significantly increase. India primarily sourced palm oil from Indonesia and Malaysia, soybean oil from Argentina, and sunflower oil from Russia. Given the limited number of suppliers, this trend is likely to persist. However, as countries like Indonesia fulfil their national biofuel mandates, there may be supply uncertainties in the medium to long term, even though this shift is more expensive. Similar to pulses, it is crucial to enhance the oilseed production in India.

The gap between the demand and supply of fruit and vegetables is generally small. However, the demand for milk is expected to exceed domestic production. Despite having the largest buffalo population and the second-largest cattle population globally and being the world's leading milk producer, the anticipated shortfall in milk production highlights the need for strategies to boost milk output. Addressing the shortage of feed and fodder is a viable solution for this problem. This shortage has historically limited livestock productivity and remains unresolved, as shown by the differences in per-animal milk yields across countries. Currently, India's average milk yield per animal is lower than those of Pakistan, China, Russia, Australia, the European Union, the United States, and Canada.

Maintaining soil health and water resources, along with improving their use efficiency, is crucial through adopting resource-saving technologies, such as micro-irrigation, and practices such as direct seeding in rice cultivation. A significant portion of the area under staple crops lies in regions that experience severe resource depletion, and regulatory policies have shown limited effectiveness. Despite years of implementation, the water use efficiency in Indian agriculture remains below 40%. Initiatives such as PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan), which integrate solar and other renewable energy sources to ensure water and energy security in agriculture, have shown promise.

Investment in research has proven highly beneficial, yielding Rs 13.85 for every rupee invested (Kandpal et al. 2024). There is an urgent need to increase public investment in agricultural research to enhance its technological contribution. Additionally, there is considerable potential to bridge existing yield gaps, particularly in crops such as oilseeds and pulses. Realizing this potential could significantly improve future food-supply systems. Infrastructure investment in markets could help encourage food value addition, manage higher production, and promote trade.

Agricultural policy reforms are needed to address environmental and sustainability concerns. These reforms may promote crop diversification, which can enhance resilience to pests and climate change, while improving nutritional outcomes. Therefore, safeguarding soil health and biodiversity is crucial for long-term agricultural productivity and ecosystem stability. Additionally, controlling input use and greenhouse gas emissions is essential for mitigating the contribution of agriculture to climate change. These solutions are being discussed and developed across various platforms, involving stakeholders from the government, academia, and private sector. The government of India has taken proactive steps, exemplified by the National Mission on Natural Farming (NMNF), to reduce farmers' dependence on external inputs by promoting the use of locally available resources. Such approaches not only have the potential to reduce production costs for farmers but also to minimize the environmental impact of agriculture.

The urgent need for expanding actions and strategies to support sustainable food system transformation is clear. Improved governance of food systems could play a pivotal role in this transformation by facilitating dialogue and negotiations among diverse societal stakeholders. This collaborative approach can help balance the needs of different actors in the food system while working towards common sustainability goals.

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Parameters and variables used in different growth scenarios

S.N.	Parameter		2050		
			PR	AG	RT
1	δ	Capital depreciation (%)	3.86	3.22	3.86
2	β	Labor share (%)	50.58	43.79	56.84
3	K_0/Y_0	Initial capital-output ratio	3.50	3.65	3.33
4	Y_0/N_0	Initial GDP per-capita (US$) *	2,085	2,085	2,085
5	I_0/Y_0	Initial investment-output ratio	0.32	0.33	0.32
6	I/Y	Investment-output ratio	0.38	0.39	0.35
7	g_{A_0}	Initial TFP growth (%)	2.80	2.80	2.80
8	g_A	TFP growth (%)	1.30	1.30	1.30
9	g_{H_0}	Initial human capital growth (%)	1.20	1.20	1.20
10	g_h	Human capital growth (%)	1.10	1.10	1.10
11	ρ_{t_0,m_0}	Initial LFPR (male) (%)	77.20	77.20	77.20
12	$\rho_{t,m}$	LFPR (male) (%)	75.50	77.20	78.90
13	ρ_{t_0,f_0}	Initial LFPR (female) (%)	32.80	32.80	32.80
14	$\rho_{t,f}$	LFPR (female) (%)	40.72	40.72	36.08

Source: Authors' selection.
Note: * at constant 2015 US$; 'initial' estimates correspond to the year 2022.

Modelling future income growth

Income per-capita growth is projected till 2050 using a neoclassical growth model. A standard production function of the form

$$Y_t = A_t K_t^{1-\beta} (h_t L_t)^{\beta}$$

is assumed, where Y_t is GDP, A_t is total factor productivity, K_t is capital stock, and $h_t L_t$ is *effective* labor used in production, which can be decomposed as h_t human capital per worker and L_t number of workers. L_t can be decomposed further into $L_t = \rho_t \omega_t N_t$, where ρ_t is the labor market participation rate, and ω_t is the worker population rate. β is the labor share. GDP per worker can be written as

$$y_t = A_t \rho_t \omega_t k_t^{1-\beta} h_t^{\beta}$$

and growth in GDP per-worker as

$$\frac{y_{t+1}}{y_t} = \frac{A_{t+1}}{A_t} \left[\frac{k_{t+1}}{k_t}\right]^{1-\beta} \left[\frac{h_{t+1}}{h_t}\right]^{\beta}$$

Adjusting to ρ_t and ω_t and rewriting in terms of growth, GDP per capita is estimated as

$$1 + g_{y,t+1}^{pc} = \left[1 + g_{w,t+1}\right]\left[1 + g_{\rho,t+1}\right]\left[1 + g_{y,t+1}\right]$$

The labor share (β) is estimated using

$$\beta = \frac{\sum_{I=1}^{N} GVA_I \beta_I}{}$$

where GVA_I is gross value added and β_I is labor share in industry I. Industry-specific labor shares provided by the Reserve Bank of India are used (RBI 2024).

Capital stock K_{t+1} in year $t+1$ is the investment I_t in year t added to K_t after accounting for depreciation, denoted as

$$K_{t+1} = (1 - \delta) K_t + I_t$$

Capital depreciation rate (δ) is estimated as

$$\delta = 1 - \frac{K_t - I_t}{I_{t-1}}$$

Estimates of K_t are obtained from RBI (2024) and I_t from the National Accounts Statistics of India.

Household food demand projections

Projections for the base year TE 2022 for various food items/groups were derived at first following the macro-economic balancing equation

$$Production + Imports = Consumption + Exports$$

The sum of production and imports equal supply, and consumption and exports equal demand. Production estimates are obtained from GoI (2024h) and export and import statistics are from GoI (2024d). Consumption is derived as the difference of exports from the sum of production and imports. Consumption estimates thus obtained covers the demand arising from both the household and rest of the segments. Their respective shares for TE 2021-22 are obtained from GoI (2024g). The supply-demand balance estimated for selected food items/groups are displayed in the table below.

Supply-demand balance for TE 2021-22 (million tons)

Food item/ group	Production	Import	Supply	Consumption	Export	Demand
Foodgrains	308	3	311	289	22	311
Cereals	283	0	283	261	22	283
Rice	124	0	124	108	16	124
Wheat	108	0	108	105	3	108
Corn	31	0	31	28	3	31
Pulses	25	3	28	28	0	28
Edible oils	11	14	25	25	0	22
Sugar	41	1	42	34	8	42
Fruits	104	1	105	104	1	105
Vegetables	199	0	199	196	3	199
Milk	210	0	210	210	0	210
Meat	9	0	9	8	1	9
Fish	15	0	15	14	1	15

Using the household demand estimates for TE 2021-22, projections are obtained till 2050. The commodity-specific household food demand is modelled as

$$D_{c,t+1} = D_{c,t} * N_t \left(1 + \frac{y_{t+1}^{pc}}{y_t^{pc}} * e_c\right)$$

where $D_{c,t+1}$ is the demand *D* for commodity *c* in year $t+1$; N_t is population at year *t* (TE 2021-22 in the present case); y_{t+1}^{pc}/y_t^{pc} is income (GDP) per-capita growth between *t+1* and *t;* and e_c is the income elasticity of demand for commodity *c*.

Income elasticities used in household food demand projection

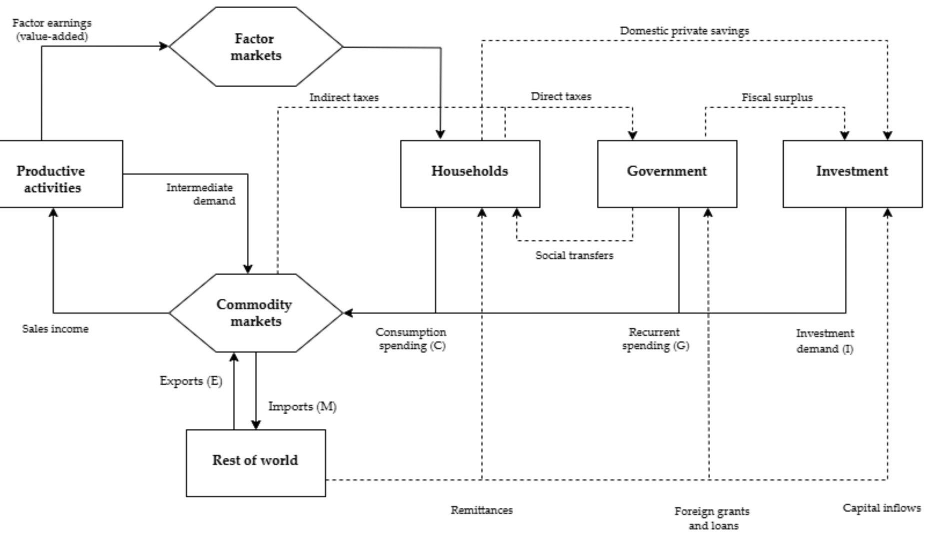
S.N.	Food item/group	Growth scenario		
		PR	AG	RT
1	Rice	0.100	0.070	0.140
2	Wheat	0.100	0.070	0.140
3	Coarse cereals	0.100	0.100	0.100
4	Cereals	0.100	0.070	0.130
5	Pulses	0.327	0.327	0.327
6	Edible oils	0.200	0.200	0.200
7	Sugar	0.200	0.200	0.200
8	Fruits	0.480	0.460	0.360
9	Vegetables	0.345	0.345	0.311
10	Milk	0.430	0.430	0.430
11	Meat	0.397	0.480	0.397
12	Fish	0.670	0.670	0.603
13	Chicken	0.740	0.777	0.703

Note: Income elasticities of the mentioned food commodities are compiled from GoI (2024e). Average of elasticities reported in selected studies, recommended based on the experts, are used. For certain items such meat, lower elasticities are used to reflect consumption satiety.

Total food demand projections

Circular flow models can be used to assess the broad economic impacts of a change. These models illustrate exchanges and transactions between different sectors, such as agriculture, industry, and services, and between various institutions, such as households, businesses, and the government. It is important to detail how industries absorb commodities and how institutions supply them through careful construction. One can employ input-output (IO)-based model to evaluate the comprehensive effects of a shock, such as a shift in consumption preferences in this scenario. The IO table records transactions between industries and calculates the backward and forward linkage effects that result from the change.

A model circular flow in an economy is displayed below.



Source: Breisinger et al. 2009

A Social Accounting Matrix (SAM) is an expanded version of the Input-Output (IO) framework, which could be employed to estimate further details. It not only tracks transactions between industries but also includes exchanges between industries and institutions, as well as among institutions, thereby illustrating the complete flow of economic activities. This matrix uses a double-entry system, in which receipts match expenditures, assigning numerical values to both. Finally, to assess the broader effects of changes, such as impacts on employment, wages, prices, tax increases, and tariff reductions, a Computable General Equilibrium (CGE) model could be employed, incorporating detailed nonlinear production technologies. Social accounting matrices serve as a foundation for calibrating these models. Examples include the International Food Policy Research Institute (IFPRI)'s Standard Computable General Equilibrium Model, the Global Trade Analysis Project (GTAP) Model, and the World Bank's LINKAGE Model (Lofgren et al. 2002; Corong et al. 2017; van der Mensbrugghe 2005).

The application of these three frameworks – Input-Output Tables (IOT) (Vats et al. 2021; Ünal et al. 2023; Lee et al. 2024; Balaji 2024), Social Accounting Matrices (SAM) (Pieters 2010), and Computable General Equilibrium (CGE) models (Pradhan and Ghosh 2022; Balaji et al. 2021; Shiferaw et al. 2016) – provides detailed insights into the economy-wide effects of changes, covering areas such as food, energy, environmental impacts, poverty, and inequality. This study utilized a SAM-based framework to calculate total economic output in response to shifts in household food demand, as previously discussed.

The projected increase in household demand for a given commodity in 2050 with reference to the base year 2022 is introduced as a shock, and the required quantity of output that had to be produced to meet this household demand is estimated as the total demand, following the equation

$$\Delta X = (I - M)^{-1} * \Delta H$$

where ΔX is the total amount of output that must be produced by TE2050, ΔH is the change in household food demand between 2022 and 2050, and *M* is the coefficient matrix capturing the linkage effects. Note that the exogenous vector excludes exports, so the difference between total demand and projected supply (production) shall be treated as the trade (exports/imports) potential by 2050.

a. GDP & GDP percapita growth in comparison to IMF's projections

Period	GDP				GDP percapita			
	Study projection (% p.a.)			IMF	Study projection (% p.a.)			IMF
	PR	AG	RT		PR	AG	RT	
2023	6.9	7.4	6.7	9.2	5.9	6.6	5.9	8.3
2024	6.9	7.4	6.7	6.5	5.9	6.6	5.9	5.5
2025	6.9	7.4	6.6	6.2	5.9	6.6	5.9	5.3
2026	6.9	7.4	6.6	6.3	5.9	6.6	5.9	5.4
2027	6.8	7.3	6.5	6.5	5.9	6.7	5.9	5.6
2028	6.8	7.3	6.4	6.5	6.0	6.7	5.9	5.6
2029	6.8	7.3	6.4	6.5	5.9	6.7	5.8	5.7

b. Projected GDP growth in comparison to USDA's projections

Period	Study projection (% p.a.)			USDA
	PR	AG	RT	
2024-33	6.8	7.3	6.4	6.0

c. Projected GDP in comparison to OECD & Ernst & Young's projections

Period	Study projection (% p.a.)			OECD, E&Y (% p.a.)			
	PR	AG	RT	S-0	S-1	S-2	S-3
2022-25	6.9	7.4	6.7	8.2	7.0	7.0	7.0
2026-30	6.8	7.3	6.4	5.9	6.6	7.0	7.3
2031-35	6.6	7.1	6.0	4.7	5.7	6.2	6.7
2036-40	6.3	6.7	5.6	3.8	4.8	5.3	5.8
2041-45	5.9	6.3	5.2	3.1	4.2	4.8	5.3
2046-50	5.3	5.7	4.6	2.7	3.8	4.4	5.0

d. Projected GDP in comparison to Goldman Sachs's projections

Period	Study projection (% p.a.)			Goldman Sachs
	PR	AG	RT	
2024-29	6.8	7.3	6.5	5.8
2030-39	6.5	7.0	5.9	4.6
2040-49	5.7	6.1	5.0	3.7

Sources: IMF (2025) for Table a, Dohlman et al. (2024) for Table b, Srivastava et al. (2022) for Table c, and Daly and Gedminas (2022) for Table d.

Food demand projections for 2050: a comparison

Food item/group	Present study			NITI (2024)*		
	PR	AG	RT	BAU	HIG-I	HIG-II
	Household demand (million tons)					
Foodgrains	261	263	272	248	250	254
Cereals	225	220	237	214	214	215
Rice	115	112	124	106	105	104
Wheat	95	93	102	96	96	97
Corn	1.9	2.0	1.8	1.7	1.7	1.7
Pulses	36	43	35	34	36	39
Edible oils	22	24	21	21	21	22
Sugar	20	23	19	18	18	19
Fruits	66	75	54	62	67	75
Vegetables	285	329	260	263	278	302
Milk	279	326	267	276	303	347
Meat	17	21	16	16	18	22
Fish	22	26	20	20	23	27
	Total demand (million tons)					
Foodgrains	435	450	446	402	415	437
Cereals	384	392	396	353	363	381
Rice	124	122	135	114	114	113
Wheat	130	115	126	119	119	120
Corn	93	118	91	86	94	109
Pulses	51	58	50	49	52	57
Edible oils	33	37	32	31	32	33
Sugar	47	49	42	44	45	45
Fruits	244	277	207	233	252	283
Vegetables	339	387	314	365	385	417
Milk	494	582	468	480	527	606
Meat	22	25	19	21	24	29
Fish	40	44	38	37	41	48

* Projections are for 2047-48; HIG-I & II assume income growth of 7% and 8%, respectively, until 2047/48.

Food supply (production) projections for 2050: a comparison

(million tons)

Food item/group	Present study			NITI (2024)*	
	PR	AG	RT	BAU	HYG
Foodgrains	430	524	378	457	594
Cereals	386	474	342	409	538
Rice	157	194	138	154	223
Wheat	143	145	134	160	187
Maize	95	119	84	80	107
Pulses	44	50	36	47	56
Edible oils	20	24	17	24	33
Sugar	62	70	53	50	51
Fruits	252	287	211	214	287
Vegetables	351	402	317	367	531
Milk	495	590	460	478	581
Meat	22	27	19	18	30
Fish	47	51	43	37	49

*projections are for 2047-48.

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