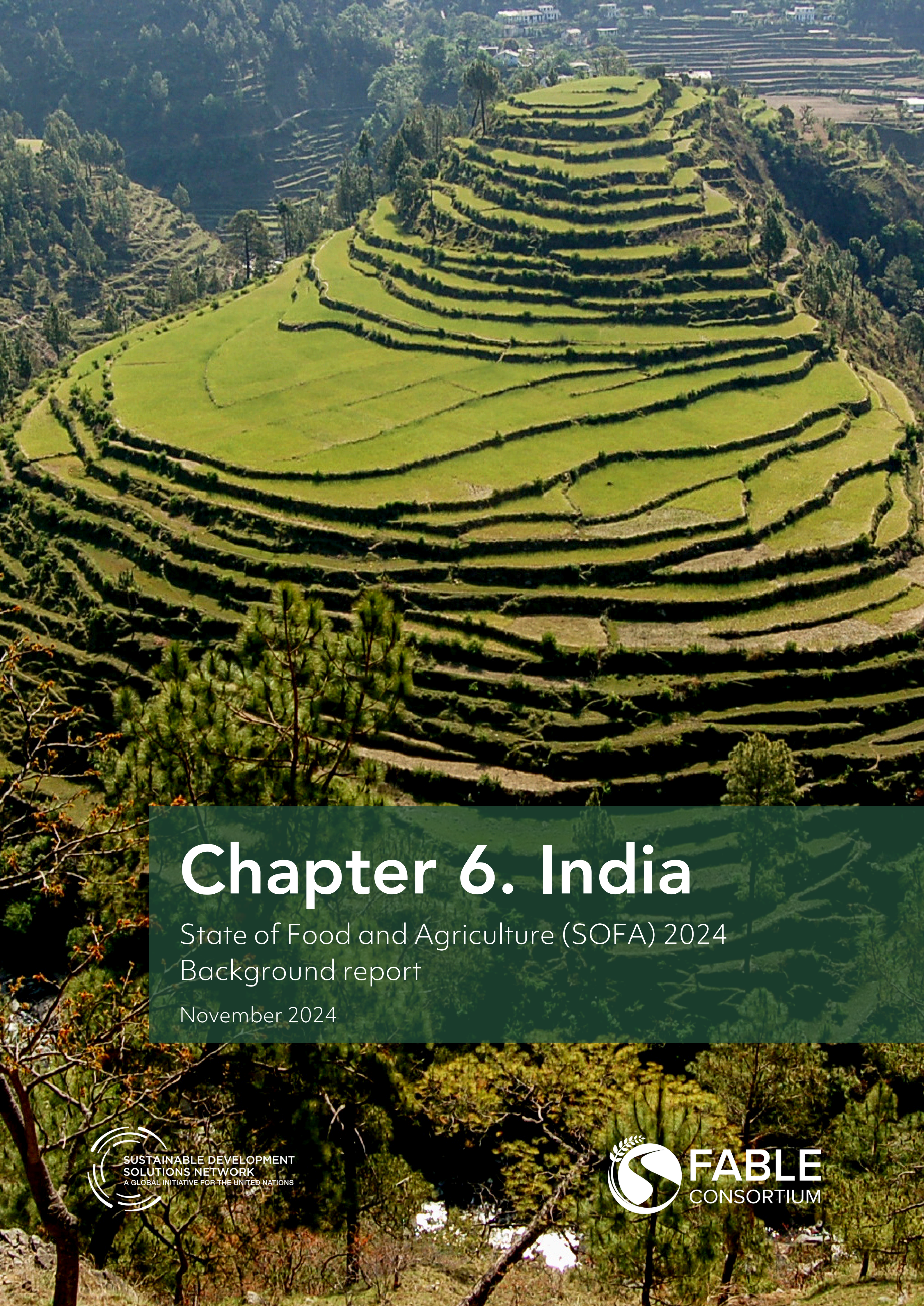

Chapter 6. India

State of Food and Agriculture (SOFA) 2024
Background report

November 2024

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

FABLE CONSORTIUM

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Highlights

- We review the hidden costs of food systems in India as developed in the FAO SOFA 2023 report and evaluate the results in the context of India. Additionally, we assess the factors of change to reduce the hidden costs of food systems in India through a multi-model approach.
- We use a suite of interconnected models to implement scenarios and assess their impact on reducing the hidden costs. We create two scenarios of transformation and evaluate them across 14 indicators of food system changes encompassing the four dimensions of health, environment, inclusion, and economic costs. We also conduct stakeholder consultations to discuss the analysis and gather stakeholder opinions.
- We find that large average hidden cost reductions until 2050 come mainly from shift towards healthy diets, improved crop and livestock production, avoided cropland expansion and mitigated NO3 run-off.
- Timely shifts in dietary patterns, curbing nitrogen emissions from cropland surface runoff, and managing land use change emerge as pivotal factors for reduction of hidden costs in India.
- Our analysis points towards the importance of assessment of hidden costs of food systems in India using existing data and evidence. At the same time, the results from our analysis highlight the importance of reviewing analysis of hidden costs, methodological validation, and forward-looking projections within agrifood systems.

Contents

6.1 Introduction

India's agricultural and food systems in the last five decades have been driven by the Green Revolution and policies surrounding the goal of increasing agricultural productivity to meet food security of the growing population. This was powered by a multitude of subsidy programs – the largest of which have been fertilizer, power, seed and machinery subsidies. It was complemented by price support policies that ensured minimum prices for key cereal crops such as rice and wheat and provided the much-needed boost to India's productivity growth over the years (Chand and Singh, 2023). However, this growth necessitated extensive use of inputs including fertilizer, water and land resources. The interconnected nature of the agricultural sector, environment and natural resources were overlooked in the policy framework. As a result, food systems in the country at present face critical challenges in sustainable agricultural development, farmer livelihoods, consumer welfare, and environmental impacts, where isolated interventions often overlook the interconnectedness of these issues (Pingali et al., 2019). On the other hand, focusing solely on climate-resilient and sustainable agriculture practices may disrupt the supply of agricultural products and create an imbalance without a matching shift in consumer demand (Scherer and Verburg, 2017). Furthermore, discussions on transforming India's food systems have largely treated agricultural advancement, food and nutrition security, and biodiversity conservation as separate entities. The policy landscape has not adequately addressed the Sustainable Development Goals' principles of equitable economic development, social justice, and inclusive growth (Bajpai and Biberman, 2020). This siloed approach hinders the holistic development and sustainable transformation of India's food systems.

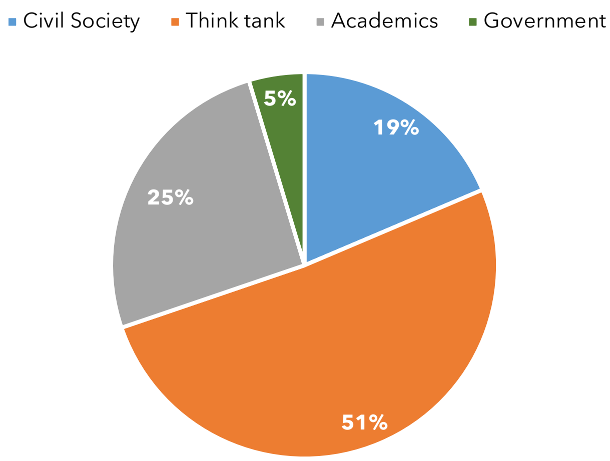
The costs of implementation of these policies to ensure food security are only analyzed through program implementation and subsidy budgets. They often overlook the future costs of land and environmental degradation as well as human health impacts due to undernourishment and burden of disease. Indicators such as gross product count the value added of current activities in purchasing power terms but do not account for the future deficits. This is why the "true" costs are hidden from national accounts and not factored into current markets. Unlike shocks such as the global financial crises or the COVID-19 global, the food system incurs costs year on year. The hidden deficit accumulates in real terms and poses risk to future growth and development.

In this chapter, we delve into the assessment of a True Cost Accounting framework for India based on the State of Food and Agriculture 2023 report (FAO, 2023). We present results from stakeholder engagements that were conducted to critically analyze the assumptions and datasets used in the analysis and any gaps that may have existed (more on stakeholder consultations is discussed below). We also present validation of SOFA 2023 results concerning hidden costs in agrifood systems, encompassing an overview of the SOFA 2023 method and an examination of primary hidden cost sources in India from 2016–2023. The exploration extends to the driving factors behind current hidden cost estimates, specifically disentangling contributions from impact quantities and marginal costs. A comparative analysis with national datasets is presented, covering dimensions such as poverty, land use, greenhouse gas (GHG) emissions, water, and health outcomes. Furthermore, this chapter identifies gaps in the SOFA 2023 analysis and offers insightful suggestions for improvements. The subsequent section explores the evolution of hidden costs by 2030 and 2050, employing the SPIQ-FS model (Lord, 2023a) and the Model of Agricultural Production and its Impact on the Environment (MAgPIE) (Dietrich et al., 2019a). This involves detailing scenarios for enhancing sustainability in contrast to current trends. This comprehensive approach ensures a thorough investigation into hidden costs, methodological validation, and forward-looking projections within agrifood systems.

Stakeholder consultations in India were conducted in two rounds in the months of December 2023 and January 2024. These consultations were conducted across north and south India (Delhi and Bangalore) to attract and represent experts from all domains and regions. Across these events, more than 50 participants from all sectors – policy, academia, practitioners, think tanks, and civil society – were represented (Figure 6-1). Critical assessment of the SOFA 2023 report including datasets, assumptions and methodology was undertaken and feedback summarized.

The stakeholders provided valuable insights that merit consideration for refining our approach. It was highlighted that policymakers may initially overlook the presented hidden cost figures, especially given the evidence from parallel studies indicating substantial value of agrifood systems in India, estimated at approximately 16% of GDP. Therefore, a cautious presentation of current results was suggested. The transition costs to alternative agrifood systems need careful consideration, acknowledging the potential variability. Recognizing India's diverse landscapes and food systems, there was a recommendation to present the analysis at the sub-national level to enhance relevance for policymaking. They underscored the method-specific nature of the calculated costs, urging for an acknowledgment of alternative calculation methods that account for demanded goods, both tradeable and non-tradeable. A need was felt to integrate broader perspectives by including net benefits from India's agricultural sector, considering it is a net sink of greenhouse gas emissions. Stakeholders also suggested that a more comprehensive evaluation of quality-of-life statistics be conducted, moving beyond the simple years of life lost metric and mooted the inclusion of awareness costs associated with shifting diets into the analysis. In short, incorporating these recommendations will enhance the relevance, accuracy, and applicability of our hidden cost analysis within the intricate landscape of India's agricultural and food systems.

Figure 6-1: *Professional background of the stakeholders consulted for SOFA 2024 across two workshops and regions in India (North and South)*



6.2 SOFA 2023 hidden costs analysis

6.2.1 Overview of the SOFA 2023 method

The SOFA 2023 report highlights the magnitude of hidden costs of agrifood systems in India to the tune of 1.17 trillion 2020 PPP dollars (Lord, 2023). India reports the third largest hidden costs of agrifood systems after China and the USA. In Indian currency, this is equivalent to approximately 220 trillion Indian rupees. The total budget on India's largest public scheme – the Public Distribution System (PDS) for food grains, for the fiscal year 2020–2021 was around 2.42 trillion Indian rupees.

These costs include the costs of annual Indian GHG emissions, nitrogen pollution, and habitat losses and returns from land use change from food production, poverty, and productivity losses from consumption of unhealthy diets. In essence, these hidden costs capture the externalities and market failures of India's agrifood systems over the period of 2016–2023, compared to their marginal damage to GDP PPP.

The figures presented in this report should not be interpreted as an indication that alternate policy options can fully eliminate the hidden costs of agrifood systems in India. Furthermore, these numbers do not imply that India's GDP could experience a 16% increase if these costs are avoided. A comprehensive comparative assessment of costs and benefits, utilizing consistent methods and assumptions, would be required to substantiate such claims.

Table 6-1: *Description of costs included in the SOFA 2023 analysis*

Environmental	**GHG emissions**	Fertilizer manufacture for agricultural use, manure management, enteric fermentation, and land use change
	Land use change	Habitat loss associated with non-food agricultural commodities such as tobacco, cotton and biofuels, land use conversion from forests to cropland, pastures and other association losses of ecosystem services
	Blue water	Agricultural losses and productivity losses due to the burden of disease from protein-energy malnutrition, due to water deprived from economic use, and scarcity in water availability for economic use in the future
	NH_3 emissions in air	Labor productivity losses due to burden of disease from air pollution
	NOx emissions	Negative impacts on agricultural and ecosystem services resulting from imbalances in nutrients and the acidification of terrestrial biomes caused by deposition
Health	**Disability-adjusted life years (DALYs)**	Productivity losses due to burden of disease due to protein-energy malnutrition and obesity (high BMI and NCDs)
Social	**Poverty**	Income shortfall below the moderate poverty line of agrifood workers

6.2.2 Main cost components and explanation of the results

Environment

The environmental costs of food systems are calculated by accounting for external costs of GHG emissions from the farm gate and land use change, land use transition to and from cropland and pasture, and blue water use for agricultural production. For the SOFA 2023 results, India reports hidden environmental costs to the tune of 0.287 trillion 2020 PPP dollars. These costs are divided by the Gross Value Added (GVA) of agriculture, forestry, and fishing sector to create the agricultural externalities impact ratio (AEIR) – it is the cost of agricultural externalities due to production, per unit of value added to GDP. As compared to the global AEIR of 0.31, India's is 0.13, thereby suggesting that the environmental costs of food systems in India are lower than the global average but indicating that every 2020 PPP dollar of agricultural production results in 0.13 2020 PPP dollars of external environmental costs, specifically nitrogen. India estimated 144 billion 2020 PPP dollars in 2023 due to nitrogen emissions, third largest after China and Brazil.

Health

From the SOFA 2023 report, India reports hidden costs to the extent of 0.73 trillion 2020 PPP dollars due to health outcomes of agrifood systems in India. As per the Global Burden of Disease 2019 study, malnutrition and air pollution are two major determinants of DALYs and contribute to the maximum hidden costs of health. This is driven by the double burden of malnutrition and obesity that currently affects India's population. Like the AEIR, a comparable measure of costs due to consumption patterns is the dietary patterns impact ratio (DPIR). This indicator is developed by dividing productivity losses from dietary patterns by national GDP PPP. This value for India is 0.07, compared to the global value of 0.072, equivalent to about 7% of India's GDP PPP. Since this value is relative to total GDP, it is considered of high concern. According to an estimate by the World Bank, the health cost of air pollution alone in India in 2019 was USD 36.8 billion.

Social

Hidden costs from agrifood systems in India report the least costs: 0.15 trillion 2020 PPP dollars. Like the environmental and health outcomes, the social distribution impact ratio (SDIR) is developed by specifically accounting for income shortfall of agrifood systems workers in moderate poverty and productivity losses from undernourishment, divided by the total income of the moderately poor. This assumes that most loss of productivity from undernourishment is experienced by the moderately poor. The value of this ratio for India is 0.24.

6.2.3 Driving factors of the current hidden cost estimates

As per the SOFA 2023 report, from 2016 to 2023, there was a 3% increase in farm gate CH_4 emissions in India, amounting to approximately 20 million tonnes of CH_4 emissions in 2023 as well as an increase of pre-and post-production activities emissions by about 5% (0.5 million tonnes in 2023). At the same time, a steep reduction of approximately 69% is observed in CH_4 emissions from land use change processes. Marginal costs across the emissions categories remain the same for India and do not change over time. The environmental challenges manifest through high marginal costs associated with nitrous oxide (NO_3) run-off and human sewerage to surface water, as well as NO_2 emissions into the air due to nitrogen deposition and ammonia (NH_3) emissions to air from particulate matter. No change in blue water withdrawals are noted in the analysis for India, which is a major gap in the analysis and is discussed later in the chapter.

We observe a significant increase from croplands to forests for India between 2016 and 2023 (1019%) (Table 6-2) which is attributable to extensive efforts towards the protection and expansion of forest cover and is accounted under the category of forest habitat return. A small degree of conversion between forest to cropland and pastures is also observed in this assessment, as is a reduction in the conversion of unmanaged grasslands to pastures.

Table 6-2: *Rate of change in land use across categories for India between 2016 and 2023*

Category of land use change	Rate of change between 2016 and 2023 (%)
Cropland to forest	1019
Cropland to unmanaged grassland	20
Forest to cropland	55
Forest to pasture	34
Pasture to forest	119
Pasture to unmanaged grassland	23
Unmanaged grassland to cropland	-19
Unmanaged grassland to pasture	-99

Source: Authors' calculations from the SOFA 2023 report. Values indicate percentage change in land use conversion rates in 2023 compared to the conversion rate in 2016.

Over the same period, there is a notable 9% decline in the marginal costs of agrifood worker productivity. This decline is attributed to rising overall incomes, subsequently reducing the mean income shortfall among agrifood workers. The burden of disease related to dietary choices, measured in DALYs, is also observed to increase by 24% from 2016 to 2023. This rise is linked to an uptick in non-communicable diseases (NCDs) and changes in BMI resulting from shifts in food consumption patterns, following the western style diets trajectory. Notably, NCDs accounted for approximately 63.7% of total annual deaths in India, with substantial associated costs reflected in out-of-pocket healthcare expenditures and income loss in 2017 (Bukhman et al, 2020). Excessive nitrogen use in the production of cereal crops remains a key driver of these health and economic challenges, posing complex implications for policy considerations. These trends are exacerbated by the continued application of high nitrogen in agriculture, fueled by adverse subsidy programs, farmer awareness, and behavioral change. Additionally, escalating air pollution, attributed to both household air pollution (HAP) and ambient air pollution (AAP), significantly contributes to the national burden of disease, with implications for mortality rates.

6.2.4 Comparison with national datasets

Poverty

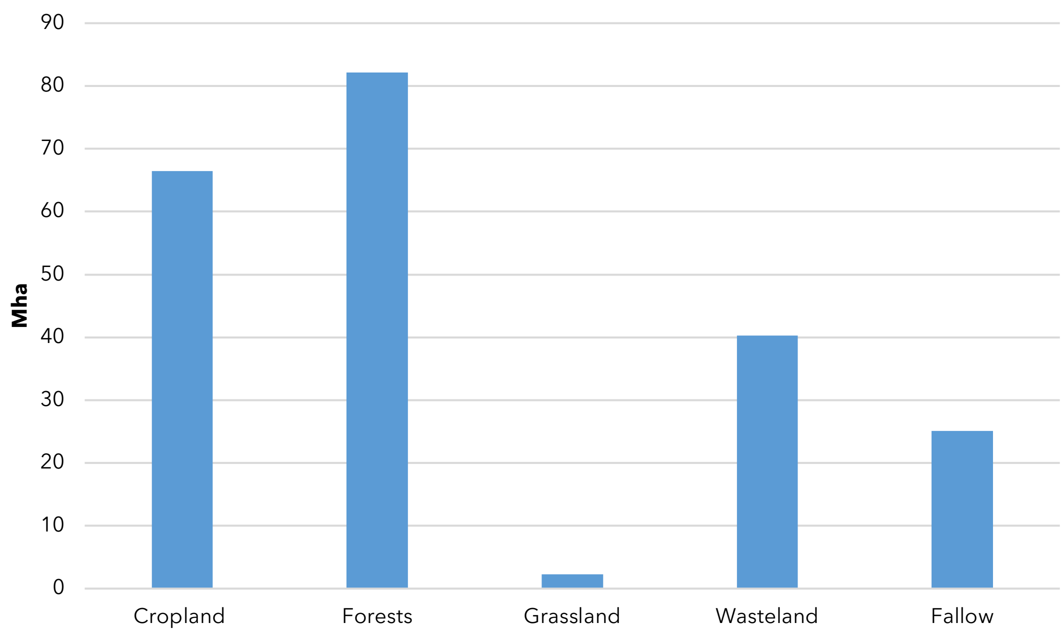
Approximately 22.2% of the Indian population remained at the USD 3.65 per day poverty threshold in 2017 (World Bank, 2024). This is equivalent to 655 million people living below the poverty line. However, in the True Cost Accounting (TCA) estimates, this number is 331 million agrifood workers under poverty and does not compare to other available statistics. As per the latest estimates from the Participation in Labor Force Survey (PLFS) (NSSO, 2023), the TCA figures are close to the USD 1.9-a-day poverty threshold instead of the USD 3.65 per day. The evaluation of poverty indicators in India relies on the Multidimensional Poverty Index (MPI) (Niti Aayog, 2023), recognizing the limitations of income as the sole metric, which may overlook crucial information about household deprivations in health, education, and living standards. India's national MPI consists of three equally weighted dimensions – health, education, and standard of living – represented by 12 indicators. Notably, the health component addresses nutrition gaps for adolescents and maternal health, suggesting a potential enhancement in the health cost metrics within the SOFA 2023 report. Furthermore, the MPI sub-indices not only account for the incidence of poverty by considering numbers but also measure the intensity of poverty by weighing the deprivation scores of all poor individuals, summing them up, and dividing by the total number of poor people. Over two rounds of this index, the report indicates that between 2015–16 and 2019–21, approximately 135 million people were uplifted from multidimensional poverty. While this does not directly attribute to poverty among agrifood system workers, the reduction in poverty within rural areas, from 32.59% to 19.28% between 2015–16 and 2019–20, serves as a proxy. This reduction mirrors a 15% decrease in agrifood worker poverty, as reported by SOFA 2023.

Land use

To compare statistics on land use change with SOFA 2023, we rely on available sources within India. One dataset is the India Water Resource Information System (WRIS) that reports the various categories of land use and land cover every year. However, the latest data is only until 2017.

Figure 6-2 presents the classification of total land across various land types, as obtained from WRIS for 2017. A trend analysis from this source is unavailable to draw relative comparisons between SOFA datasets which only report change in land use categories.

Figure 6-2: *Classification of various land use types in national dataset*



Source: Authors' calculations using data from the Water Resource Information System (WRIS), Government of India, for 2017 (indiawris.gov.in)

Latest statistics from land cover maps of NRSC in India suggest that cropland occupies about 46% of total land areas in India, followed by forests at 38%, fallow at 8% and pastures at 3%. We also gather data from the NASA LP DAAC at the USGS EROS Center and curate yearly MCD12Q1.061 MODIS Land Cover Type to determine the following conversion rates between land types between 2016 and 2022 (Table 6-3).

While a direct comparison cannot be made between the two sources due to difference in methodologies, estimates from the alternative dataset show large changes from grasslands to croplands and grasslands to forests over the years, and only small conversions from cropland to forests or grasslands.

Table 6-3: *Change in land cover type between 2016 and 2022*

Land use change type	Change from 2016 to 2023 in million hectares
Forest to croplands	0.73
Cropland to forest	0.83
Cropland to grassland	1.37
Forest to grassland	2.64
Grassland to cropland	3.43
Grassland to forest	2.80

Source: Author's calculations using yearly land cover data from The Terra and Aqua combined Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1) Version 6.1.

GHG missions

Greenhouse gas emissions comparisons for India use data from the GHG Platform for India (Solanki et al., 2022) which reports GHG emissions from all sectors including AFOLU from 2005 until 2018. Statistics from this platform were used by India in their third Biennial Update Report (BUR III) to the United Nations Framework Convention on Climate Change (UNFCC) (MoEFCC, 2021). 2018 is the latest year for which comparisons can be made with the SOFA 2023 report as presented in Table 6-4 below. Challenges in comparing data sources arise from variations in source classification and differing accounting methods, as illustrated below. For example, CH_4 emissions from SOFA 2023 classified as "farm-gate" are approximately 19.73 million tonnes. To compare with data from the national dataset, we combine CH_4 emissions from all these sources: biomass burning in cropland, biomass burning in forest land, rice cultivation, enteric fermentation, and manure management. This value is 14.02 million tonnes, much less than the SOFA estimate. Total CO_2 emissions from the SOFA 2023 report are 261.22 million tonnes. This is much higher than the emissions from AFOLU sector reported in India (170 million tonnes of CO_2) in 2018.

Table 6-1 shows the difference in contribution of each emission type between data sources (India's report to UNFCC and the SOFA 2023) for the year 2016. The comparison reveals that the SOFA 2023 dataset underestimates methane (CH_4) emissions from agricultural production in India while overestimating carbon dioxide (CO_2) emissions. Notably, SOFA 2023 fails to report any CO_2 emissions attributed to land use change in India, an omission significant in scale, as these emissions approximate 180 million tonnes of CO_2 equivalent. Such a substantial omission compromises the conclusiveness of the comparison.

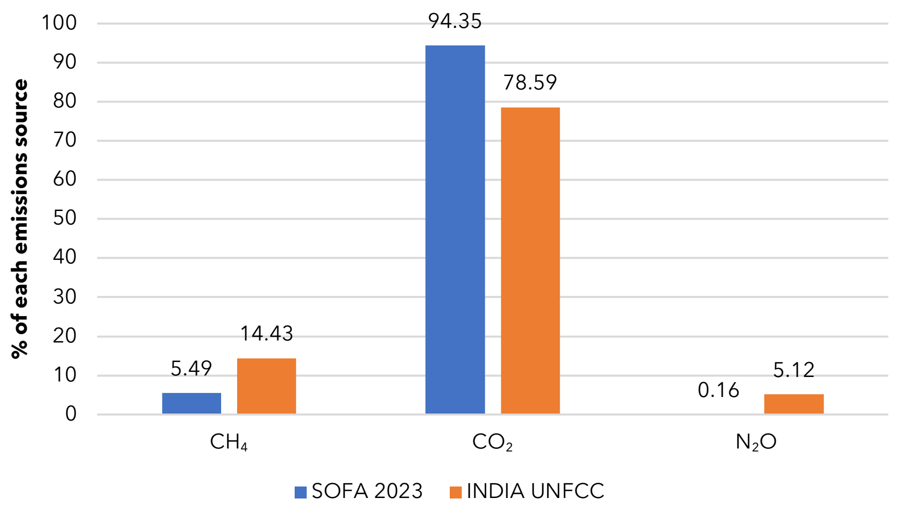
Table 6-4: *Comparison of GHG emissions from GHG platform India and SOFA 2023*

GHG platform	Type	2016	2017	2018
Agriculture soils	CO_2e (t) GWP-AR6	44.79	44.81	46.29
Biomass burning in cropland	CO_2e (t) GWP-AR6	7.82	8.45	8.79
Biomass burning in forest land	CO_2e (t) GWP-AR6	1.98	1.90	1.91
Rice cultivation	CO_2e (t) GWP-AR6	88.88	89.29	89.94
Enteric fermentation	CO_2e (t) GWP-AR6	267.50	267.65	267.81

Manure management	CO_2e (t) GWP-AR6	27.37	27.41	27.45
Land use change	CO_2e (t) GWP-AR6	-104.98	-104.98	-180.97
Agriculture soils	N_2O (Mt)	0.16	0.16	0.17
Biomass burning in cropland	N_2O (Mt)	0.01	0.01	0.01
Biomass burning in forest land	N_2O (Mt)	0.00	0.00	0.00
Manure management	N_2O (Mt)	0.00	0.00	0.00
Biomass burning in cropland	CH_4 (Mt)	0.22	0.24	0.25
Biomass burning in forest land	CH_4 (Mt)	0.06	0.06	0.06
Rice cultivation	CH_4 (Mt)	3.19	3.20	3.22
Enteric fermentation	CH_4 (Mt)	9.59	9.59	9.60
Manure management	CH_4 (Mt)	0.96	0.96	0.96
SOFA 2023				
Farm gate	CH_4 (Mt)	19.73	19.88	20.03
Land use change	CH_4 (Mt)	0.03	0.02	0.01
Pre- and post- production	CH_4 (Mt)	5.60	5.65	5.69
Farm gate	CO_2 (Mt)	18.51	16.34	14.92
Land use change	CO_2 (Mt)			
Pre- and post- production	CO_2 (Mt)	417.15	439.57	442.79
Farm gate	N_2O (Mt)	0.72	0.73	0.75
Land use change	N_2O (Mt)	0.00	0.00	0.00
Pre- and post- production	N_2O (Mt)	0.03	0.03	0.03
Total		**461.77**	**482.23**	**484.22**

Source: Authors' calculations from data obtained from the GHG platform. All values are in million metric tonnes.

Figure 6-3: *Greenhouse gas emissions across data sources*



Source: Author's estimations using data from SOFA 2023 and UNFCC report of India. Values reflect percentage difference in CO2 equivalents

Water

The representation of blue water withdrawals for India matches the statistics from FAO AQUASTAT with withdrawals at 688 billion cubic meters per year for the year 2023. However, there is scope for improvement in the analysis by incorporating irrigation water use efficiency in the analysis. Additionally, assessment of true costs of water would also benefit from accounting of water use for various other agricultural activities such as fertilizer production.

Health/dietary patterns

In India, the high prevalence of poor dietary patterns and the corresponding burden of disease are supported by India's State of Health Report (ICMR et al. 2017). This report shows the change in burden of disease between 1990 and 2016 and reports that for India, 33% of the total DALYs resulted from communicable, maternal, neonatal, and nutritional diseases (CMNNDs) and, 55% from non-communicable diseases (NCDs), and 12% from injuries in 2016. In 1990, this was 61%, 30%, and 9% of DALYs, respectively, thereby suggesting a reduction in the extent of CMNNDs and an increase of NCDs. The SOFA 2023 report has integrated the burden of disease from NCDs and high BMI and reports an increase in the total burden of disease between 2016 and 2023 by 0.24% which is much lower than the assessment of the ICMR report. In further support of the TCA data, several studies have shown that the consumption patterns of most Indians are not diverse. Specifically, a study by Sharma et.al. (2020) used the nationally representative Consumption Expenditure Survey (CES) Data from 2011–12 in India to demonstrate that the average daily calorie consumption in India was below the recommended 2503 kcal/capita/day across all groups compared, except for the richest 5% of the population. They found that processed food accounts for nearly 10% of the average total caloric intake in both rural and urban India, with urban households consuming as much as 30%. Most recent highlights from the latest CES survey reveal an alarming trend in the consumption of processed foods across both rural and urban areas where processed foods contribute to approximately 20% share in total food expenditure in rural areas, and 27% in urban areas (MoSPI 2024). Another study on physical activity assessments had also found that about 34% of Indians were physically inactive, thereby suggesting that productivity losses from inactivity/burden of disease could also be high (Gautam et al., 2023). Healthier diets are also associated with the costs of consumption and studies have shown that healthy diets are not affordable by more than two thirds of the population in India (Raghunathan et al., 2021; Sharma et al., 2020).

6.2.5 Recommendations for tailored country hidden costs analysis

Notable gaps in the SOFA 2023 report necessitate attention for comprehensive improvement:

- Agricultural production accounting: The absence of a distinction between agricultural production for domestic consumption and import stands as a major gap. While this differentiation may not directly impact cost estimations, its inclusion would significantly enhance the analysis, prompting countries to consider hidden costs associated with their trading patterns.
- Incomplete consideration of blue water withdrawals: The current analysis overlooks the critical aspect of whether all blue water withdrawals for agriculture are utilized in crop production. Poor water use efficiency contributes to high withdrawals with relatively low rates of crop production. Furthermore, the substantial freshwater usage by fertilizer industries, estimated at 182 million cubic meters in India in 2019, underscores the need for a more comprehensive evaluation, as reported by the Centre for Science and Environment.
- Unaccounted pesticide use: The report fails to account for pesticide use, despite its significant implications for both

human and environmental health. To provide a holistic assessment of hidden costs, it is crucial to incorporate the cost of pesticide production and the industrial use of water and power in the overall analysis.

- Alternative data sources: In assessing disease burden and health-related indicators, demographic data, including age-specific death rates and population age distribution, can be sourced from the Registrar General of India. This dataset provides updated information that can be used to analyze the disease burden. The Periodic Labor Force Survey 2022 provides recent labor force statistics, particularly those related to individuals employed in agrifood systems. Furthermore, data from the National Sample Surveys and the National Family Health Survey (5th round) play crucial roles in determining food consumption patterns and evaluating protein-energy malnutrition, essential for understanding and improving productivity losses due to undernourishment in India. Some studies have utilized the 75th round of the National Sample Survey Organization, specifically the "Key indicators of social consumption in India: Health" for 2018, to assess quality-adjusted life years (QALYs) as an alternative to DALYs for representing health outcomes.

Several observations were made by stakeholders in the two consultation events organized by IIMA in India in December 2023 and January 2024. Key points that emerged are as below:

1. The calculation of environmental costs should include the role of agricultural machinery during production and transport to provide a comprehensive analysis.
2. Include energy costs associated with the production of pesticides and fertilizers to ensure a more accurate assessment of hidden costs.
3. Account for health issues arising from the application of pesticides in production, acknowledging the potential impacts on both human health and the environment.
4. Incorporate the climate impact and associated costs in the analysis to address the broader environmental consequences of agricultural practices.
5. Evaluate hidden costs related to bringing about the transformation of food and land use systems, recognizing the intricate implications for sustainability.
6. Consider future trends and evolving consumer tastes to provide insights into the shifting dynamics of the agrifood sector.
7. Recognize the significant awareness costs associated with transitioning diets and incorporate them into the analysis.
8. Revisit marginal cost calculations to ensure accuracy and relevance in capturing the dynamic nature of economic factors, especially exchange rates and fiscal policies in countries.
9. Include bifurcation of trade in the analysis, especially for countries like India where a substantial portion of food production is exported. Distinguish between the costs of food production for internal consumption versus exports.
10. Explore alternative methods that account for the production of goods for demand, both tradeable and non-tradeable, and elucidate how cost calculations from these methods might differ in the Indian context.

6.3 Evolution of hidden costs by 2030 and 2050

6.3.1 The Model of Agricultural Production and its Impact on the Environment (MAgPIE)

To simulate scenarios for transforming India's food systems, the India country case study employs the Model for Agricultural Production and its Impact on the Environment (MAgPIE). MAgPIE, a partial equilibrium optimization global land-use model, integrates economic, environmental, and biophysical data (Dietrich et al., 2019a) to the minimization of the global agricultural production costs and the fulfilment of agricultural demand. It projects the potential impacts of various agricultural policies and practices on land use, crop yields, and resource utilization and is therefore instrumental in understanding how different policy choices can influence India's agricultural landscape, food security, and environmental sustainability. This model has previously been used to determine sustainable transformation pathways for India, as well as specifically to identify appropriate water governance policy measures in India (Jha et al., 2022; Singh et al., 2023). The scenarios used here are part of a larger suite of scenarios developed for the Food Systems Economics Commission (FSEC) early in 2023. Details of the multi-model system developed for this analysis are presented in Bodirsky et al. (2023) with India specific analysis in Singh et al. (2024).

To identify the main intervention areas for agrifood system transformation and the most influential factors of reducing the hidden costs, we create multiple individual food system measures (FSMs) and external transition pathways that comprise points of action outside the food systems (presented in Table 6-5). Several FSMs are combined into packages and evaluated as individual scenarios to evaluate their contribution towards the desired transformational change represented by the full systems transformation pathway. We call it the "food systems transformation sustainable development pathway" (FSDP). The effects of all scenarios are systematically evaluated across 14 indicators of food system changes encompassing the four dimensions of health, environment, inclusion, and economic costs: underweight, obesity, premature mortality, crop area diversity, biodiversity intactness index, nitrogen surplus, GHG emissions, environmental flow violations, poverty, expenditure on agricultural products, employment, agricultural wages, bioeconomy supply, and production costs.

6.3.2 Scenarios

The baseline scenario, Business-as-usual (BAU) or Current Trends (CT) is the first scenario. This scenario is parametrized according to the "middle-of-the-road" narrative of the shared socioeconomic pathways (SSP2) (O'Neill et al., 2017; Popp et al., 2017; Riahi et al., 2017) where the plausible future state of the food system continues with the current trends. Indicators like human development, lifestyles, economic growth, and technological development align with the currently observed trends. The population in India under this scenario is expected to reach 1.65 billion by 2050 from 1.39 billion in 2020. Urbanization trends are expected to grow moderately as the urban population is expected to increase to 0.87 billion by 2050 from 0.49 billion in 2020. The expected climate change impact on crop yields is based on RCP 6.0 projections (Representative Concentration Pathway). This scenario assumes moderate mitigation efforts to reduce emissions, resulting in a stabilization of radiative forcing at 6.0 W/m^2 by the year 2100 (van Vuuren et al., 2011). Dietary changes reflect the historical food consumption patterns with moderate consumption growth and increasing share of animal sourced foods (ASFs) along with rising income. Future simulations for crop yields are obtained from the LPJmL global hydrology and vegetation model (Von Bloh et al., 2018). Crop yields are further projected in MAgPIE through spatial allocations and an endogenous investment in yield-increasing R&D and technology which improves future yields at optimal costs. Afforestation targets that are in line with India's commitments on the Nationally Determined Contributions (NDCs) to the Paris Agreement, whereby India has pledged to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through afforestation and reforestation by 2030. Trade patterns in the model for India adhere to historical trends, prioritizing self-sufficiency goals. The objective is to fulfil agricultural demand through a combination of domestic production and export-oriented strategies at minimum production costs. The model considers trade costs, tariffs and trade margins, to fully account for the dynamic nature of trade. Area-based land conservation approach is implemented in this scenario. Land reserved for area-based conservation is derived from World Database on Protected Areas (WDPA) and is based on observed land conservation trends. The WDPA database includes all areas under legal protection meeting the IUCN and CBD protected area definitions (including IUCN categories Ia, Ib, III, IV, V, VI and "not assigned" but legally designated areas). Natural vegetation and grasslands or pastures within protected areas are not allowed to be converted to other land types.

In comparison, we create an alternative sustainable transformation pathway (FSDP) or Food System's Transformation (FST) which integrates 23 individual food system measures (FSMs). Sustainable food system transformations, especially in the context of developing economies, are intertwined within broader socioeconomic and structural changes outside of the food system (Béné et al., 2022; Nguyen, 2018). Identifying the significance of sustainable external transitions, the FSDP pathway therefore includes an additional five transformation domains from outside the food system.

The total of 28 transformation domains (comprising both within and outside food system changes) are represented by five distinct packages or policy measure bundles: 1) healthy diets and sustainable consumption patterns (Diets); 2) nature-positive agricultural transition (Agriculture); 3) biodiversity protection (Biodiversity); 4) equitable livelihoods (Livelihood); and a broader socioeconomic development external to the food system (CrossSector). However, for the purposes of assessment of hidden costs in the transformations of agrifood systems in India, we use a selection of single transformation pathways, addressing the findings from the SOFA 2023 report, along with three policy measure bundles and the final package FSDP that integrates each of these measures.

The FSDP scenario represents a range of interventions such as healthy dietary changes, sustainable consumption patterns, and targeted reductions in prevalence of malnutrition like increased intake of fruits and nuts, leguminous crops, reduced food waste and loss, sustainable agriculture and biodiversity protection measures including nitrogen efficiency, water conservation through environmental flow protection, land conservation and nitrogen use efficiency in agriculture. Under this scenario, the population would reach 1.60 billion by 2050 from 1.39 billion in 2020 based on the underlying SSP1 parameterization assumption. The urban population is expected to increase to 1.01 billion by 2050 from 0.52 billion in 2020. The climate change scenario is based on RCP 1.9 which limits global warming to below 1.5ºC, aligning with the Paris Agreement. Crop yields increase 0.3% between 2020 and 2050 in this scenario to meet future demand given the transition to SSP1 trajectory of population and GDP. Afforestation targets remain the same as BAU, whereby India's commitments to NDC targets are implemented. A liberalized trade regime that encourages trading patterns through comparative advantage is implemented in the model. This encourages reduction in exports of land- and water-intensive cereal crops in India and increases India's imports of these crops. An expansion of protected areas through the conservation of biodiversity hotspots and intact forest landscapes, in addition to WDPA restrictions, are implemented in this scenario.

These two scenarios – BAU and FSDP – differ in several other indicators. Details of the scenarios selected for this analysis are presented in Table 6-5.

Table 6-5: *FSEC scenario description*

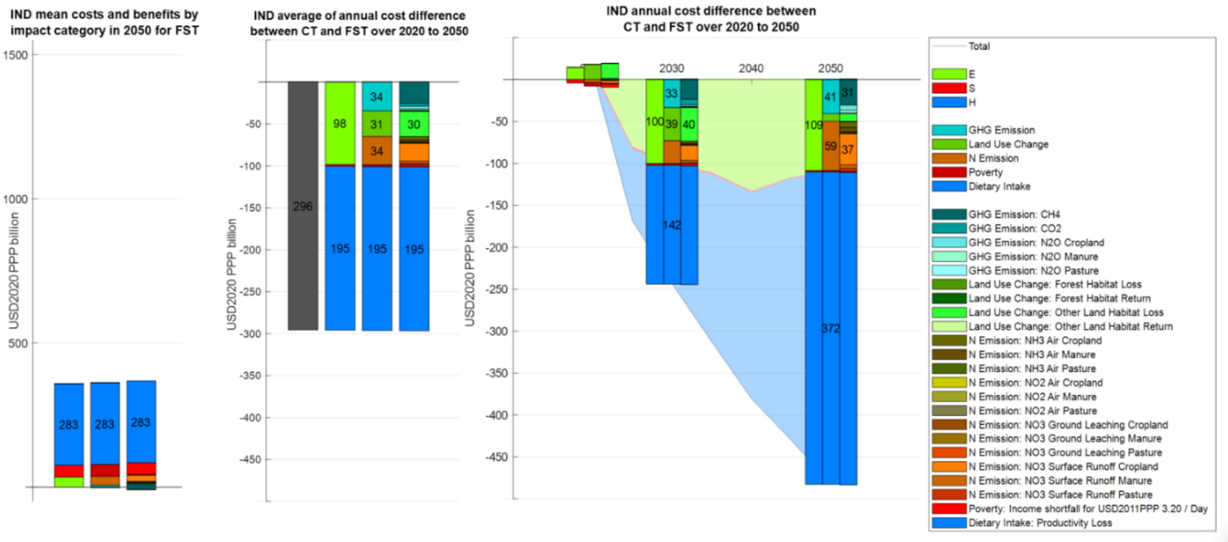
Scenario parameter(s)	BAU/CT	FSDP/FST
Population	SSP2 (1.65 million people by 2050)	SSP1 (1.6 million people by 2050).
Food demand	SSP2 trends	Transition to healthy diets recommended by the EAT-Lancet Commission.
Obesity reduction	No target	Calorie intake is reduced to achieve a reduction of overweight and obesity by 50% relative to BAU. Calorie reduction is BMI-class, country, age-group and sex specific. The intake of half of the people overweight or obese (BMI>25 for adults, BMI +/-1STD for children) is reduced to intake recommended for a healthy BMI (20-25, BMI <+1STD). Relative dietary composition is not affected. The intake of people in other BMI classes is not affected.
Malnutrition reduction	No target	Calorie intake is increased in line with a complete eradication of underweight until 2050 for all age cohorts and sex classes
Trade	Self-sufficiency imposed	Relative cost-competitiveness, in terms of production and trade margins and tariffs are implemented. Liberalized trade is implemented, increased share for crops from 20 to 30% for crops, and from 10 to 20% for livestock and secondary products.
Agricultural wages	No change	A global minimum wage increases wages in the lower income countries. The minimum wage scenario increases wages to at least 3 USD 2005 Market Exchange Rate per hour by 2050.
Agricultural labor	No change – 96 million people employed in agriculture by 2050	Labor supply is increased to reach labor: capital ratio of 80:20 – results in 89 million people employed in agricultural labor by 2050.
Afforestation	Afforestation targets follow NDC/NPI policies to ensure 33 Mha afforestation by 2030 and no change thereafter	Afforestation targets follow NDC/NPI policies to ensure 33 Mha afforestation by 2030 and no change thereafter.
Biodiversity conservation	The protected area based on World Database on Protected Areas (WDPA) is included	The Biodiversity Intactness Index (BII) in each biome of each world region cannot decrease after 2020.
Livestock productivity	No change	Improved future livestock productivity developments and related changes in feed baskets towards more concentrate feeds, using SSP1 instead of SSP2 parametrization (Weindl et al., 2017).
Crop productivity	Endogenous changes in crop yield to meet food demand	Endogenous changes in crop yield to meet food demand.
CH_4 emissions from agricultural production	44 CO_2e by 2050	28 CO_2e by 2050 (reduction by ~50%).
Water withdrawal for agricultural production	40% reduction in water withdrawals by 2050 due to improved irrigation efficiency	Change in crop production and water efficiency results in 35% reduction in water withdrawals by 2050, as compared to 2020.

Use of bioplastics	No change	Of the projected total plastic demand (675 Mt by 2050 (OECD, 2022)), 30% is replaced by bioplastics. Bioplastics require bio-materials as substrates.
Share of food expenditure out of total expenditure	Reduces from 0.06 in 2020 to 0.03 by 2050 (reduction of 50%)	Same.
Timber cities	No target	Wood is used as construction material for cities. We assume that 50% of new urban dwellers (after 2020) are housed in buildings made of engineered wood (Mishra et al., 2022) to replace carbon-intensive steel and concrete housing construction. This increases future timber demand by 2212 million m^3 (compared to 2020) and thereby increases the need for increased harvesting from forests.
Landscape habitats	No target	Conserving at least 20% permanent semi-natural habitats at the landscape level (e.g., for pollination, pest control, soil protection). Semi-natural habitats include forest, non-forest and grassland habitats that can maintain and restore native species diversity.
Nitrogen surplus	Increased nitrogen surplus from land and manure management from 22 Mt Nr/yr in 2020 to 31 Mt Nr/yr by 2050	Reduction in nitrogen surplus from land and manure management by ~45% by 2050 (17 Mt Nr/yr). This occurs through technical measures such as improved land manure application, spreader maintenance, improved agronomic practices, sub-optimal fertilizer applications, nitrification inhibitors and fertilizer free zones.

6.3.3 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

The breakdown of India's annual hidden cost reduction under FSDP in 2020 PPP dollars in 2020, 2030 and 2050 is shown in Figure 6-4. Large average hidden cost reductions under FSDP over 2020–2050 come from a reduction in burden of disease from dietary change, CH_4 emission reductions from livestock and rice production, avoided cropland expansion, and mitigating NO_{3^-} run-off from cropland (middle panel). These values also include uncertainty in production costs emerging from GHG and reactive nitrogen emissions as well as the loss of habitat from land use changes. Details of the uncertainty estimates are presented in (Lord 2023b). Reduction in nitrogen pollution contributes more during the later period (right panel). Environmental hidden cost reduction and productivity losses from the burden of disease arising out of food consumption have an approximately equal contribution to hidden cost reduction over the period 2020–2050 (middle panel). The reduction in environmental hidden costs stabilizes while the avoided productivity losses from burden of disease increase over the period (right panel). Residual hidden costs by 2050 under the FSDP trajectory are predominately productivity losses from food consumption, income shortfall from the USD 3.20/day (2011 PPP) poverty line, and nitrogen pollution (left panel). There is little difference between BAU and FSDP in income shortfall from the USD 3.20/day (2011 PPP) poverty line and this is because poverty reduction is driven by economic growth of all sectors in SSP2 and not in the implementation of FSDP measure.

Figure 6-4: *Change in hidden costs across cost heads and scenarios BAU and FSDP between 2020 and 2050*



Note: Breakdown of India annual hidden cost reduction under FST in 2020 USD PPP in 2020, 2030 and 2050, developed and presented in (Lord 2023b).

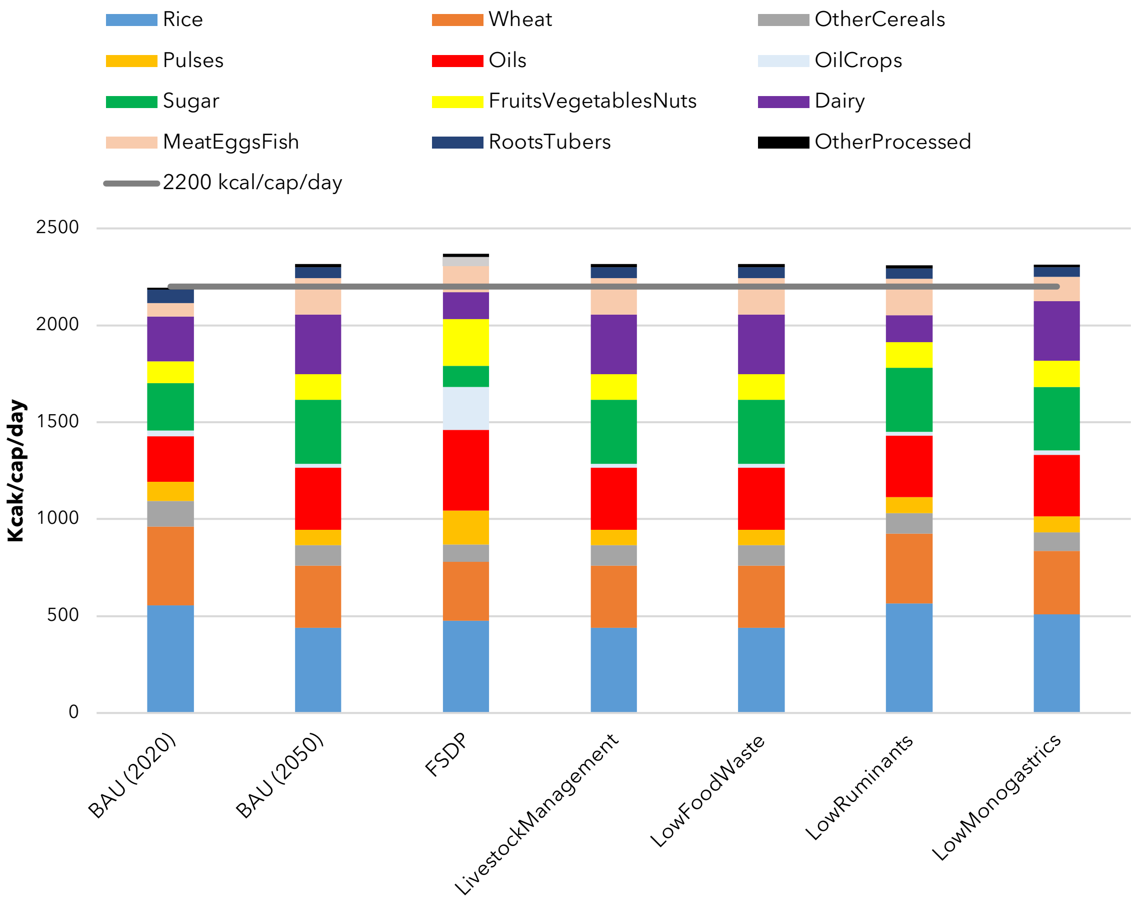
To further elaborate on the drivers of change for the key indicators, we undertook a decomposition analysis with eight single scenarios (scenarios in which only one parameter is changed in comparison to the BAU). We compared each of these between the BAU and FSDP and present detailed results on the ways in which these reductions can be obtained.

Food demand

Since dietary patterns are major drivers of hidden costs in India, we find that changing food demand through the transition to EAT-Lancet diets in the FSDP scenario increases the overall calorie intake to 2,369 kcal per capita per day by 2050. Although the difference in calorie intake between BAU and FSDP is not high, major differences reflect in the change in consumption of key food groups such as rice and wheat, sugars and dairy and meat products. There is no difference in overall calorie intake across single scenarios as food demand is the main driver of the model. In our modeling scenario, it is the change of consumption of various food groups that causes a difference in hidden costs (Figure 6-5).

Transitioning to healthy diets recommended by the EAT-*Lancet* Commission in the FSDP scenario results in overall higher calorie intake than the BAU and the changes in consumption of cereals, legumes and dairy, resulting in the lowering of hidden costs. The EAT-*Lancet* is typically a low meat scenario, but largely applicable for regions with historically high levels of meat consumption. For regions such as India, where meat consumption is historically lower, there is a need to maintain normal levels of consumption. Recent statistics from India's food consumption surveys reveal a remarkable increase in protein sources such as dairy, eggs, and meat over the past two decades. The recommendations for India in our analysis points towards a reduction in cereal crops, milk and sugars and increase in consumption of fruits and vegetables. Other dietary scenarios that target consumption of specific food groups, such as ruminants and monogastrics, also reduce the intake of those food groups, with the calorie gap compensated by cereals. As a result, the consumption of cereals is higher than the FSDP and BAU scenario in 2050 in these scenarios. This is also a contributing factor in the lower hidden costs in the FSDP scenario as compared to BAU.

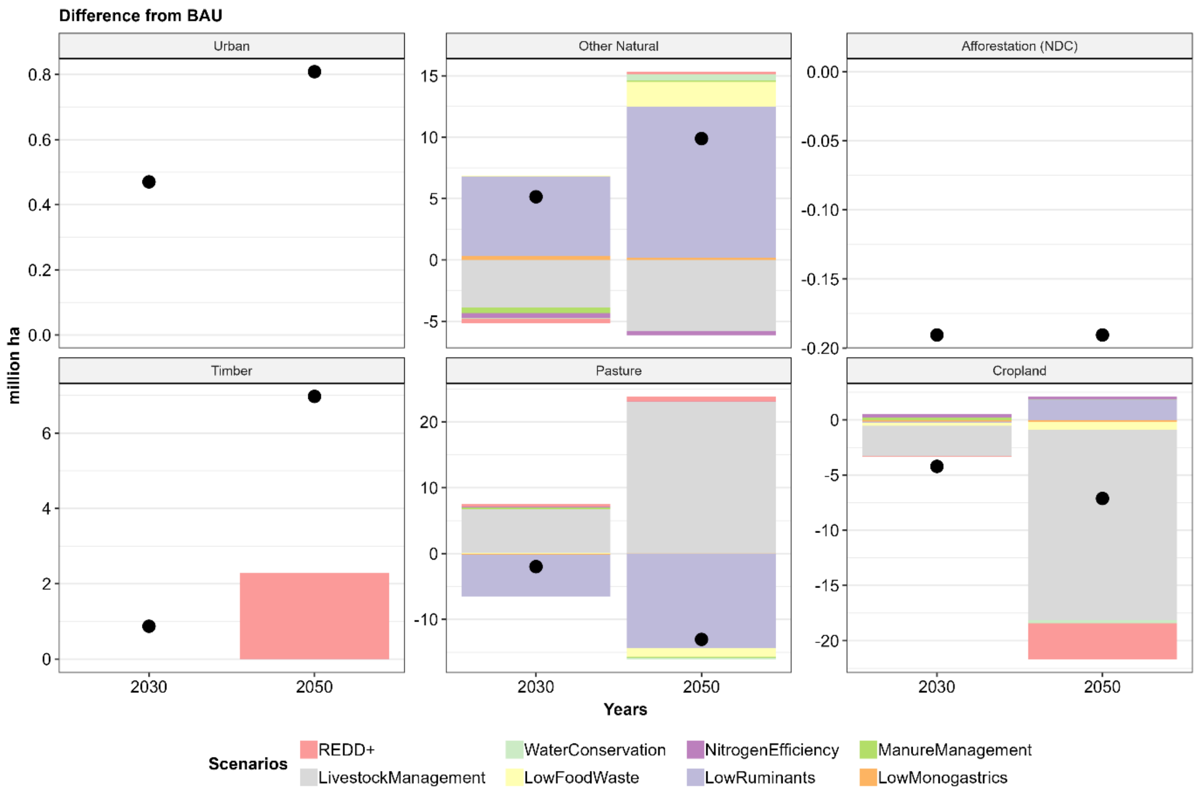
Figure 6-5: *Consumption of various food groups across dietary scenarios between 2020 and 2050*



Land use change

We present the change across land use types across scenarios by 2030 and 2050, in comparison to BAU in Figure 6-6. The livestock management scenario results in greater changes in cropland and pasturelands by 2050 due to improvement in feed efficiency that results in lower requirement of pasture lands and lower requirements of croplands (for production of fodder crops). A large reduction is observed in pasturelands between the two scenarios, with a reduction of approximately 57% between the BAU and FSDP scenarios by 2050. On the other hand, slight increases in timber and urban lands are observed in the FSDP as compared to BAU scenario. We observe no change in afforestation across scenarios from BAU due to the assumption of India's NDC targets even in the BAU scenario.

Figure 6-6: *Changes in land use types across scenarios by 2050, in comparison to BAU*

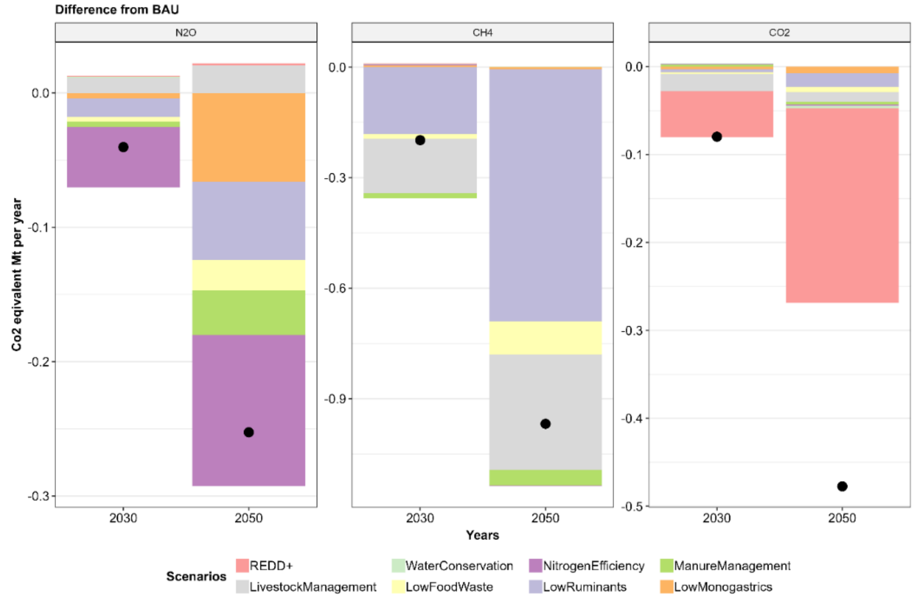


Note: Black dot refers to the FSDP scenario

GHG emissions

We present the trajectory of three types of GHG emissions (N_2O, CH_4 and CO_2) from agricultural activities and land use change in Figure 6-7. We find that the highest reductions in N_2O emissions are brought by the nitrogen efficiency scenario that targets the nitrogen application to soils through advanced practices such as improved manure management. Additionally, mitigation pricing is implemented in this scenario through improved soil nutrient uptake efficiency, resulting in an overall reduction of N_2O emissions by 31% in 2050, as compared to BAU. Similarly, methane emissions are lowest in the low ruminants scenario (reduction by 56%) by 2050 because of the reduced demand for ruminant meat consumption in this scenario, as compared to the BAU. We observe the largest reductions in CO_2 emissions in the REDD+ scenario (200%). This comes from the implementation of carbon prices, which disincentivize deforestation and promote the regeneration of natural vegetation.

Figure 6-7: *Difference in emissions of GHG gases (CH_4, N_2O and CO_2) across scenarios in 2050, in comparison to BAU*

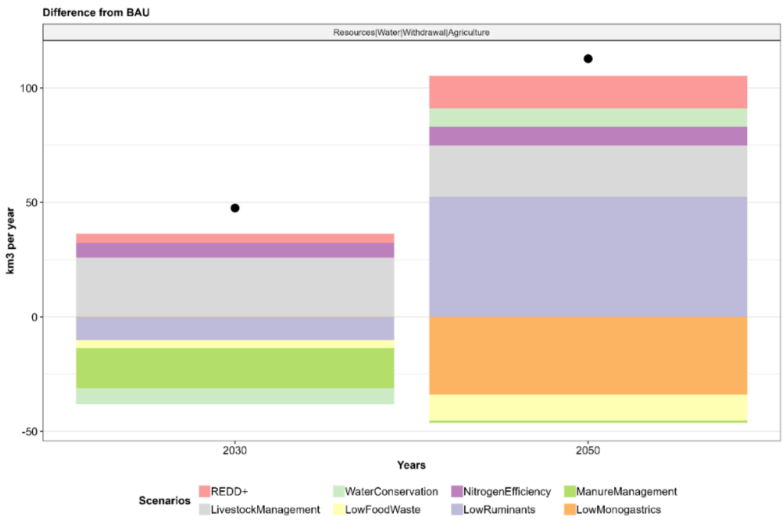


Note: Emission values are converted in CO_2 equivalent for all gases. Black dot represents the FSDP scenario. Emission values represent a result of agricultural activities and land use change.

Water withdrawals

We observe significant trade-offs in blue water use for agricultural withdrawals across the scenarios (Figure 6-8). While benefits of the FSDP measures are observed across all indicators, we find higher withdrawals of blue water in the FSDP scenario (423 billion cubic meters by 2050) and a 36% increase than BAU by 2050. Single scenarios that contribute most to this higher rate of water withdrawals are low ruminants and livestock management, which are 17% and 7% higher than BAU in 2050, respectively.

Figure 6-8: *Change in agricultural water withdrawals across scenarios by 2050, in comparison to BAU*

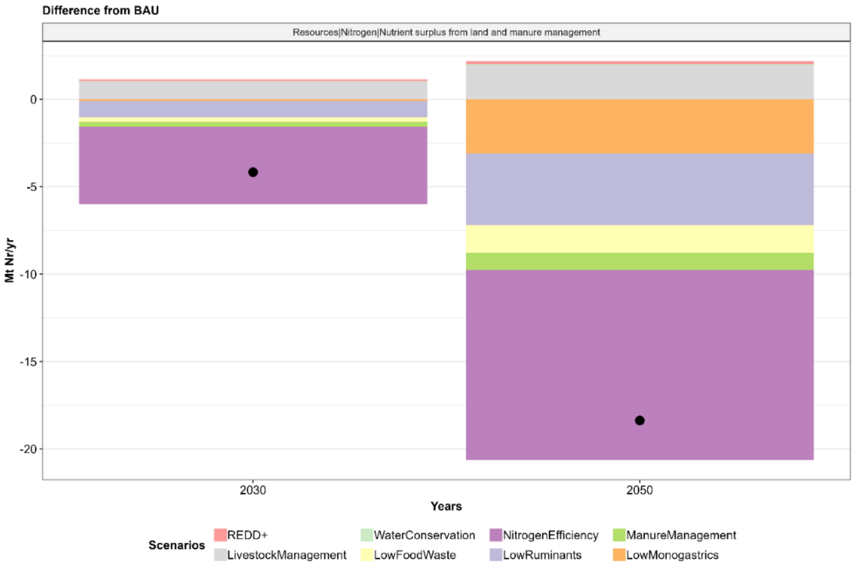


Note: Black dot represents the FSDP scenario.

Nitrogen surplus from land and manure management

We find significant effects of policy measures that target nitrogen usage (nitrogen efficiency scenario) and manure management (manure management scenario) on nitrogen surplus from land and manure (Figure 6-9). Combined in the FSDP, these scenarios result in a reduction of nitrogen surplus on land and manure by 61% in the FSDP scenario by 2050, as compared to the BAU. This occurs due to an increase in nitrogen efficiency uptake rates through technical measures such as improved land manure application, spreaders, but also to meet mitigation rates under nitrogen budgets.

Figure 6-9: *Changes in nitrogen surplus from agriculture and land use change, across scenarios by 2050, in comparison to BAU*



6.3.4 Entry points for action and foreseen implementation challenges

We highlight key entry points for action towards reduction of hidden costs in India as below:

Food security and health

- Strengthen the National Food Security and Nutrition Mission 2021 to promote diverse food group consumption, emphasizing legumes, fruits, vegetables, and nuts, to improve health outcomes.
- Encourage policies to reduce rice consumption and shift towards alternative grains to lower CH4 emissions, considering regional diet preferences.
- Address high disease burden by reducing consumption of sugars and oils (processed foods) in both urban and rural areas to improve labor productivity and mitigate hidden food system costs.

Agriculture

- Reform agricultural incentives by reducing subsidies on nitrogenous fertilizers to curb adverse soil deposition and nitrate run-off impacts.
- Government investments in assessment of soil and water health in croplands. This will help determine the degrading conditions and provide evidence to farmers to nudge towards reducing the excessive nitrogen application.
- Reform energy subsidies aimed at efficient water use to discourage over-extraction of groundwater, thus reducing hidden costs associated with water usage in India.

Land use

- Implement policies to restrict land use changes from forests to cropland and pastures to preserve forest cover.
- Focus on no-deforestation policies and promote afforestation initiatives to minimize forest loss and maintain ecological balance.
- The AFOLU sector in India is a net carbon sink and therefore adequate efforts need to be made to reduce the CH_4 and N_2O emissions from land use and land use change.

These recommendations highlight specific actions needed in the areas of nutrition, agriculture, and land use to address hidden costs and improve the sustainability of India's food system and environment. Each recommendation targets key factors contributing to hidden costs and offers practical strategies for policy action. Notably, shifts in dietary patterns, curbing nitrogen emissions from cropland surface run-off, and managing land use change emerge as pivotal factors for cost reduction in India. Over the 2020–2050 period, substantial reductions in hidden costs are evident, attributed to factors such as decreased burden of disease from food consumption, methane emission cuts from livestock and rice, avoided cropland expansion, and effective mitigation of nitrate run-off from cropland. The study highlights the balanced contribution of factors like production cost uncertainty, greenhouse gas emission reduction, habitat reservation, and nitrogen pollution reduction to the overall reduction in hidden costs.

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