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Pathway to achieve a sustainable food and land-use transition in India

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Abstract

India has committed to reducing the emissions intensity of GDP by 33–35% from the 2005 level by 2030 in alignment with objectives of the Paris Agreement. This will require a significant reduction in greenhouse gas (GHG) emissions from the food and land-use sector. In this paper, we construct three potential food and land use pathways for India to achieve its emissions target by 2050 involving moderate ambitions of mitigation action (BAU), moderate ambitions combined with achieving healthy diets (BAU+NIN), and high levels of mitigation action inclusive of healthy diets. Using an integrated accounting tool, the FABLE Calculator, that harmonizes various socioeconomic and biophysical data, we project these pathways under the conditions of cross-country balanced trade flows. Results from the projections show that the demand for cereals will increase by 2050, leading to increased GHG emissions under BAU. Under the Sustainable pathways, GHG emissions will decrease over the same period due to reduced demand for cereals; whereas, significant crop productivity and harvest intensity gains would lead to increased crop production. The exercise reveals the indispensability of healthy diets, improved crop, and livestock productivity, and net-zero deforestation in achieving India's mid-century emission targets from the agriculture sector.

Keywords: SDGs, Integrated Assessment, Shared Socio-Economic Pathways, FABLE Calculator, GHG emissions essential

1. Introduction

The food, agriculture and land use system is one of the largest contributors to greenhouse gas (GHG) emissions (Loboguerrero et al., 2019; Clark & Tilman, 2017), with various estimations putting them in the range of 21-37% of the total GHG emissions in the world (IPCC, 2019; Crippa et al., 2021; Rosenzweig et al., 2020; Tubiello et al., 2021). Increases in population, incomes and food demand is expected to exert further pressure on the land-use system (Kearney, 2010; Westhoek et al., 2014; Mohan, 2018), thereby weakening the chances for meeting SDG targets in the planned timelines. Since agriculture is one of the major sector in terms of rural livelihood, it is important to understand the tradeoffs in meeting food demands and sustainability targets. Despite of the low value addition from the agriculture sector to total GDP, agricultural led growth will play an important role in rural development, poverty reduction, and reduction in undernutrition (Pingali, P., & Aiyar, A., 2018; Pingali et al., 2019). For instance, 90% of total freshwater is used for agricultural activities (FAO, 2020), while 44% of the country's land area is degraded due to overuse of agrochemicals, excessive irrigation, deforestation, soil erosion and hazards such as floods (Mythili & Goedecke, 2016; Damerau et al., 2020; Harris et al., 2017; Hinz et al., 2020; Alexandratos & Bruinsma., 2012, Priya, 2021; Majhi et al., 2021). While cropland intensification and technological deepening is a proposed solution (Mauser et al., 2015; Brahmanand et al., 2013), they pose serious negative externalities of higher fertilizer use and faster groundwater depletion; as well of increased land use change related emissions.

Food and nutrition insecurity adds to the challenge as solving these require increased agricultural production. Current food demand in India is neither very favourable to good health nor to emissions (Vetter et al., 2017; Springmann et al., 2018; Pingali et al., 2019; Green et al., 2016; Milner et al., 2017; Rao et al., 2018). There is a high dependency on water intensive cereals and sugarcane crops for meeting the minimum daily energy requirements (MDER). Overconsumption of sugar leads to non-communicable diseases and obesity and under-consumption of key nutritious food groups have caused malnutrition in a large section of the population. Agricultural diversification, increased participation in agricultural activities and change in dietary patterns also cause the increase in obesity and decrease in nutritional intake among women in rural India (Padmaja et al., 2018; Vemireddy and Pingali, 2021). India's National Institute of Nutrition (NIN) has made dietary intake recommendations for the Indian population based on age, gender and

activity levels (ICMR, NIN). While these dietary recommendations can lead to a healthy transition, the environmental impacts of those are unknown (Gavaravarapu et al., 2018).

Even if food production is increased to meet demand through healthy dietary transitions, food loss and waste can puncture the efforts at achieving security and reduced emissions. In India, food losses in the supply chain range between 3.9-6.0% for cereals, 4.3-6.1% for pulses, 5.8-18.1% for fruits, and the maximum for vegetables (6.9-13.0%) during post-harvest operations and storage (Jha et al., 2015; Nanda et.al. 2012), amounting to post-harvest losses of approximately INR 926.51 billion (USD 15.19 billion) (Agarwal et al., 2021). Combined with a shift in diets and increased crop productivity, a reduction in food supply chain losses has the potential to aid sustainable transitions

However, there have been no studies so far that have undertaken a joint assessment of these different aspects of sustainable transformations for India. Pingali et al., 2019 highlighted several concerns related to the transformation of the food system in India. One of the major concerns highlighted in the literature is managing climate risk in the food system especially related to first, how the climate change is going to alter the agriculture productivity and will have a negative impact on the nutritional availability. Second, Reduction in GHG emissions from the agriculture sector, and third, impacts on trade that leads to the exports of other goods. In our study, we tried to address these concerns by modeling the several aspects of food and land use system. In this paper, we present three potential scenarios that determine long-term strategies for food and land use systems with potential mitigation actions for India using a new accounting tool that integrates multiple sectors with agriculture as the main driver. Our analysis focuses on understanding trade-offs between the various demands for food and land use allowing a possible sustainable pathway for India to achieve its GHG emission reduction targets by 2050. These pathways have been developed based on the current trajectories extended upon the targets to meet a nationally recommended healthy diet, and further extended to meet certain sustainability targets through several mitigation strategies, including dietary transition. This allows us to assess the feasibility of meeting healthy diet targets across land-use systems, *ceteris paribus*, and parallelly determine the benefits of other transformations in meeting SDG targets.

This paper is divided into 6 sections. In Section 2, we discuss the materials and methods used for the creation of three potential long-term pathways for India. This is followed by a discussion on

scenarios and related assumptions in Section 3. In Section 4, we highlight main results concerning implications on food intake, land-use change, changes in emissions from respective sources as well as changes in water use across the different pathways. We undertake a discussion of our results in light of the existing literature and policy landscape in India in Section 5, and in Section 6 we conclude the paper with remarks for policy action.

2. Materials and Methods

The FABLE Calculator is a tool for both researchers and policymakers as it has been developed using Microsoft Excel (Mosnier *et al.*, 2020). The tool was designed to make it user-friendly across persons with different skill sets, and hence it does not demand any knowledge of specific tools and software. It works transparently for calculations, assumptions, data inputs, and outputs. In its current settings, the Calculator's historical data and future results are computed for every five years' time step over the period 2000-2050. Built-in formulae connecting various sheets and assumptions that lead to multiple dynamic changes are easily visible and tested iteratively. The Calculator uses national-level data on indicators such as food use, agricultural production, water use in crop production, GHG emissions from various sources, and land use across different competing categories, including wastelands. All socioeconomic and biophysical data are gathered and harmonized in respective sheets for formulation and creating projections of critical parameters of interest. Projections in the model are developed using various assumptions regarding demand, trade, agricultural and livestock productivity growth rates, post-harvest losses, food waste, and land-use management.

Global trade flows are balanced across countries as part of a marathon-like exercise called the `Scenathon` (more details in SI). A country's food demand and supply projections account for import and export relationships with trading partners to create future forecasts of food production and trade scenarios. Assumptions on a country's trade patterns are made using historical data and national trade policies for outlook. The average impact of climate change on crop productivity at the national level is computed based on the ISIMIP database (van Vuuren *et al.*, 2011).

In this paper, we estimate the projections until 2050 based on three scenarios for a Sustainable food land-use system: a) Business as usual (BAU) as a reference scenario, b) BAU along with a dietary shift towards recommendations made by the National Institute of Nutrition (NIN), named

BAU+NIN, and c) SUSTAINABLE, where food demand is also on the lines of NIN diets. Since NIN recommendations form the central point of deviation between the scenarios, Figure 1 below demonstrates the key differences in dietary intake recommendations between the scenarios. These values represent the proportion of food groups for a 2000 kcal target by the average population. Recommendations from NIN encourage reduced consumption of cereals crops and much lesser consumption of sugars. There is at present no distinction between plant and meat-based sources of protein in these recommendations. For comparison purposes, we have combined the plant and meat sources of protein for the BAU scenario as well.

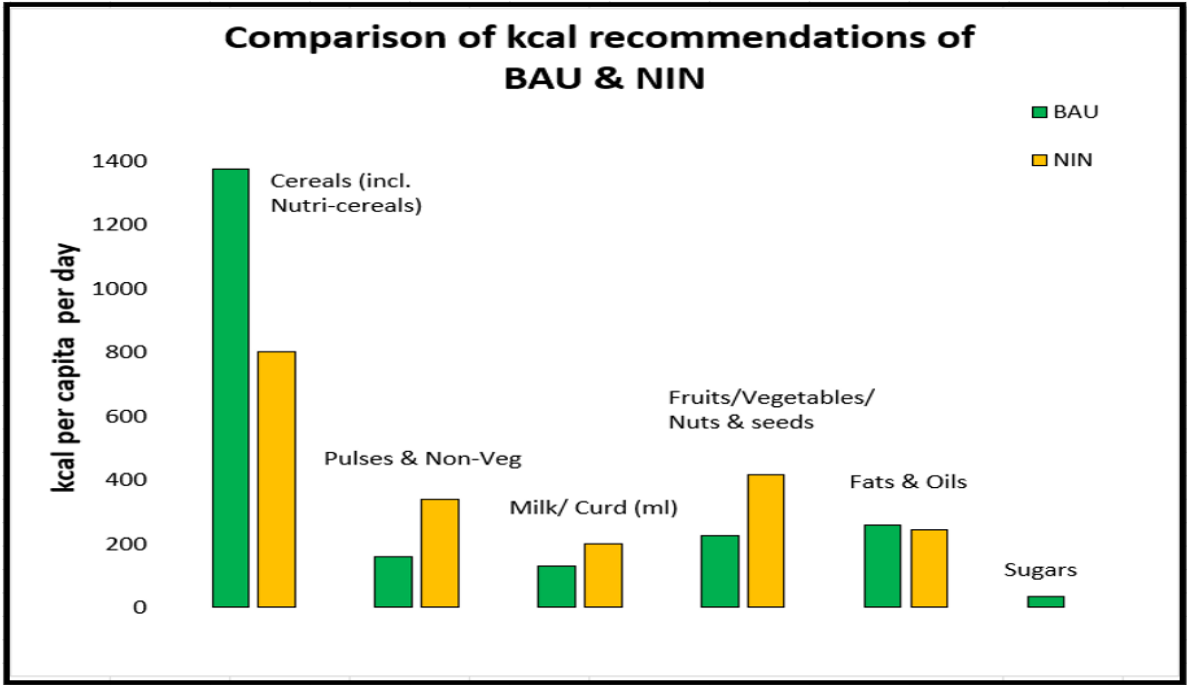


Figure 1: Comparison of kcal intake recommendations between BAU and NIN

The underlying assumptions across the scenario for the primary drivers such as population, GDP, and food are on the lines of shared socioeconomic pathways (SSPs). Levels of other indicators are mostly parameterized based on no growth versus high growth (crop and livestock productivity), reduced versus increased food loss, different afforestation target, high versus low trade volume and low versus high resource efficiency (water), among others.

Table 1. Key assumptions of our scenarios - BAU, BAU+NIN, and SUSTAINABLE pathways.

| <i>Scenarios</i> | <i>GDP</i> | <i>Population</i> | <i>Food</i> | <i>Trade</i> | <i>Climate Change</i> |
|--------------------|------------|-----------------------------|-------------|---|---|
| <i>BAU</i> | SSP2 | SSP2 (1.63 billion by 2050) | FAO2010 | Exports- Moderate Increase Imports- Stable | RCP6p0 (change in global temperature by 3 to ~3.5 ⁰ C by 2100) |
| <i>BAU+NIN</i> | SSP2 | SSP2 (1.63 billion by 2050) | ICMR-NIN | Exports- Moderate Increase Imports- Stable | RCP6p0 (change in global temperature by~3 to ~3.5 ⁰ C by 2100) |
| <i>Sustainable</i> | SSP1 | SSP1 (1.48 billion by 2050) | ICMR-NIN | Exports- Increased Imports- Reduced | RCP2p6 (change in global temperature by~1.5 to ~2 ⁰ C by 2100) |

In our BAU pathway, future GDP and population growth are based on SSP2 projections (Popp et al., 2017). The GDP projections under the BAU and BAU+NIN are 6.5 trillion USD (2005) by 2030 and 11.99 trillion USD (2005) respectively by 2050. The population projection under the same scenario is 1.5 billion by 2030 and 1.71 billion by 2050. All the assumptions for parameters such as GDP, population, food demand are taken based on these values. In the BAU+NIN pathway considering food demand as in FAO 2010, we have targeted the ICMR NIN recommendations (ICMR-NIN, 2020). In the SUSTAINABLE pathway, GDP and population projections assumptions follow SSP1 trajectory (Leimbach et al., 2017; PWC, 2017). The GDP projections under the BAU and BAU+NIN is 7.09 trillion USD (2005) by 2030 and 13.26 trillion USD (2005) by 2050 whereas population projection is 1.5 billion by 2030 and 1.71 billion by 2050. The assumptions for food demand in the SUSTAINABLE pathway follow the BAU-NIN scenario. In SSP1, GDP per capita is higher than SSP2, and the population growth rate is lower than SSP2. Since the prices are not included in the model and only used ex-post to compute production and trade values,

the prices do not influence the consumer preference and food demand.” Further to that the price elasticity has not yet been considered in the FABLE Calculator. The model account the income elasticity (Alexandratos and Bruinsma, 2012 and Valin et al., 2014) for demand as we assume change in per capita income across the scenario. In both the BAU and BAU + NIN pathways, we assume that livestock and crop productivity undergo moderate growth. In SUSTAINABLE, we assume both of them to increase at a high growth rate in comparison to growth between 2000 and 2010. We assume that under BAU, productivity growth will be the same as between 2000 and 2010. In addition to that, we assume the climate scenarios to be on the lines of RCP6.0. Under SUSTAINABLE, we assume an increase in crop productivity compared to the growth rate between 2000 and 2010 and a less severe climate scenario (RCP 2.6). These assumptions align with India's ambition to close the yield gaps of major crops through intensification. As per NCAER (2015), increased technological adoption would enable yield improvements; and that livestock and crop growth are not based on land expansion. In all the three pathways, therefore, we assume that there is no land expansion for agriculture (Mogollón et al., 2018; Valin et al., 2013).

The afforestation target included in our analysis aligns with the Government of India's pledge to uphold Bonn Challenge Commitments (Binod et al., 2017) of achieving afforestation to 21 Mha by 2030 in the BAU and BAU + NIN pathways (Borah et al., 2017). In a recent report by the Prime Minister's Office (Prime Minister's Office, 2019), the afforestation target for India has been further increased to 26 Mha by 2030, and therefore, in our SUSTAINABLE pathway, we assume this target. Other than these parameters, we also assume that the food waste and post-harvest loss under the SUSTAINABLE pathway would reduce to 5% as compared to the present levels. We assume a higher bioenergy demand based on OECD_AGLINK demand projections, which are OECD-FAO projections until 2028 (OECD-FAO, 2019), with stable levels afterward. Our assumption of biofuel demand is on the lines of India's new biofuel policy (Ministry of New and Renewable Energy, 2018).

Our pathways are set under different sets of atmospheric concentration of GHG trajectories, known as Representative Concentration Pathways (RCPs). Climate change impacts are introduced as shifters applied to crop yields, crop water requirements, and fertilizer use for each time step between 2015 and 2050. We use climate change impact data for both irrigated and rain-fed crops, based on two crop models, GEPIC and LPJmL, for four and 20 twelve crops respectively³ from

the ISIMIP database (Arneth et al., 2017). Under the BAU as well as BAU+NIN, we assume that the global temperature increase is restricted between 2 to 3 degrees, i.e., RCP 6.0 (GEPIC), whereas in SUSTAINABLE we assume global temperature increase is limited to 2 degrees i.e., RCP 2.6 (GEPIC) (Bondeau et al., 2007; Muller & Robertson, 2014).

3. Results

3.1. Food Demand

We assess our results on the base of international Minimum Dietary Energy Requirements (MDER) (FAO, 2008) for food demand and consumption outcomes. MDER represents the minimum daily energy requirements of the population (based on Body mass index (BMI) of different population groups by sex) along with varying population activity levels. In the case of India, MDER is approximately 2100 Kcal/capita/day under the SSP2 and SSP1 populations. Our results are in Figure 3 and show that feasible Kcal consumption is 1911 and 2018 Kcal/capita/day under the BAU by 2030 and 2050, respectively. These values are slightly below but close to MDER. Under the BAU+NIN scenario, Kcal/cap/day is 1792 and 1601 respectively by 2030 and 2050 and falls much below the MDER. Under the SUSTAINABLE, we are able to meet the MDER by 2030 and 2050 where feasible Kcal/cap/day reaches 2032 and 2296 kcal/cap/day by 2030 and 2050, respectively.

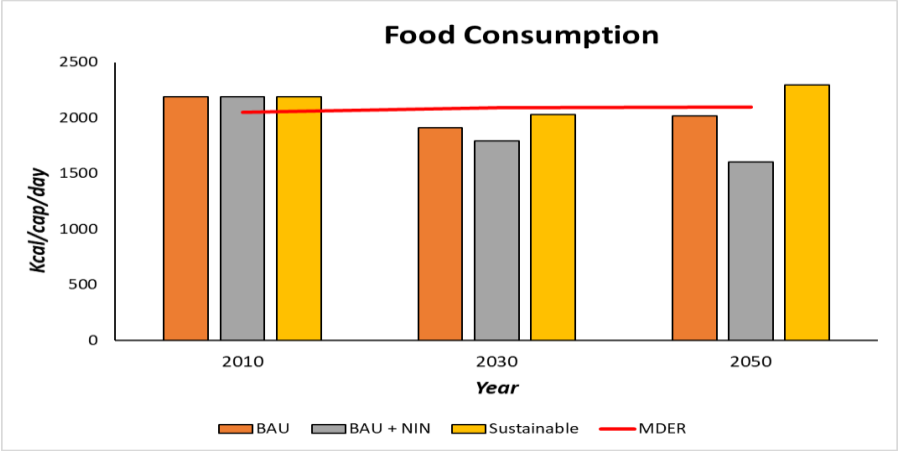


Figure 2. MDER and feasible Kcal consumption per capita per day under all scenarios

Changes in overall consumption patterns are exogenous across the scenarios and depend on underlying changes in food demand for that specific scenario. Therefore, our results align with the assumptions regarding the consumption of different food groups. Figure 4 summarizes the resultant dietary composition of the population in terms of food group consumed in kcal per capita per day across the scenarios up to 2050.

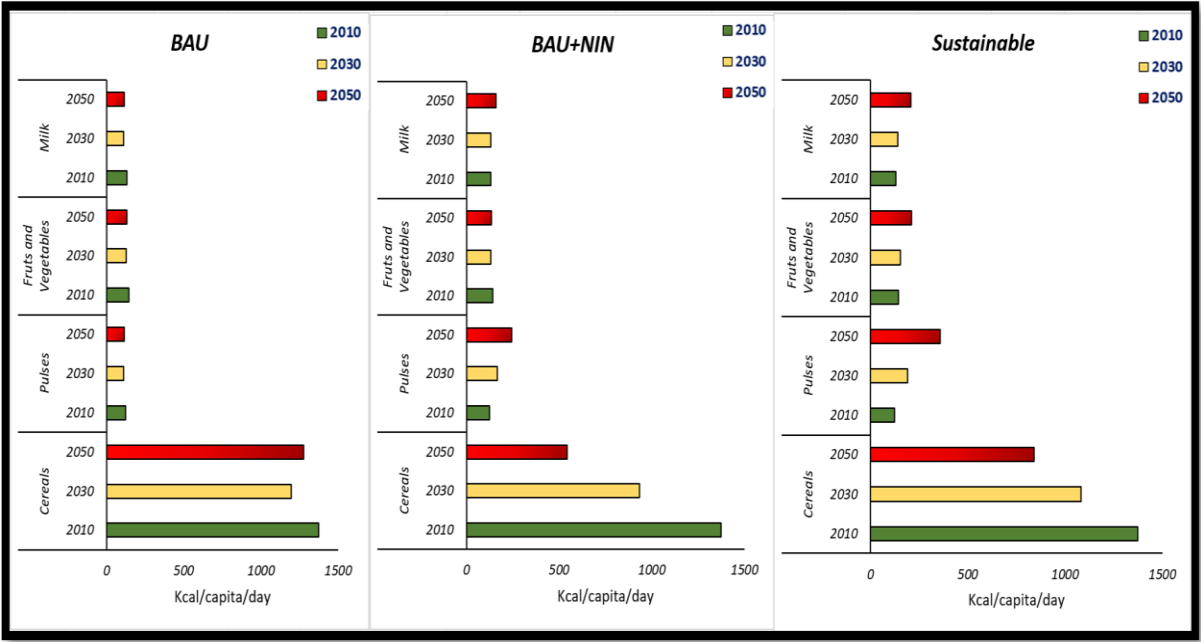


Figure 3. Food group-wise per capita consumption under the three pathways.

For cereal consumption, our results suggest a reduction in the case of SUSTAINABLE and BAU+NIN pathways in 2050 compared to the BAU. Cereals form only 33% and 36% of total calories consumed in both the scenarios involving healthy diets, as compared to the BAU, where cereals form 63% of the total kcal consumption/capita/day in 2050. Additionally, we observe that the dependency on pulses increases largely with the implementation of NIN dietary guidelines. Per capita calorie consumption from pulses increases from 108 Kcal/cap/day under BAU to 166 and 189 Kcal/cap/day under BAU+NIN and SUSTAINABLE pathways, respectively by 2030. Similarly, calorie consumption from pulses in 2050 increases to 244 and 357 Kcal/cap/day under BAU+NIN and SUSTAINABLE, respectively, from 123 Kcal/capita/day. Pulses contribute to 7% in BAU and 22% of total consumption each in BAU+NIN and SUSTAINABLE in 2050, respectively. As we have mentioned above (Section 2), the NIN recommendation do not distinguish between plant and meat-based protein, and more precisely pulses and meat we are only accounting for pulses. Consumption of fruits and vegetables also witnesses a significant increase in the case of healthy diet scenarios due to underlying food demand changes.

3.2. Crop Production and Yield

Shifts in crop production across the pathways can be explained mainly due to our underlying food demand and export assumptions. The difference in production between BAU and BAU+NIN is due to the shift in food demand. While the food demand assumptions under the BAU+NIN and SUSTAINABLE are the same, the difference in production is observed due to a change in export quantity. The higher exports in SUSTAINABLE than in BAU+NIN are due to higher global demand for some products after the shift towards healthier diets in other regions of the world. Other factors that can explain a difference in production between BAU+NIN and SUSTAINABLE is due to change in food waste (it reduces the overall demand) and food loss (reduces the required level of production to satisfy the same level of demand). We observe that the production of rice decreases by approximately 10% under BAU+NIN and SUSTAINABLE by 2030 and by 35% in 2050. Similarly, overall production of crops drops by 30% as compared to BAU by 2050 where the production of pulses increases by 3 Mt and 11 Mt, respectively. Similarly, the overall production of groundnuts and soybean decreases under BAU but increases under the SUSTAINABLE to meet the increased food demand through higher productivity assumptions (Figure 5).

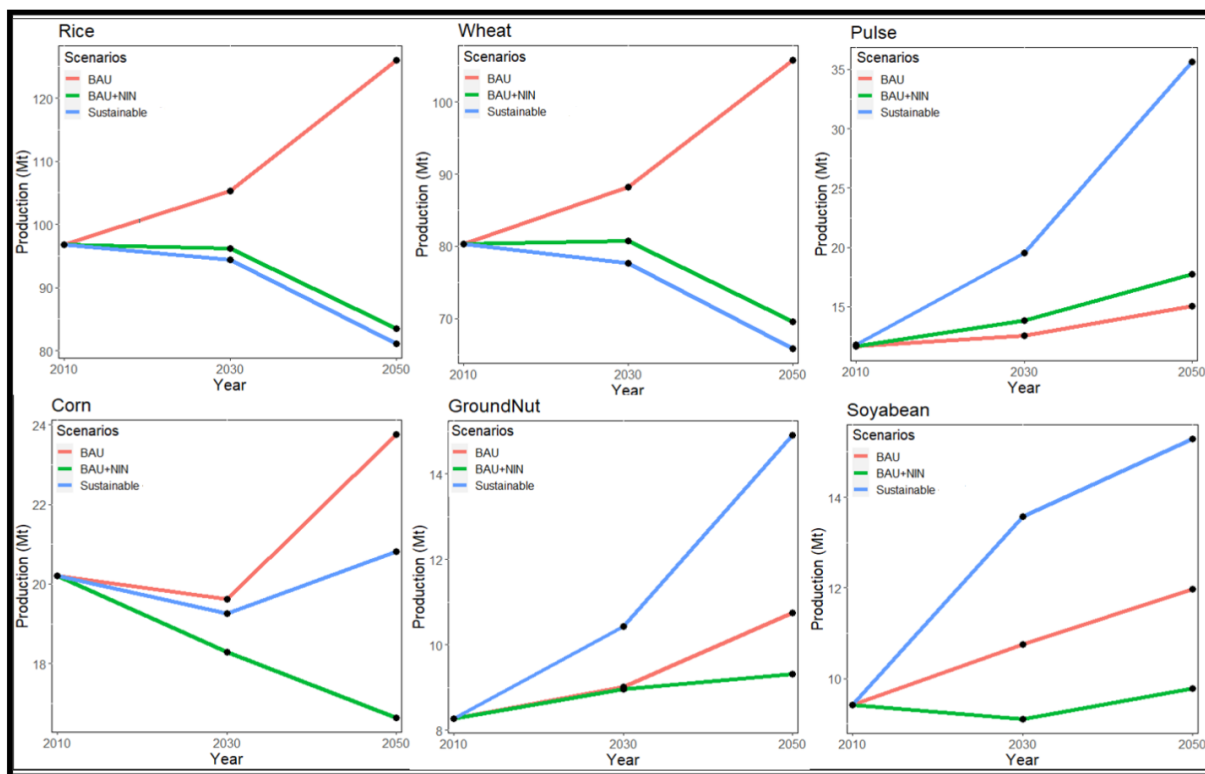


Figure 4. Crop production of the major food crops across the scenarios between 2010 and 2050.

Under the SUSTAINABLE pathway, we assume a gradual increase in the yields of several important crops such as rice, wheat, corn, pulses, groundnuts, and soybean as compared to BAU. Our results show that under the above assumptions, productivity of rice increases by 16% in 2030 and 59% in 2050 under SUSTAINABLE in comparison to BAU and BAU+NIN. A similar increase is observed for corn, for which productivity increases by 27% in 2030 and 62% in 2050 under SUSTAINABLE. The productivity of pulses, groundnuts, and soybean will increase by 41%, 126%, and 248%, respectively, by 2050 under SUSTAINABLE (Figure 6). Higher productivity assumptions mainly explain this along with the lower impact of climate change (RCP 2.6) under the SUSTAINABLE pathway. Since, under SUSTAINABLE the major dependency is increasing on pulses, groundnuts, and soybean, this higher productivity will help to meet the domestic food demand.

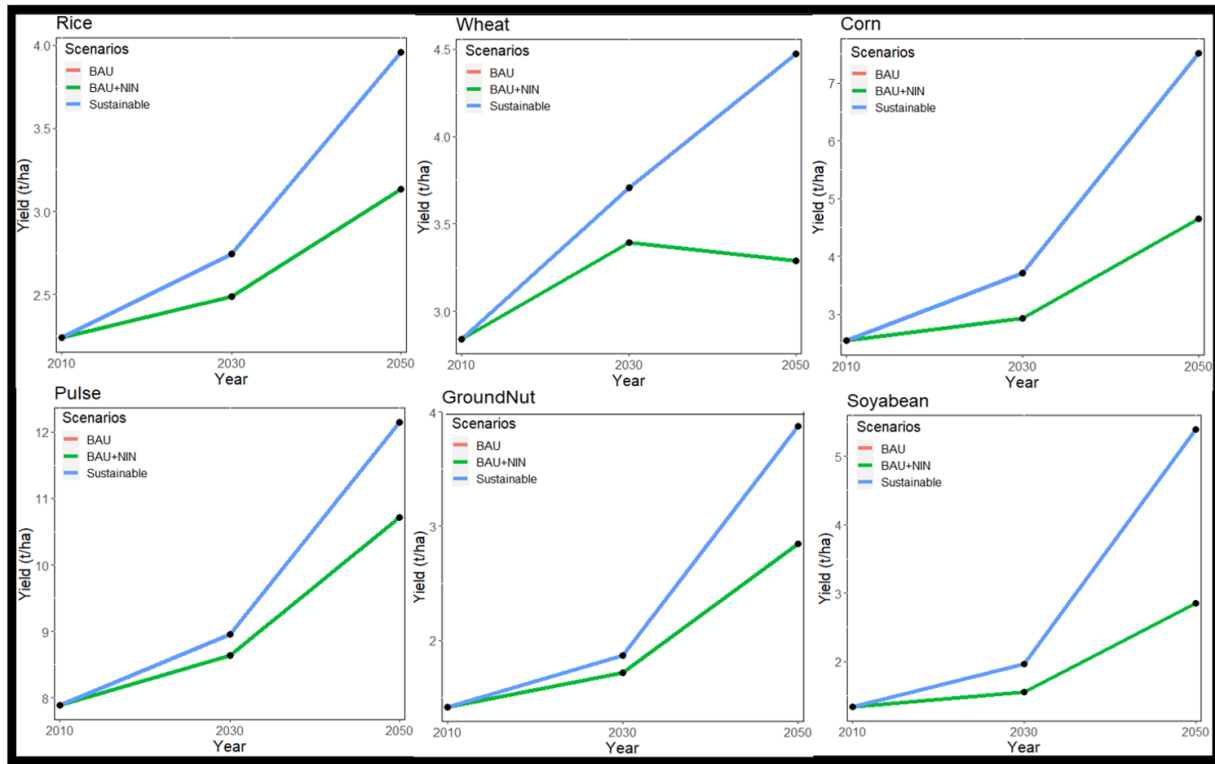


Figure 4. Crop yields of the major food crops across the scenarios between 2010 and 2050. Since there is no difference in the productivity between BAU and BAU+NIN, the green line also represents the red line here.

3.3. Land Cover

We report the results of land-use change across pathways in Figure 4 below. Between BAU and the BAU+NIN, we observe only a marginal increase (2%) in the cropland area by 2050. Since the only difference between these pathways is the assumption of food demand, this implies that transitioning to healthy diets has a marginal impact on the overall cropland area. Under SUSTAINABLE, we observe a decrease in cropland area by 8% and 7% in comparison to BAU and BAU+NIN respectively in 2050. This is explained by several other assumptions related to

lower population, high productivity, and harvest intensity. Similarly, the pasture area is unchanged between BAU and BAU+NIN. This is mainly because there is no change in the demand of livestock products among the pathways. We find a marginal decrease (2-3%) by 2050 in the pasture area under SUSTAINABLE in comparison to other scenarios, which can be explained mainly due to an increase in livestock productivity.

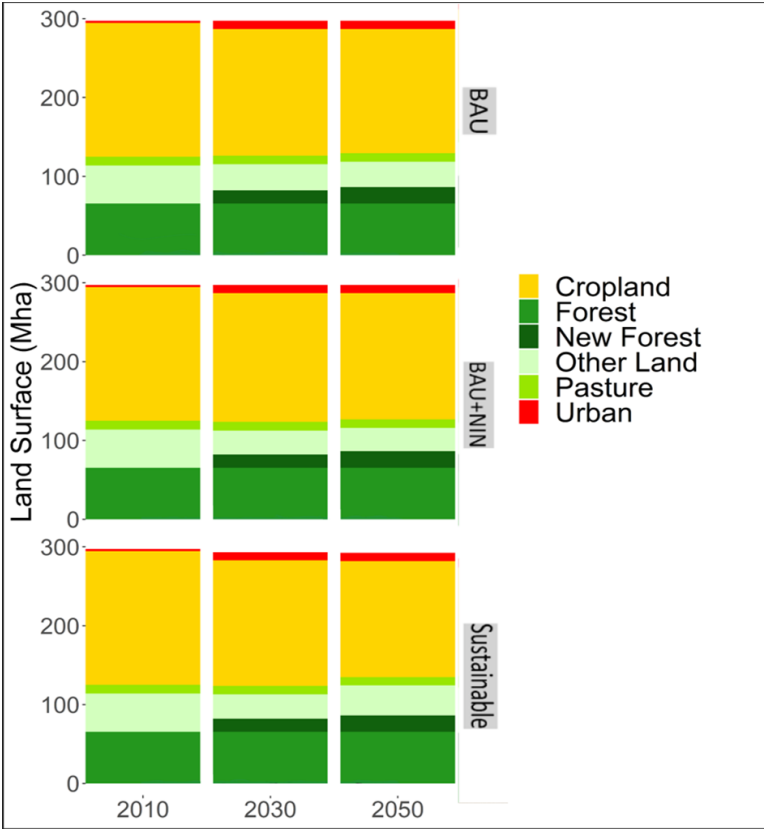


Figure 6. Land use change by land type between 2010 and 2050.

Due to the implementation of the Bonn Challenge which commits 21 Mha of afforestation area by 2030, we also observe additional new forest area increases in BAU and BAU+NIN and an additional 5 Mha new forest area under SUSTAINABLE due to implementation of revised Bonn challenge (26 Mha additional forest area by 2030). We observe a slight decrease in the `other lands` category under BAU+NIN and SUSTAINABLE (3 Mha and 2 Mha respectively) in comparison with BAU in 2030 due to a marginal increase in cropland area and implementation of the afforestation policy. Under SUSTAINABLE, we have observed that the `other lands` increased from 31 Mha in 2030 to 38 Mha in 2050 which is directly explained by the decrease in cropland

during the same period. Despite different population assumptions between BAU and SUSTAINABLE, the urban land area stays unchanged. Targeted urban area is computed based on historical expansion rates computed based on ESA-CCI land cover maps from 2000 and 2005 but capped at 3.5% of total land area maximum.

3.4. GHG Emissions

Under BAU, total crop emissions are projected to be 326 and 319 Mt CO₂ equivalent (CO₂e), respectively, by 2030 and 2050. Compared to this, a decrease in crop-related emissions is observed under BAU+NIN and SUSTAINABLE, as shown in Figure 5 below.

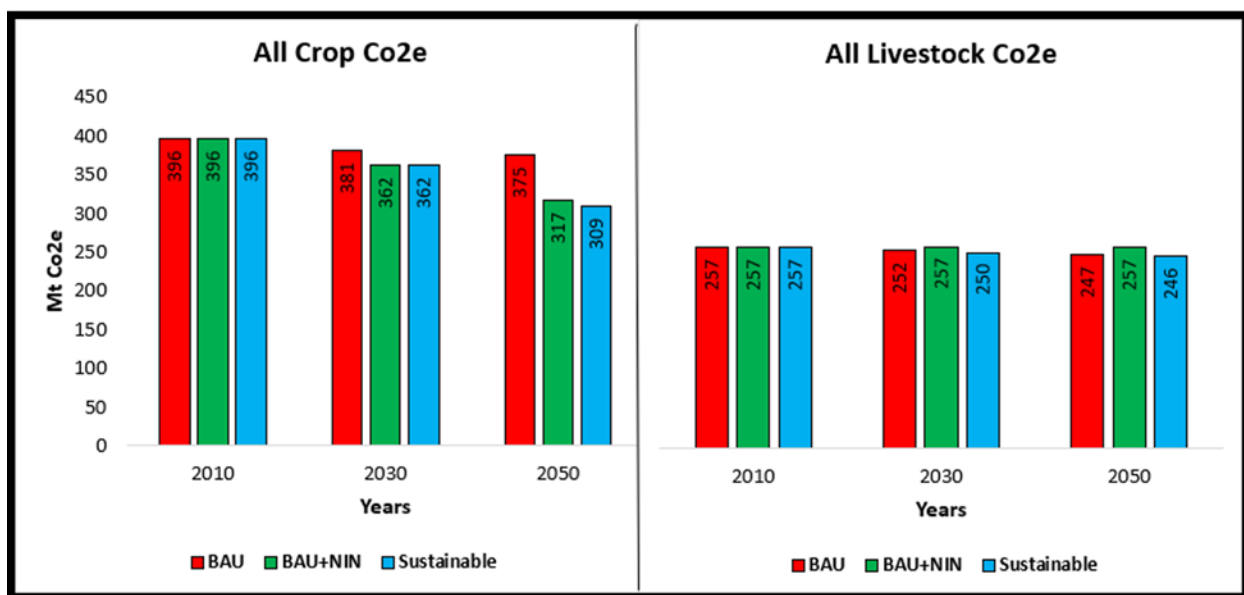


Figure 7. Projected GHG emissions from the crop and livestock sector between 2010 and 2050.

We observe that total emissions from crops under the BAU+NIN and SUSTAINABLE pathways reduce by 5 % in 2030 compared to the BAU. This reduction further reaches 16% under BAU+NIN and 18 % under SUSTAINABLE by 2050 in comparison to BAU. The observed reduction under alternative scenarios is mainly due to the implementation of the national recommended healthy diet (ICMR-NIN), which recommends lesser dependency on cereal crops. Among the cereals, rice is a major food crop (FAO 2020) and the highest source of emission (CH₄). Under SUSTAINABLE, the reduction in emissions is also explained by low population growth assumptions (in line with SSP1), leading to lower food demand and increased crop productivity.

There is no major change in emissions from the livestock sector across the pathways. Only 4% emission reductions are observed under BAU+NIN in comparison to BAU by 2050 from the livestock sector. This is mainly because we do not find a reduction in the consumption of milk and other livestock products under the ICMR-NIN diet scenario.

3.5 Trade

Changes in trade dynamics of a few crops are observed, mainly because total production exceeds domestic food demand due to increased productivity in alternative pathways as compared to the baseline (BAU). Also, under SUSTAINABLE, we assumed that import quantity would reduce and export will double from its 2010 values. Results of these are presented in Figure 8 below. Our analysis shows that the export of corn will reduce by 10 % and 31% in 2030 and 2050 respectively, under BAU+NIN in comparison to BAU. This is mainly due to corn's lower food demand, which results in lower cropland area for corn and further results in lower corn production under BAU+NIN and SUSTAINABLE. In contrast, export increased by 26 % and 43% in 2030 and 2050, respectively under SUSTAINABLE as compared to BAU. Similarly, net trade further increases by 40% and 107% in 2030 and 2050 under SUSTAINABLE as compared to BAU and BAU+NIN, respectively. Due to higher crop productivity, the overall production of corn exceeds domestic food demand allowing higher export of corn. At the level of crops, we observe that wheat exports are reduced by 13% and 15% in 2030 and 36% and 42% in 2050 under BAU+NIN and SUSTAINABLE, respectively, compared to BAU. Due to increased domestic food demand under alternative scenarios, other major changes in trade dynamics are found for pulses. To match the internal food demand, the import quantity of pulses increases by 56% and 161% in 2030 and 2050 respectively under BAU+NIN compared to BAU. Even in SUSTAINABLE, where productivity of pulses is increased, we observe a similar increase in import quantity 51% and 136% in 2030 and 2050 respectively, in comparison to BAU.

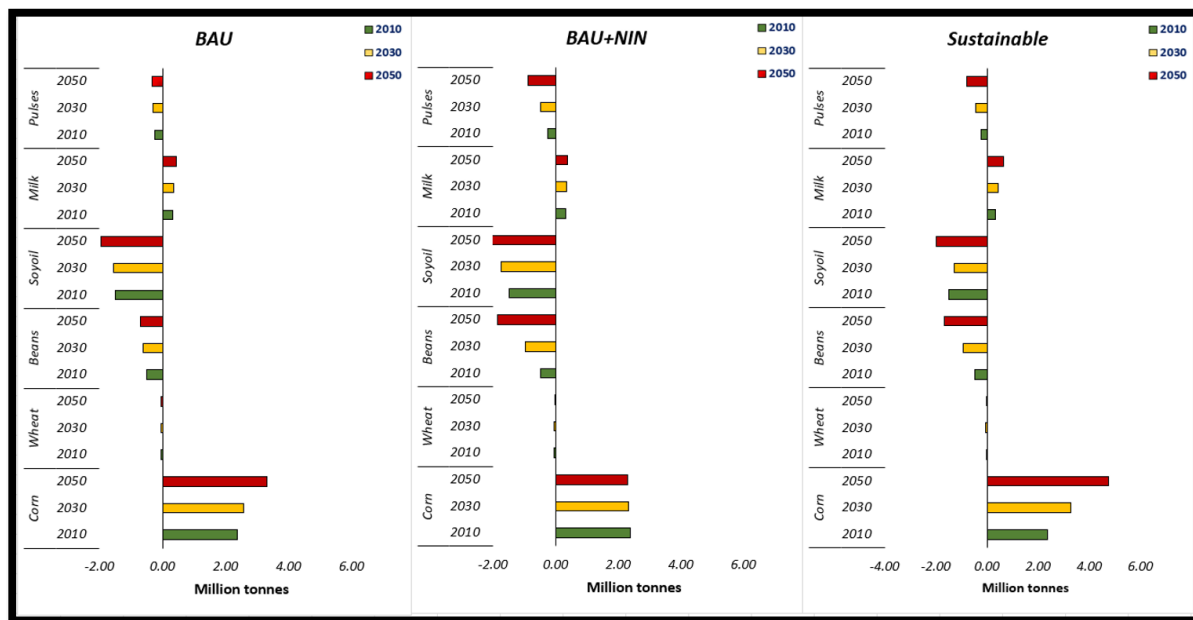


Figure 8. Net trade of major food crops across the scenarios between 2010 and 2050.

A similar increase is observed for the imports of beans under BAU+NIN and SUSTAINABLE as compared to BAU. For milk, we observe a reduction in export quantity by 5% and 14% in 2030 and 2050 under BAU+NIN as compared to BAU due to an increase in domestic demand for the same. In contrast to that, the exported quantity of milk is observed to increase by 22% and 49% in 2030 and 2050 due to higher livestock productivity assumptions in the SUSTAINABLE.

4. Discussion

Our results show that under the BAU and BAU+NIN pathways, the overall cropland area remains the same in 2030 and 2050 and BAU+NIN. Only a marginal decrease in cropland is observed under SUSTAINABLE by 2050 due to higher crop productivity and higher cropping intensity. This decrease in cropland area is not large, mainly because of the higher bioenergy demand based on OECD_AGLINK demand projections and assumption to increase export in comparison to BAU and BAU+NIN. The `OECD_AGLINK` alternative assumes an increase in demand for biofuels until 2028 and then becomes stable afterward. Similarly, the pasture area also remains unchanged across the scenarios in 2030 and slightly decreases in 2050 in comparison to 2030 under SUSTAINABLE due to higher livestock productivity. New forest area increases across the pathways by 2030 in comparison to 2010 because of increased afforestation requirements as per

the Bonn Challenge target. Our results are consistent with the findings of (IUCN 2017; PIB 2019) which shows how India is progressing towards meeting the afforestation target.

Our analysis shows that under the BAU and BAU+NIN pathways, where food demand is in line with SSP2 and ICMR+NIN, respectively, we are unable to meet the MDER in 2030 and 2050. This implies that under the current circumstances as per the BAU, higher population growth and a moderate increase in income levels will restrict India's ability to meet the minimum food demand requirements of the population. Our trade assumptions under BAU+NIN and SUSTAINABLE do not allow to meet the deficit through the trade. Under the BAU+NIN we assume the import will be stable to the 2010 level and under the SUSTAINABLE the import level will reduce. Further to that we also assume that under SUSTAINABLE the export level will increase by 2050 .

Our results show that it may be possible to meet the MDER, even though slightly, under a SUSTAINABLE pathway. This is made possible by higher incomes and low population growth and an increased crop productivity growth rate. These results are similar to observations made by Kc & Lutz, (2017) whereby they find that switching to a SUSTAINABLE pathway will help in meeting food security targets under lower food demand, higher crop and livestock productivity, higher harvest intensity, and less impact of climate change (RCP2.6) on crop yields. The ICMR-NIN recommendations suggest reducing dependency on cereals and increasing the consumption of pulses, soybean, fruits, and vegetables. Under the SUSTAINABLE pathway, we observe that production of these recommended crops is higher than the other two pathways due to higher productivity, harvest intensity, and available additional land due to lower demand for cereal products. Under SUSTAINABLE, we also assumed that crop productivity will be higher than the historical growth rate between 2000 and 2010. Our assumptions of increasing crop productivity and increasing cropping intensity are on the lines of historical trends of India over time (Department of Agriculture Cooperation and Farmers Welfare, 2018). Findings show that when crop productivity of major food crops increases over time, it results in fulfilling food demand needs with reduced cropland. This could be possible through various government initiatives such as subsidies on innovative technologies and increasing economies of scale that result in higher crop productivity (Ministry of Agriculture and Farmers Welfare, 2017). In this regard, agricultural cooperatives such as farmer-producing organizations (FPO) can provide the practical approach to

provide access of such initiatives. The FPOs can facilitate linkage with various stakeholders, which allows members to gain better access to technical, technological, and financial support.

In our analysis we find an overall decline in emissions under the BAU+NIN and SUSTAINABLE pathways in comparison to the BAU. Lower domestic demand for cereals in our assessment has resulted in lower production of rice, thereby causing lower CH₄ emissions. Our finding is consistent with India's third submission to the UNFCCC on progress towards meeting climate mitigation targets (MoEFCC, 2021). The report indicated that a 3% reduction in emissions from rice cultivation is directly related to reduction in area under rice. Our trade results, on the other hand, demonstrate that trade dynamics change only marginally despite a change in overall food demand under the alternative pathways. These results are consistent with India's new trade policy where the maximum focus is to reduce imports and increase exports. Here we assume that exports will increase by 2 times by 2050, following the targets of doubling agricultural exports from the current USD 30 billion to USD 60 billion by 2022 and reaching USD 100 billion in the next few years (Department of Commerce, 2018).

4.1 Limitations

Unlike other land-based models, the FABLE Calculator is not a price endogenous optimization model, implying that prices do not influence the results and vice versa. One of the major shortcomings of the Calculator is related to production practices which are not represented through the technologies used. This restricts the ability of the model to analyze the technical and economic feasibility of the pathways. Crop productivity in the Calculator is mainly derived by the multiplier effect based on observed trends in the historical period. Other limitations of the model are related to the representation of the emissions from agriculture and mitigation options for agriculture, such as improved rice management, animal feed supplements, fertilization techniques, or anaerobic digesters, which are not yet represented and thereby do not fully explain the emission reductions observed. The model is not accounting the water efficiency because it is based on needs by the plant. Similarly, the constraint of water availability is also not considered within the FABLE calculator.

5. Conclusions

Our analysis, using a simple yet integrated food and land use assessment tool shows that if current trends were to continue, India would not be able to meet its nationally determined minimum daily energy requirements (MDER) and GHG emissions targets simultaneously. In the alternative, sustainable pathway, MDER is met through increased food demand but without any additional pressure on cropland via crop and livestock intensification, and afforestation on the lines of the targets of the Bonn challenge. The implementation of ICMR-NIN dietary recommendations reduces the emissions from crops due to decreased demand for cereal crops. Increased demand for food and bioenergy do not impact trade dynamics severely and a large share of the targets can be met through domestic production, except for corn where imports would increase.

India has been relatively resilient to the Covid-19 shock as far as the food supply segment is concerned, with the situation changing on a daily basis. One of the major reasons is its inherently short supply chains, reliance on mom-and-pop stores over supermarkets and extensive network of push cart FFV (fresh fruit and vegetable) vendors). In this regard, the analysis of the nationally recommended healthy diet can provide the pathways to achieve food and nutritional security in the time of pandemic outbreaks. There could be a change in the trade balance and it is expected that the country will be pushed in the direction of agricultural self-reliance. Moving ahead, while our analysis and assumptions have greatly benefitted from inputs from various stakeholders, we aim to continue to improve our assumptions within the model to generate specific and actionable results through continued stakeholder engagement in the future. Through additional assumptions, we will be able to address additional sustainability objectives at the national level that may be relevant for our stakeholders.”Our insights highlight the need for a strategic policy framework that focuses on increasing the productivity and reducing trade dependency of the major food crops, mainly pulses, oil crops, fruits, and vegetables. Additionally, the diversion of subsidies from cereal crops to pulses, oil crops, fruits, and vegetables will go a long way in achieving India's emissions targets from the food and land use sectors while simultaneously meeting the population's nutritional requirements.

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