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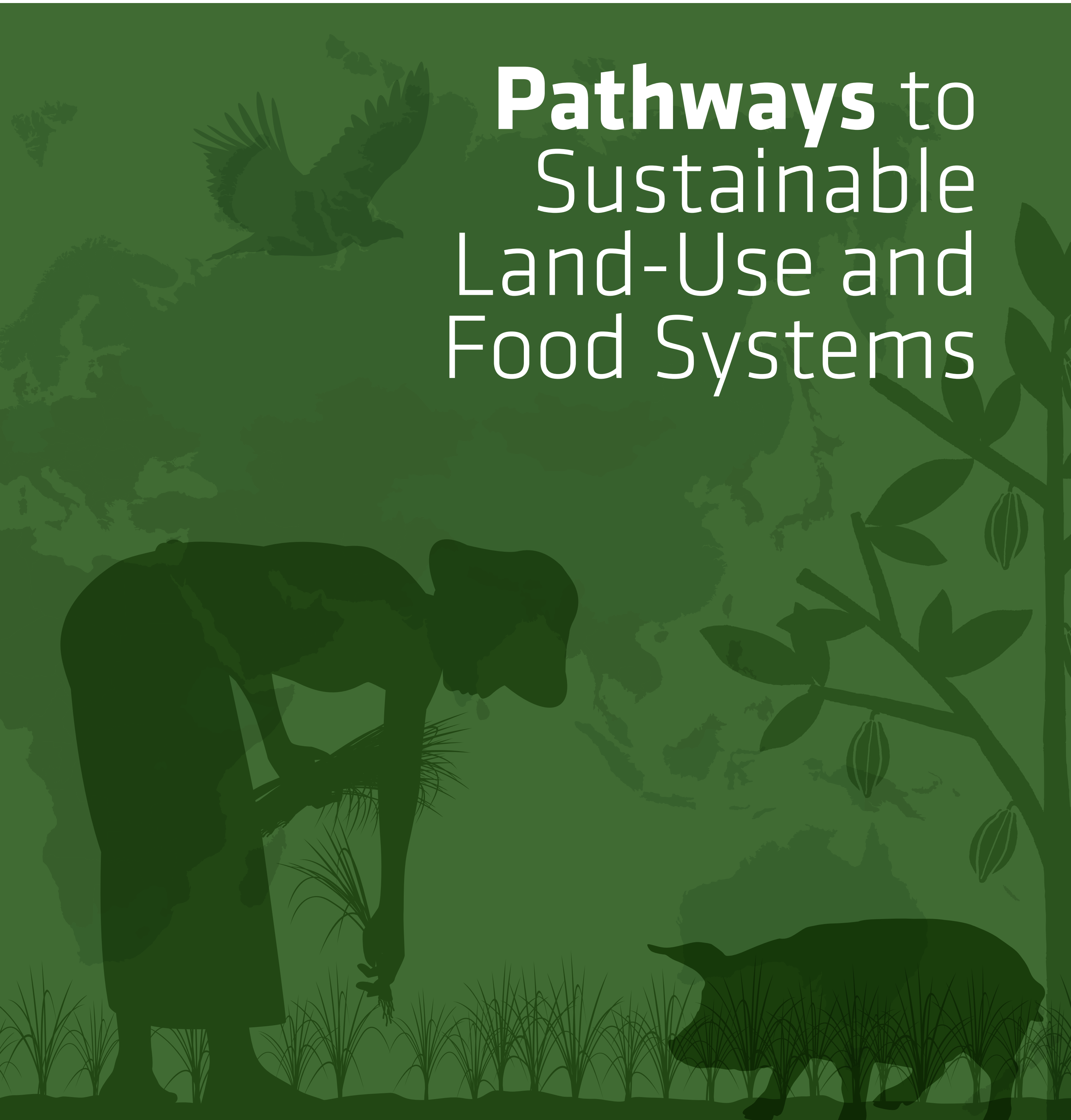
2020 Report of the FABLE Consortium



Pathways to Sustainable Land-Use and Food Systems

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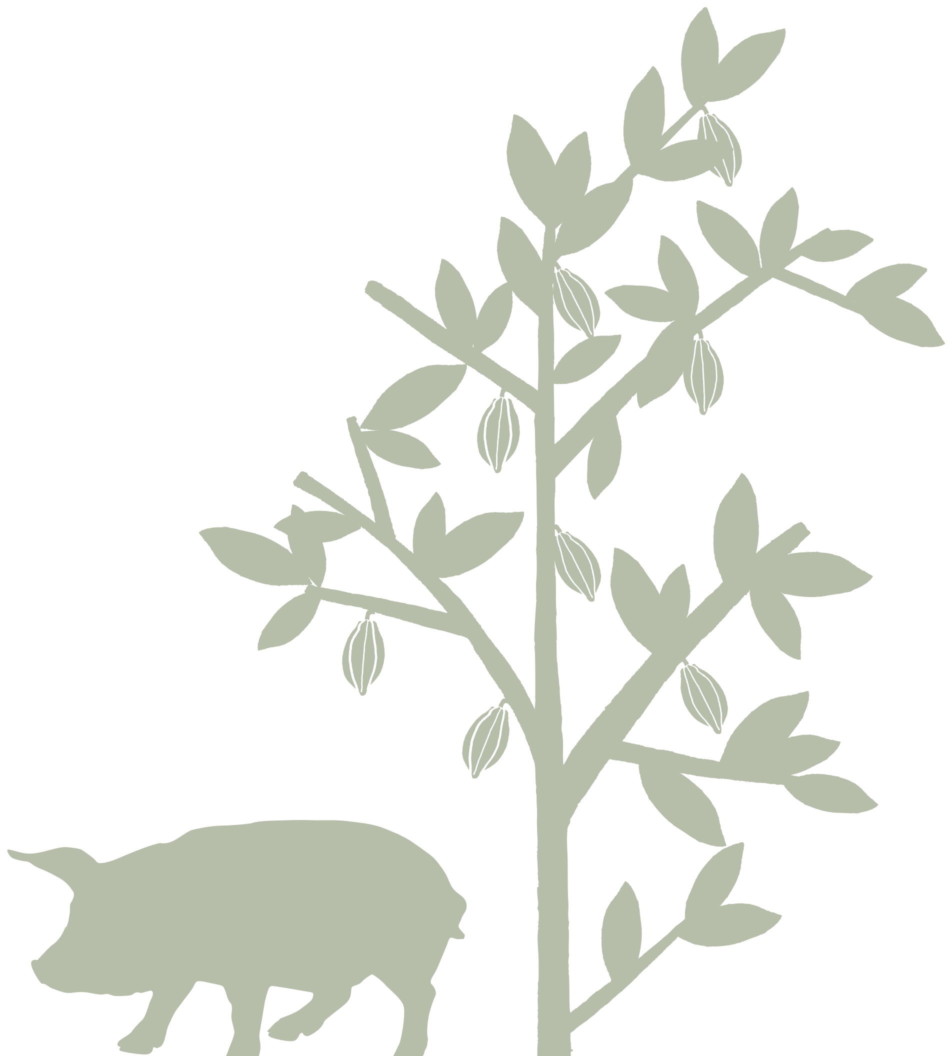
2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems in India by 2050



India

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This chapter of the 2020 Report of the FABLE Consortium *Pathways to Sustainable Land-Use and Food Systems* outlines how sustainable food and land-use systems can contribute to raising climate ambition, aligning climate mitigation and biodiversity protection policies, and achieving other sustainable development priorities in India. It presents two pathways for food and land-use systems for the period 2020-2050: Current Trends and Sustainable. These pathways examine the trade-offs between achieving the FABLE Targets under limited land availability and constraints to balance supply and demand at national and global levels. We developed these pathways in consultation with national stakeholders and experts[1], including from WRI India, the Council on Energy, Environment and Water, The Energy and Resources Institute, and implemented them within a global partial equilibrium model—the Model of Agricultural Production and its Impact on the Environment—MAgPIE (Dietrich et al., 2019; Lotze-Campen et al., 2008; Popp et al., 2017). See Annex 1 for more details on adapting the model to the national context.

1 The authors are thankful to contributions from FOLU India, particularly Shri Vijay Kumar (FOLU India lead - TERI), Dr. KM Jayahari (FOLU India coordinator – WRI India), Dr. Ruchika Singh (WRI India), Dr. Manish Anand (TERI), Abhishek Jain (CEEW), Niti Gupta (CEEW) and Shanal Pradhan (CEEW) for providing inputs in the development of these pathways and for providing feedback on the chapter. We also thank Abhijeet Mishra and Felicitas Beier from PIK for providing technical support with the model.

Climate and Biodiversity Strategies and Current Commitments

Countries are expected to renew and revise their climate and biodiversity commitments ahead of the 26th session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 15th COP to the United Nations Convention on Biological Diversity (CBD). Agriculture, land-use, and other dimensions of the FABLE analysis are key drivers of both greenhouse gas (GHG) emissions and biodiversity loss and offer critical adaptation opportunities. Similarly, nature-based solutions, such as reforestation and carbon sequestration, can meet up to a third of the emission reduction needs for the Paris Agreement (Roe et al., 2019). Countries' biodiversity and climate strategies under the two Conventions should, therefore, develop integrated and coherent policies that cut across these domains, in particular through land-use planning which accounts for spatial heterogeneity.

Table 1 summarizes how India's Nationally Determined Contribution (NDC) and Forest Reference Emission Level (FREL) treat the FABLE domains. According to the NDC, India has committed to reducing the carbon emissions intensity of its GDP by 33–35% compared to 2005 levels by 2030. This includes emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include the National Initiative of Climate Resilient Agriculture (NICRA), National Mission on Sustainable Agriculture (NMSA), *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY), the Prime Minister's Micro-Irrigation Scheme, and measures to minimize residue burning and livestock intensification policies (Ministry of Environment, Forest and Climate Change, 2018). Under its current commitments to the UNFCCC, India mentions biodiversity conservation.

Table 1 | Summary of the mitigation target, sectoral coverage, and references to biodiversity and spatially-explicit planning in current NDC and LT-LEDS

	Total GHG Mitigation					Mitigation Measures Related to AFOLU (Y/N)	Mention of Biodiversity (Y/N)	Inclusion of Actionable Maps for Land-Use Planning[2] (Y/N)	Links to Other FABLE Targets
	Baseline		Mitigation target		Sectors included				
	Year	GHG emissions (Mt CO_2e/yr)	Year	Target					
NDC (2017)	2005	n/a	2030	Reduce the emissions intensity of GDP by 33-35% by 2030	Energy, industrial processes, agriculture, land-use change and forestry, and waste	Y	Y	N	Afforestation
FREL (2018)	2008	n/a	-	**-49.70 million CO_2e**	n/a	n/a	n/a	n/a	n/a

Note. The NDC "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)
Sources: UNFCC(2015), UNFCC(2018)

2 We follow the United Nations Development Programme definition, "maps that provide information that allowed planners to take action" (Cadena et al., 2019).

Table 2 provides an overview of the targets included in the National Biodiversity Strategies and Action Plan (NBSAP) from 2014 (NBSAPs received since COP10), as listed on the CBD website (CBD, 2020) which are related to at least one of the FABLE Targets. This NBSAP includes 12 National Biodiversity Targets from 2010-20. In comparison with the FABLE targets on biodiversity and deforestation, the NBSAPs targets are similar, in particular on protecting a minimum share of terrestrial land to support biodiversity conservation and zero net deforestation.

Table 2 | Overview of the NBSAP targets in relation to FABLE targets

NBSAP Target	Global FABLE Target
(5) By 2020, measures are adopted for sustainable management of agriculture, forestry and fisheries.	**DEFORESTATION:** Zero net deforestation from 2030 onwards
(6) Ecologically representative areas on land and in inland waters, as well as coastal and marine zones, especially those of particular importance for species, biodiversity and ecosystem services, are conserved effectively and equitably, on the basis of PA designation and management and other area-based conservation measures and are integrated into the wider landscapes and seascapes, covering over 20% of the geographic area of the country, by 2020	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate

Brief Description of National Pathways

Among possible futures, we present two alternative pathways in line with the FABLE Targets for food and land-use systems in India, Current Trends and Sustainable. The Sustainable Pathway is a high ambition path to meet national sustainability objectives. Our underlying assumptions for both pathways are in the line of Shared Socio-economic Pathways (SSPs) (O'Neill et al., 2014) (Figure 1). We assume SSP2 parameterization for the Current Trends Pathway and a storyline that builds on SSP1 (e.g. dietary shifts beyond SSP1) for the Sustainable Pathway, including greenhouse gas mitigation efforts and dietary changes (Figure 2) (see Annex 2 for more details on the underlying assumptions).

Figure 1 | Shared Socio-economic pathways (SSPs) from O'Neill et al., (2014)

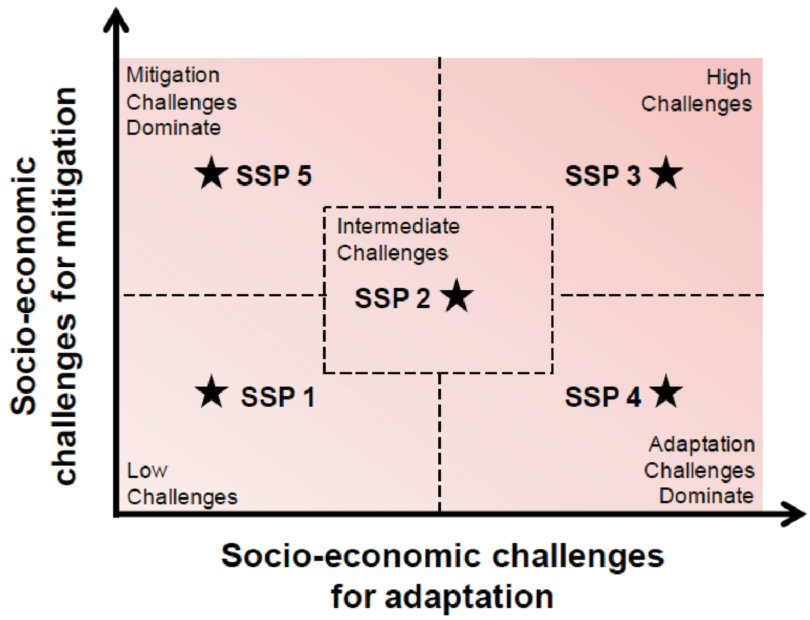
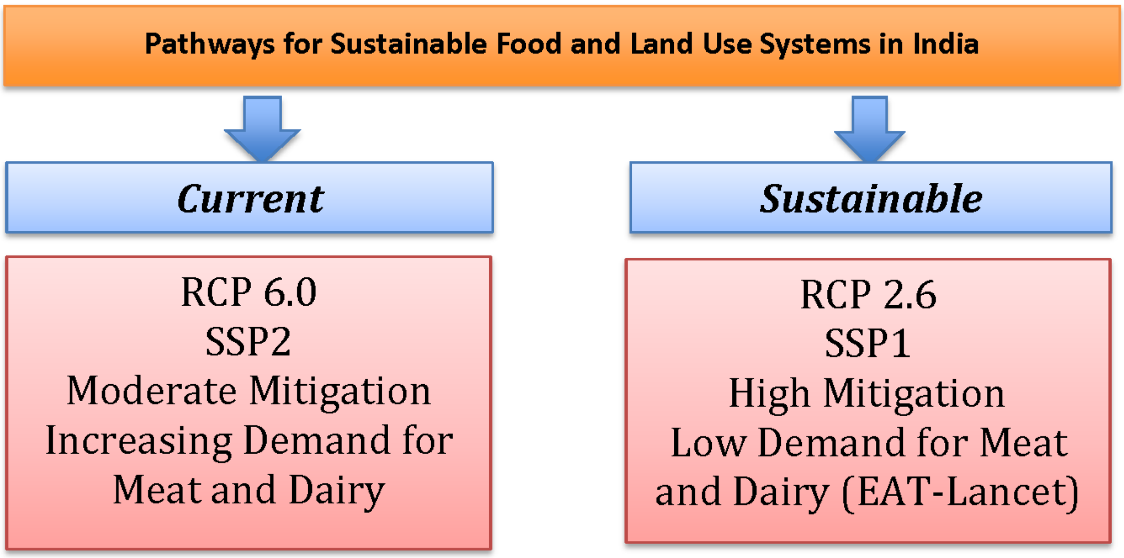


Figure 2 | Description of main assumptions underlying the Current Trends and Sustainable Pathways



Our Current Trends Pathway corresponds to the medium boundary of feasible action. It is characterized by medium population growth (from 1,389 million in 2020 to 1,734 million in 2050), significant constraints on agricultural expansion, a medium afforestation target (21 Mha by 2030) with no change in the extent of protected areas, moderate increases in crop productivity, an evolution towards a diet with relatively high consumption of animal-based products (O'Neill et al., 2017), and other important assumptions (see Annex 2). This corresponds to a future based on current policies and historical trends that would also see moderate population growth and increasing demand for food, moderate growth and lower inequality, stronger nutrition requirements and changes in dietary patterns that follow increases in income, continuous improvements in technologies to increase yields and the high use of fertilizers to increase productivity, moderate mitigation activity to cope with climate change with low enforcement of environmental protection and low targets of renewables and first generation biofuels. These factors underpinning the Current Trends Pathways are based on country level historical trends and current policies and practices (FAO, 2019; Forest Survey of India, 2019; Government of India, 2015; Indian Council of Agricultural Research, 2015; Ministry of Agriculture & Farmers Welfare, 2018; Ministry of Agriculture and Farmer's Welfare, 2017; National Council of Applied Economic Research, 2015). Moreover, as with all FABLE country teams, we embed these Current Trends Pathways in a global GHG concentration trajectory that would lead to a radiative forcing level of 6.0 W/m^2 (RCP 6.0), or a global mean warming increase likely between 2°C and 3°C above pre-industrial temperatures, by 2100. We assume a moderate water-use efficiency scenario under this pathway along with climate change impact (RCP 6.0) Our model includes the corresponding climate change impacts on crop yields by 2050 for cereals, oil crops, sugar crops, fruits and vegetables and for all crops simulated within the model (see Annex 2).

Our Sustainable Pathway represents a future in which substantial efforts are made to adopt sustainable policies and practices and corresponds to a high boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would lead to higher afforestation targets and lower population growth (see Annex 2). This corresponds to a future based on India's pledges under international commitments such as the Paris Agreement, Bonn Challenge, and Aichi Targets, as well as other aspirational targets to reach higher production of renewables and biofuels with more efficient technologies and transition towards healthy diets (i.e. according to recommendations of the EAT-*Lancet Commission*) (Willett et al., 2019) that would also see considerable progress with regards to the achievement of sustainable development goals. We assume a higher water-use efficiency scenario under this pathway along with climate change impact (RCP 2.6). Therefore, we include environmental flow requirements in our model assumptions that reserve a certain fraction of water for environmental purposes and that are not available for agricultural activities. We also assume that the interest rate and technological cost will be low in line with SSP1, which leads to higher crop yields. These pledges and targets are the major factors underpinning our Sustainable Pathway and are in line with national targets to achieve the Sustainable Development Goals (Borah, Bhattacharjee, and Ishwar, 2017; Ministry of New and Renewable Energy, 2018; Ministry of Statistics and Programme Implementation, 2020; Ministry of Environment, Forest and Climate Change, 2018). With the other FABLE country teams, we embed this Sustainable Pathway in biophysical drivers consistent with a global GHG concentration trajectory that would lead to a lower radiative forcing level of 2.6 W/m^2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

Land and Biodiversity

Current State

In 2010, India was covered by 67% cropland, 5% grassland, 19% forest, 1% urban land, and 4% other natural land. Most of the agricultural area is located in northern and western India while forest and other natural land can be mostly found in the southwest and east (Map 1). In a developing economy with a growing population and a focus on economic development, impacts can be seen on the increasing pressure on biodiversity. Habitat loss, degradation, invasive alien species, over exploitation of fisheries and increasing incidence of forest fires are some of the major biodiversity threats in India (Ministry of Environment and Forests, 2014).

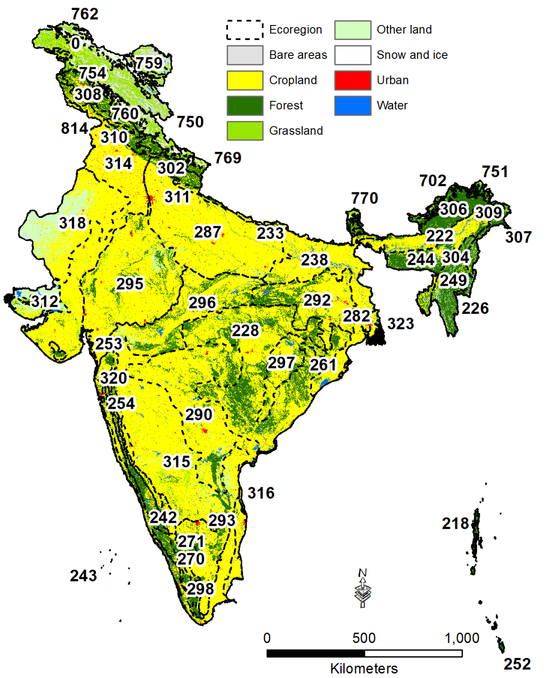
We estimate that land where natural processes predominate[3] accounted for 12% of India's terrestrial land area in 2010. The 770-Yarlung Zanbo arid steppe holds the greatest share of land where natural processes predominate, followed by the 307-Northern Triangle temperate forests and the 751-Eastern Himalayan alpine shrub and meadows (see Annex 4). Across the country, while 18.2 Mha of land is under formal protection, falling short of the 30% zero-draft CBD post-2020 target, protected land where natural processes predominate is mainly located along the southwestern coast. In contrast, the last remaining patches of land where natural processes predominate in the north and east of the country lie unprotected and are at risk of losing their biodiversity if action is not taken to better protect these areas (Map 2).

Approximately 15% of India's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively biodiversity-friendly croplands are most widespread in forested northern regions including the 226-Chin Hills-Arakan Yoma montane forests, 750-Central Tibetan Plateau alpine steppe, and 307-Northern Triangle temperate forests. These ecoregions have relatively small areas of cropland intermixed with natural vegetation, while cropland dominates landscapes in many other ecoregions of India, pushing natural vegetation to the margins. The regional differences in the extent of biodiversity-friendly cropland can be explained by cropping intensity (Ministry of Agriculture and Farmer's Welfare, 2016).

3 We follow Jacobson, Riggio, Tait, and Baillie (2019) definition: "Landscapes that currently have low human density and impacts and are not primarily managed for human needs. These are areas where natural processes predominate, but are not necessarily places with intact natural vegetation, ecosystem processes or faunal assemblages".

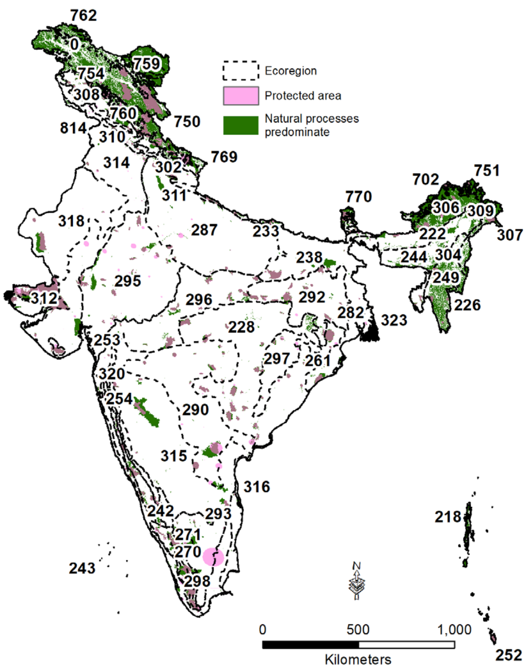
India

Map 1 | Land cover by aggregated land cover types in 2010 and ecoregions



Sources: countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)
Notes: Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3.

Map 2 | Land where natural processes predominate, protected areas and ecoregions in 2010



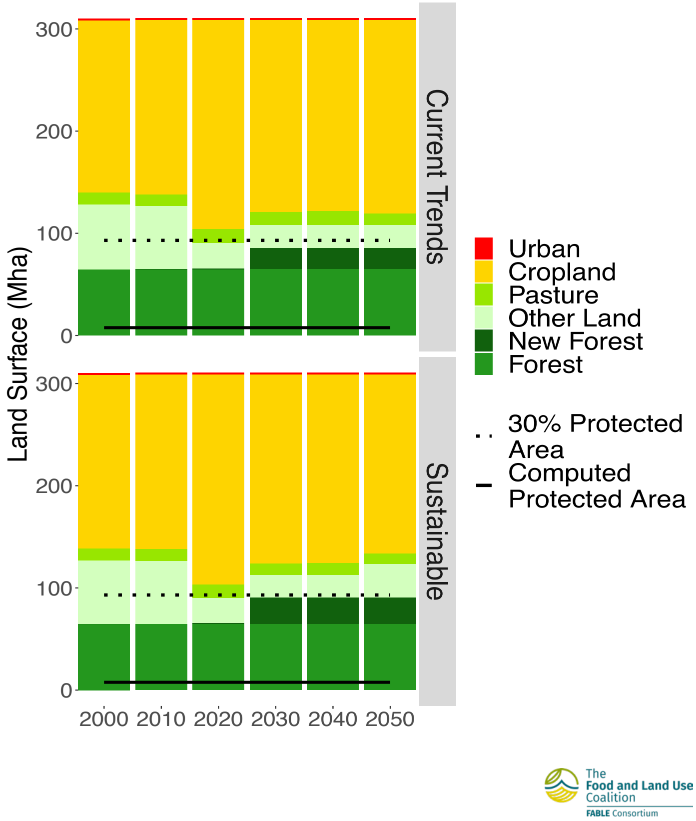
Sources: countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); protected areas – UNEP-WCMC and IUCN (2020); natural processes predominate comprises key biodiversity areas – BirdLife International (2019), intact forest landscapes in 2016 – Potapov et al. (2016), and low impact areas – Jacobson et al. (2019)
Note: Protected areas are set at 50% transparency, so on this map dark purple indicates where areas under protection and where natural processes predominate overlap.

Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions: deforestation will be halted beyond 2005 and the expansion of agricultural land into natural forests is halted. Agricultural land can be increased by converting other natural vegetation areas that have lower carbon densities compared to natural forests. Moreover, 21 Mha are reforested or afforested by 2030, and protected areas remain at 181,404 km2, representing 6% of total land cover in 2050 (see Annex 2).

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result in an increase in the forest cover area and a decrease of other land areas. Decreases in other land occurs due to cropland area expansion between 2010 and 2025, after which other land remains stable. Forest area remains stable until 2025, increases between 2025 and 2030, before stabilizing (Figure 3) due to our assumption to achieve the Bonn Challenge target for India (21 Mha by 2030). The expansion of the planted area for corn and soybean explains 99% of total cropland expansion between 2010 and 2025. For corn, the expansion is largely explained by an increase in feed use. For soybean, the expansion is primarily due to an increase in exports of soybean. The marginal pasture expansion between 2010 to 2035 is driven by the increase in demand for livestock products, in particular dairy products. Between 2030-2050, the increase in forest area is explained by actions to meet afforestation targets set under the Bonn Challenge (Borah et al., 2017). There is no change between 2000 and 2050 in the area of land where natural processes predominate, which is explained by cropland or pasture area expansion and stabilization, respectively.

Figure 3 | Evolution of area by land cover type and protected areas under each pathway

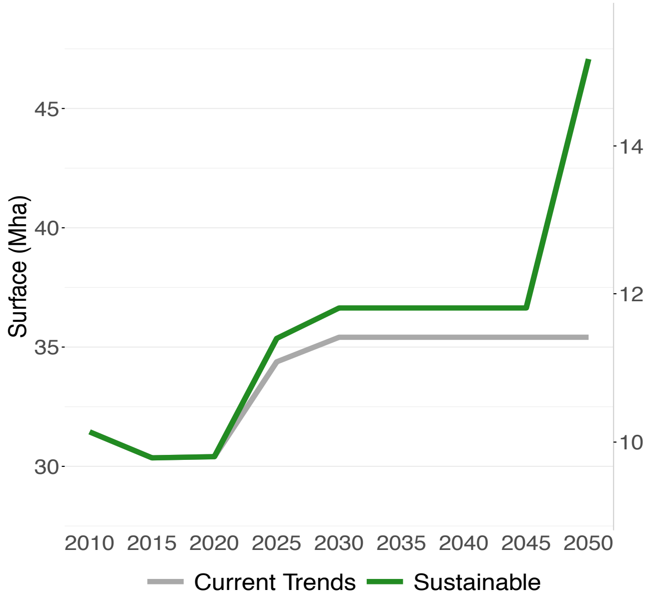


Sources. Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000, and the World Database on Protected Areas data (UNEP-WCMC & IUCN, 2020) for 2020

In the Sustainable Pathway, assumptions on agricultural land expansion remain similar to the Current Trends Pathway, except for an additional afforestation assumption that includes 26 Mha of new forest area by 2030 based on the revised Bonn Challenge target for India. Protected areas remain constant at 6% of the total land area (see Annex 2).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in India in the Sustainable Pathway: (i) a decrease in the loss of natural land, (ii) a moderate increase in agricultural land, and (iii) an increase in afforested land. In addition to the changes in assumptions regarding land-use planning, these changes compared to the Current Trends Pathway are explained by cropland expansion and afforestation targets. Under the Current Trends Pathway, natural processes increase by 1.5% between 2010 and 2030, then stabilize. Under the Sustainable Pathway, land where natural processes predominate increases by 1.8% between 2010 and 2030, stabilizes until 2045, then sharply increases by a further 3% by 2050 (Figure 4).

Figure 4 | Evolution of the area where natural processes predominate



GHG emissions from AFOLU

Current State

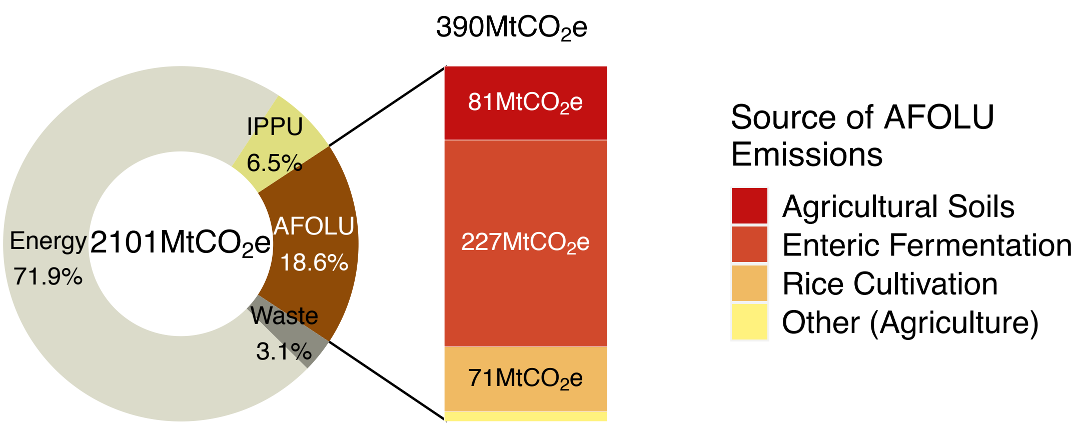
Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 18.6% of total emissions in 2010 (Figure 5). Enteric fermentation and field burning of agricultural residues is the principal source of AFOLU emissions, followed by agricultural soils, and rice cultivation.

Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU increase to 1,140 Mt CO_2e/yr in 2030 before reaching 1,550 Mt CO_2e/yr in 2050 (Figure 6). In 2050, enteric fermentation is the largest source of emissions (1,067 Mt CO_2e/yr), while emissions from other land-use change act as a sink (13 Mt CO_2e/yr). Over the period 2020–2050, the strongest relative increase in GHG emissions is computed for enteric fermentation (170%), while a reduction is computed for emission from rice cultivation (-40%).

In comparison, the Sustainable Pathway leads to a reduction of AFOLU GHG emissions by 300% in 2050 compared to the Current Trends Pathway (Figure 6). The potential emissions reductions under the Sustainable Pathway are dominated by a reduction in GHG emissions from the livestock sector. Our assumptions related to diets (EAT-Lancet recommendations) under the Sustainable Pathway, which assume a reduction in demand for livestock products and other assumptions in

Figure 5 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2010



Note. IPPU = Industrial Processes and Product Use
Source. Adapted from GHG National Inventory (UNFCCC, 2020)

line with an SSP1 narrative, are the most important drivers of this reduction.

Compared to India's commitments under UNFCCC (Table 1), our results show that AFOLU could contribute moderately to the total GHG emissions reduction objective by 2030 (reducing the emissions intensity of GDP by 33% to 35% by 2030 compared to 2005 levels). Such reductions could be achieved through policies to promote a strong shift in diets, improvements to the livestock feeding system, meeting afforestation targets, and increasing bioenergy production. Such policies could be particularly important when considering targets to create an additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through afforestation/ reforestation by 2030 as per India's commitment to UNFCCC (INDC, 2015). The National Biofuel Policy (2018) in particular relates to India's new biofuel targets (Ministry of New and Renewable Energy, 2018) which is also important to meet India's commitment to UNFCCC.

Figure 6 | Projected AFOLU emissions and removals between 2010 and 2050 by main sources and sinks for the Current Trends Pathway

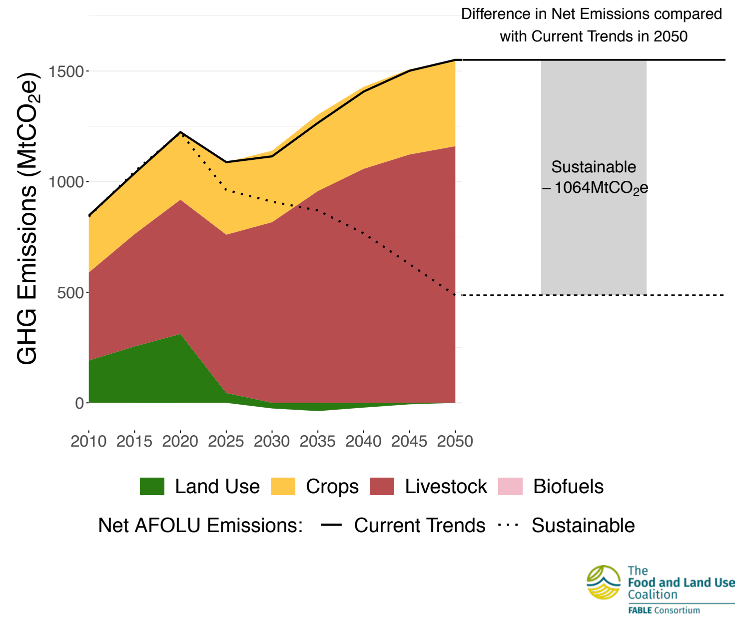
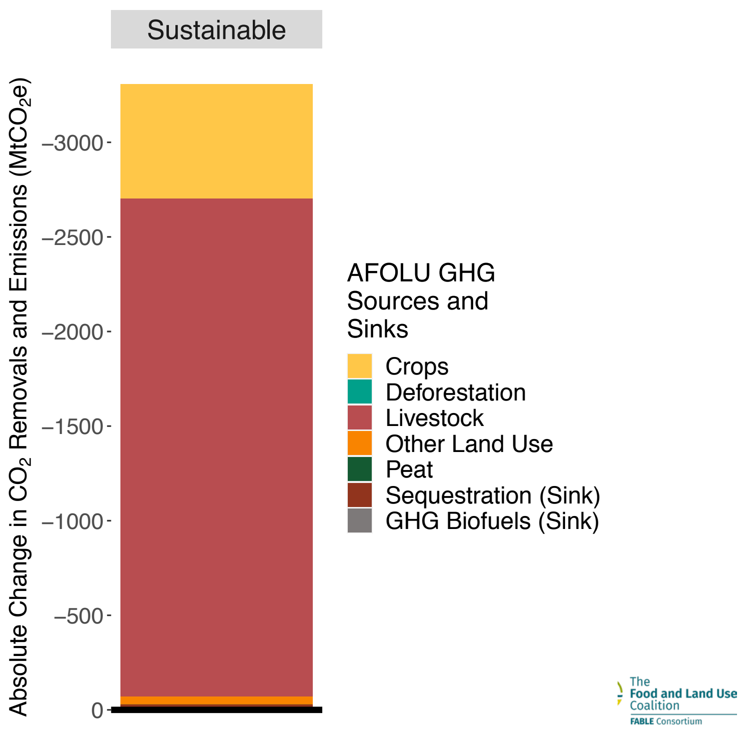


Figure 7 | Cumulated GHG emissions reduction computed over 2020-2050 by AFOLU GHG emissions and sequestration source compared to the Current Trends Pathway



Food Security

Current State

The "Triple Burden" of Malnutrition

Undernutrition

14.5% of the population undernourished in 2019. This share has decreased since 2005 (von Grebmer et al., 2019).

38.4% of children under 5 stunted and 21% wasted in 2016 (Indian Institute of Population Sciences, 2016).

Micronutrient Deficiency

50.1% of women and 57.3% of children suffer from anemia in 2016, which can lead to maternal death (NLIS, 2018).

5% of pregnant women were deficient in vitamin A (Akhtar et al., 2013), which can notably lead to blindness (West, 2002) and child mortality, and 34% of the population is deficient in iodine, which can lead to developmental abnormalities (Andersson, Karumbunathan, & Zimmermann, 2012).

Overweight/ Obesity

3.9% of adults and 2% of children were obese in 2016. These shares have increased since 2005 (Global Health Observatory, 2018).

19.7% of adults and 6.8% of children, were overweight in 2016. These shares have increased since 2005 (Global Health Observatory, 2018).

Disease Burden due to Dietary Risks

20.8% of deaths are attributable to dietary risks, or 152.77 deaths per year (per 100,000 people) (Global Burden of Disease Collaborative Network, 2018).

Table 4 | Daily average fats, proteins and kilocalorie intake under the Current Trends and Sustainable Pathways in 2030 and 2050

	2010	2030		2050	
	Historical Diet (FAO)	Current Trends	Sustainable	Current Trends	Sustainable
Kilocalories (MDER)	2,097 (2,181)	2,260 (2,252)	2,286 (2,281)	2,325 (2,255)	2,272 (2,284)

Notes. Minimum Dietary Energy Requirement (MDER) is computed as a weighted average of energy requirement per sex, age class, and activity level (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015) and the population projections by sex and age class (UN DESA, 2017) following the FAO methodology (Wanner et al., 2014). For fats, the dietary reference intake is 20% to 30% of kilocalories consumption. For proteins, the dietary reference intake is 10% to 35% of kilocalories consumption. The recommended range in grams has been computed using 9 kcal/g of fats and 4kcal/g of proteins.

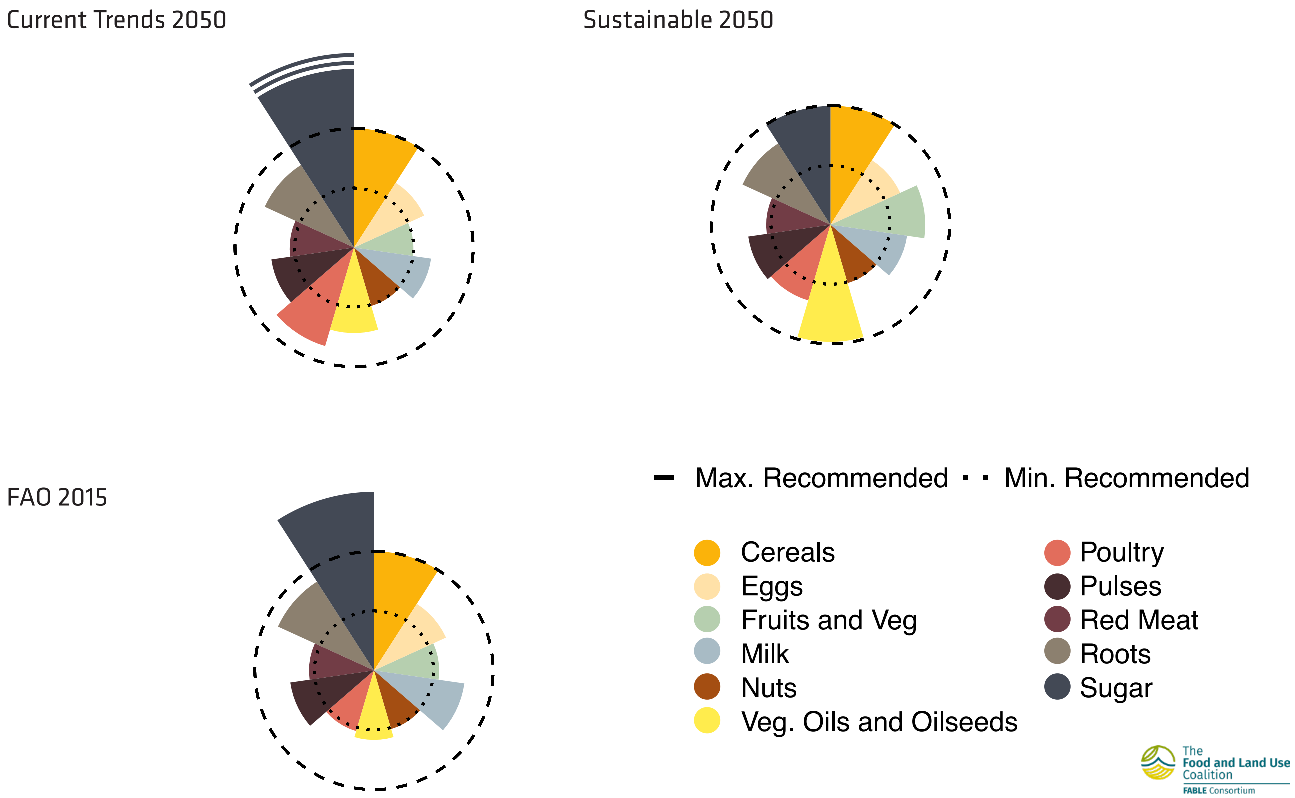
Pathways and Results

Under the Current Trends Pathway, compared to the average Minimum Dietary Energy Requirement (MDER) at the national level, our computed average calorie intake is 0.3% higher in 2030 and 3% higher in 2050 (Table 4). The current average intake is mostly satisfied by cereals, sugar and oils, and animal products, which represent 13% of the total calorie intake. We assume that the consumption of animal products will increase by 57% and by 106% for poultry meat between 2020 and 2050. The consumption of dairy, sugar, fruits and vegetables, and nuts will also increase while the consumption of oil crops, cereals, and pulses will decrease. Compared to the EAT-Lancet recommendations (Willett et al., 2019), which is in line with the assumptions of our Sustainable Pathway, only sugars are over-consumed whereas no products are under-consumed (Figure 8).

Under the Sustainable Pathway, we assume that diets will transition towards EAT-Lancet recommendations. The ratio of the computed average intake over the MDER increases to 0.3% in 2030 and decreases to 0.4% in 2050 under the Sustainable Pathway.

India's changing food demand landscape partially promotes the transition to healthy food systems. While we find that, on average, the number of food groups consumed by Indian households has increased from 8.8 (out of 12 food groups) to 9.7 between 1990 and 2012 in rural India and from 9.3 to 9.5 in urban India (Pingali, Aiyar, Abraham, & Rahman, 2019), there is still a need to reduce the over-dependence on certain food groups, particularly ultra-processed foods, sugars and cereals, to achieve overall dietary diversity as recommended by our Sustainable Pathway (EAT-*Lancet* recommendations). A shift from the current over-dependence on the consumption of cereals, which is rooted in existing regulatory reforms that highly subsidize the production and consumption of cereals, towards a focus on diversifying the food basket to include more fruits, vegetables, nuts, and pulses will be important to achieve the EAT-*Lancet* dietary recommendations. The gap between current Indian diets as compared to EAT-*Lancet* recommendations calls for public health and nutrition policies that address malnutrition as well as agricultural, trade, and consumer awareness policies. With an aim to address broader societal context, these policies shall aim to affect the accessibility, acceptability, and affordability of healthier dietary options in India (Sharma, Kishore, Roy, & Joshi, 2020).

Figure 8 | Comparison of the computed daily average kilocalorie intake per capita per food category across pathways in 2050 with the EAT-Lancet recommendations



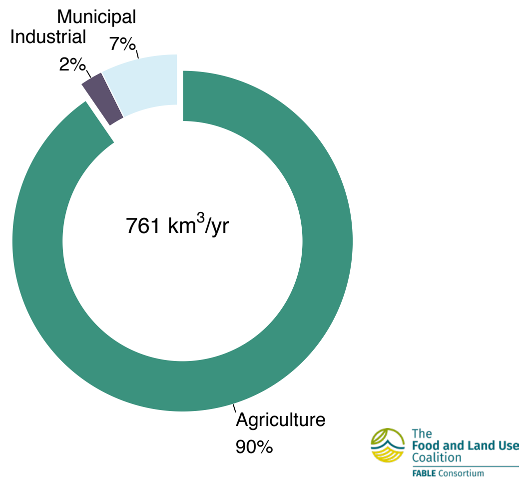
Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings), therefore different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended values for cereals: when the kcal intake is smaller than the average recommendation it is displayed on the minimum ring and if it is higher it is displayed on the maximum ring. The discontinuous lines that appear at the outer edge of sugar indicate that the average kilocalorie consumption of this food category is significantly higher than the maximum recommended.

Water

Current State

India is characterized by tropical monsoon climate with unreliable rainfall and 1,183 mm average annual precipitation that mostly occurs between June and September. The agricultural sector represented 90% of total water withdrawals in 2010 (Figure 9; FAO, 2017). Moreover, in 2013, 70.4 Mha of agricultural land was equipped for irrigation, representing 50% of estimated irrigation potential (FAO, 2017). The three most important irrigated crops, rice, soybean, and pulses, account for 26%, 15%, and 7% of total harvested irrigated area. India exported 61% of soybean, 23% of cotton lint and 6% of rapecake in 2020.

Figure 9 | Water withdrawals by sector in 2010

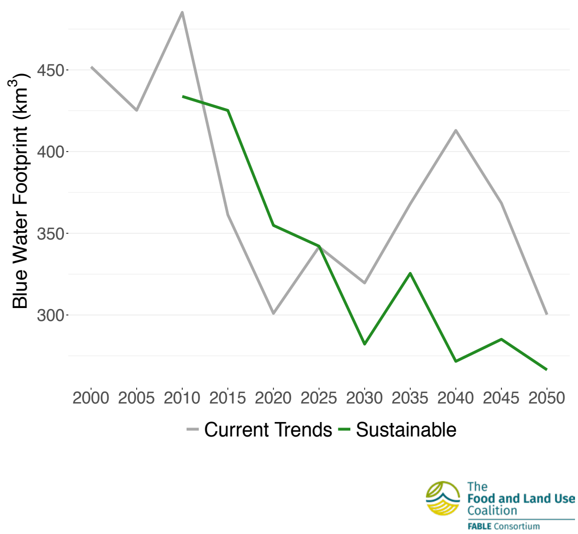


Source. Adapted from AQUASTAT Database (FAO, 2017)

Pathways and Results

Under the Current Trends Pathway, annual blue water use decreases between 2000 and 2015 (685 km^3/yr and 547 km^3/yr), before reaching 484 km^3/yr and 455 km^3/yr in 2030 and 2050, respectively (Figure 10), with rice, wheat and chicken accounting for 37%, 23%, and 12% of computed blue water use for agriculture by 2050. In contrast, under the Sustainable Pathway, the blue water footprint in agriculture reaches 427 km^3/yr in 2030 and 403 km^3/yr in 2050, respectively. This is explained by accounting for environmental-flow-protection policies as well as climate change impacts in the MAgPIE model (see Annex 2), which leads to an 11% decrease in water withdrawals in agriculture by 2050 and changes in the production of rice, wheat, and raw sugar due to a decline in internal food demand as well as demand for biofuels. Water withdrawal values in the model do not fully reflect underground water use for agricultural production which was beyond the scope of this analysis.

Figure 10 | Evolution of blue water footprint in the Current Trends and Sustainable Pathways



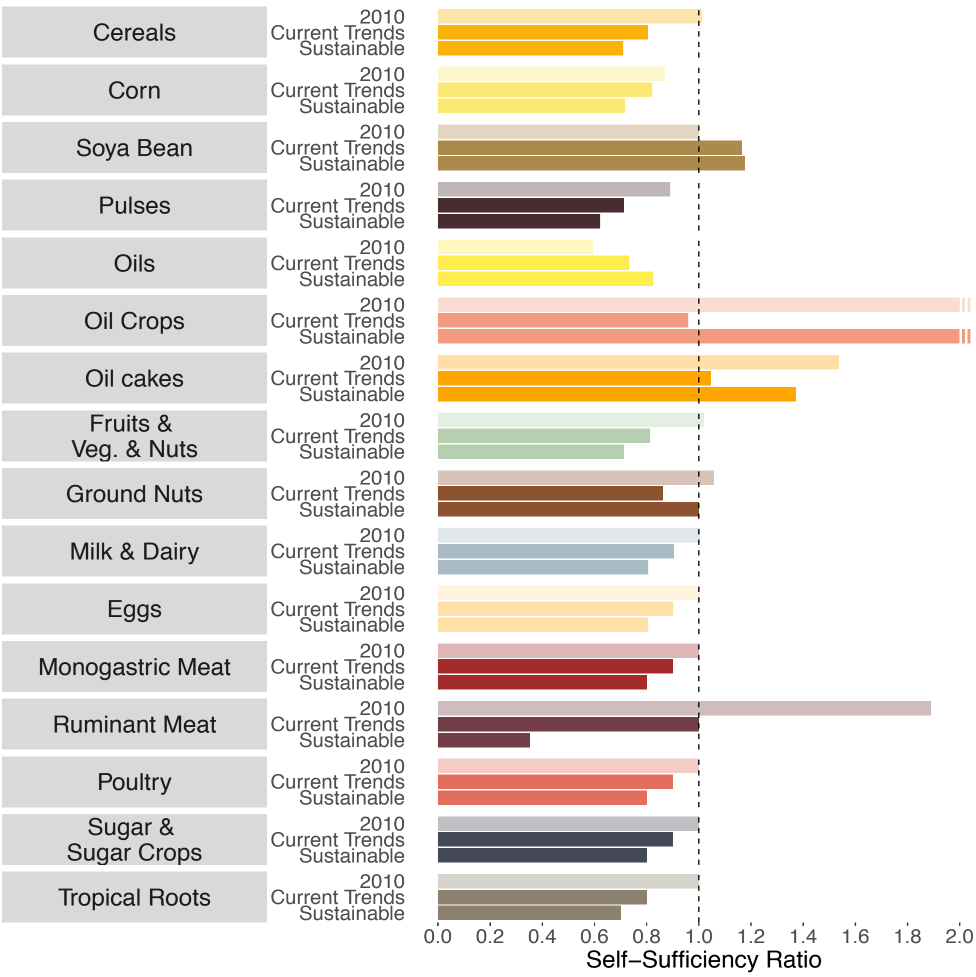
Resilience of the Food and Land-Use System

The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge India's resilience to agricultural trade and supply disruptions across pathways: the rate of self-sufficiency and diversity of production and trade. Together they highlight the gaps between national production and demand and the degree to which we rely on a narrow range of goods for our crop production system and trade.

Self-Sufficiency

According to the historical data (2010), India is self-sufficient for the major food categories, such as cereals, fruits and vegetables, nuts, oilseeds and vegetable oils, soya bean, ruminants, eggs, sugar and sugar crops, oil crops, mild and dairy, fruits, vegetables and nuts and poultry meat. Self-sufficiency is low for corn and oils.

Figure 11 | Self-sufficiency per product group in 2010 and 2050



Note. In this figure, self-sufficiency is expressed as the ratio of total internal production over total internal demand. A country is self-sufficient in a product when the ratio is equal to 1, a net exporter when higher than 1, and a net importer when lower than 1. The discontinuous lines on the right side of this figure, as appear for beverages, spices and tobacco, nuts, oilseeds and vegetable oils, indicate a high level of self-sufficiency in these categories.

The Food and Land Use Coalition
FABLE Consortium

Under the Current Trends Pathway, we project that India would be self-sufficient in pulses, fruits vegetables and nuts, and ruminant meat in 2050, with self-sufficiency by product group remaining stable for the majority of products between 2010 and 2050 (Figure 11). The product groups for which India depends the most on imports to satisfy internal consumption are roots and tubers, poultry meat, milk and dairy, sugar and sugar crops, and eggs. According to our projections, this dependency will decline until 2050. In contrast, under the Sustainable Pathway, India's self-sufficiency remains stable overall, with full self-sufficiency for pulses, fruits and vegetables, ruminant meat, and nuts but with a further decline in the self-sufficiency for roots and tubers, dairy, and sugar crops by 2050. This is explained by changes in the volume of imports and exports, productivity, and change in diets.

Diversity

The Herfindahl-Hirschman Index (HHI) measures the degree of market competition using the number of firms and the market shares of each firm in a given market. We apply this index to measure the diversity/concentration of:

- **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- **Exports and imports:** where concentration refers to a situation in which a few commodities represent a large share of total exported and imported quantities, and diversity refers to a situation in which many commodities account for significant shares of total exported and imported quantities.

We use the same thresholds as defined by the U.S. Department of Justice and Federal Trade Commission (2010, section 5.3): diverse under 1,500, moderate concentration between 1,500 and 2,500, and high concentration above 2,500.

Figure 12 | Evolution of the diversification of the cropland area, crop imports and crop exports of the country using the Herfindahl-Hirschman Index (HHI)

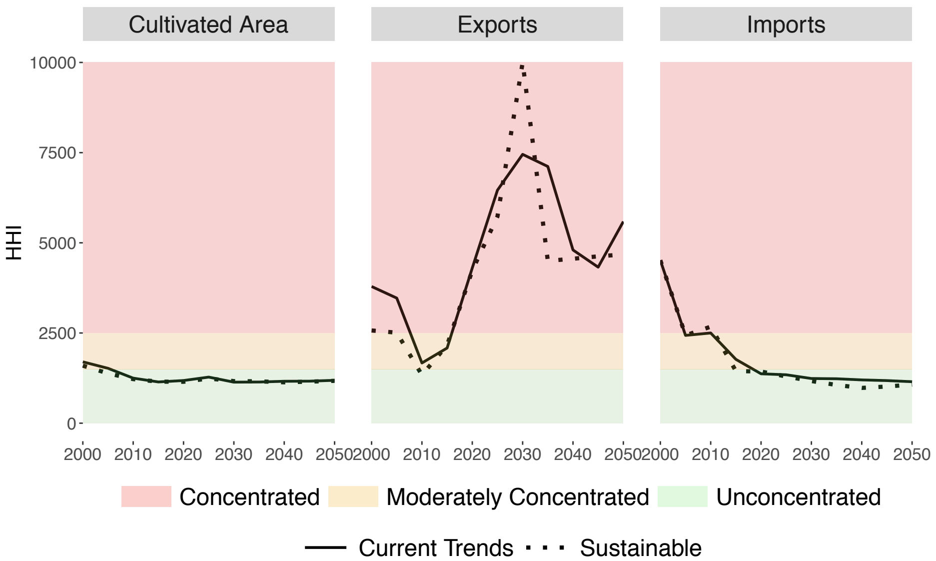


Figure 12 shows that the planted area is quite diverse in 2010 and that imports and exports are, respectively, moderately and highly concentrated during the historical period 2010 to 2015.

Under the Current Trend Pathways, we project moderate concentration in crop exports between 2010 to 2015 and a high concentration between 2020 to 2050. Crop imports are moderately concentrated during the period 2010-2020 and unconcentrated between 2020-2050. The range of crops planted is projected to experience low concentration, a trend which is stable over the period 2010 - 2050. This indicates high levels of diversity across the national production system and imports and low diversity across exports. Similarly, under the Sustainable Pathway, we project a high concentration of crop exports, and low concentration of crop imports and in the range of crops planted in 2050. Sustainable scenarios do not change the diversification patterns of crops despite the range of different assumptions. This is explained by several changes in the assumptions related to population, diets, crop productivity, biofuel policy, among the pathways.

Discussion and Recommendations

To explore viable ways to sustainably transform food and land-use systems in India, this study developed Current Trends and Sustainable Pathways using the global land systems model MAgPIE. The differences between these two Pathways are meant to help stakeholders and policy makers to better understand the differences between current trajectories and potential future trends of sustainable indicators to support the setting of national targets and monitor their progress. We hope our results can be useful in developing a framework of policy actions that aim to achieve several international commitments for climate mitigation and forest conservation, such as the Paris Agreement, the Convention on Biological Diversity, the Sustainable Development Goals, and the Bonn Challenge. For example, our analysis projects an emission reduction of 1064 Mt CO_2e per year under the Sustainable Pathway compared to Current Trends Pathway by 2050. This reduction is primarily due to our assumptions of a transition towards healthy diets, an improvement in livestock production systems (including the feed basket content), an afforestation target of 26 Mha by 2030, and others, which are in line with SSP1. Moreover, we find the livestock sector would be the major contributor towards these emissions reductions. Finally, the inclusion of the national biofuel mandate (Ministry of New and Renewable Energy, 2018) in our analysis, shows the impact on land-use dynamics and the potential for bioenergy crop use to meet India's blending targets.

Relevant and suitable policy transformations are required if the goals identified under the Sustainable Pathway are to be reached. For example, the successful implementation of the National Biofuel Policy of 2018 will be important in bringing about an increase in bioenergy crops which have implications on overall water use for production as well as GHG emissions. Similarly, our results indicate significant policy implications for ensuring the country's food security. The national Public Distribution System provides subsidized grains (rice and wheat) to economically disadvantaged segments of the population (up to 75% of rural population and 50% of urban population) under the National Food Security Act of 2013. However, the focus on cereals wards off the relevance of other nutritionally rich food products that shall help improve the dietary diversity of the Indian population. According to our projections, dietary shifts towards healthy diets will promote the advancements towards Sustainable Development Goals and thereby imply significant changes in the NFSA to include nutritionally rich foods such as pulses too.

From our analysis, focus on balanced diets can be brought out with the support of varied production of crops and livestock, while limiting the impact of this shift on water-use. About 90% of India's water use is dedicated to agricultural production, with rice and poultry production responsible for the largest blue water footprint. Under the Current Trends Pathway, the consumption of livestock products and cereals is expected to increase - in line with historical trends and rising household incomes, thereby placing additional pressures on land-use systems. While in the past, Indian diets have relied on cereals and a greater share of plant-based proteins, India currently faces a triple-burden of malnutrition, with high incidences of both under-nutrition and obesity in the population. High production and consumption of ultra-processed foods, sugars, and cereals leaves little room for protein and fiber-rich foods in the food basket. In the Sustainable Pathway, we assume that future dietary requirements will move towards plant-based nutrients, in line with the recommendations of EAT-*Lancet* Commission. These recommendations encourage lower consumption of animal products combined with greater consumption of fruits and vegetables. Our results point towards large environmental benefits from a shift to these healthier diets and that it may be possible to do so without expanding the cropland cover.

We conducted our analysis and assumptions with the dynamic, global partial-equilibrium MAgPIE model, which we have applied to India. Using a global modeling framework for a regional analysis has certain advantages and disadvantages. In terms of advantages, there is a benefit to building on an existing global model when no national land-system model with a comparable scope exists. In particular, our model includes many processes that are likely superior to static assumptions, even though they are only parametrized through international datasets. These include dynamic feed baskets, endogenous technological change, fertilization management, and emissions accounting. Finally, a global model might be better suited to account for international drivers such as trade, or for long-term trajectories of Indian land systems and how they compare to trajectories in other countries. On the other hand, using a global model for regional analysis also has its downsides. Firstly, as the input data is required on a global scale, more comprehensive and detailed data that may exist on the national scale cannot be easily incorporated into the model. For example, the MAgPIE model accounts for irrigation efficiency as a global weighted average of water losses from source to field ("conveyance efficiency times management factor") from Rohwer, Gerten, and Lucht (2007), which means we must use the same irrigation efficiency for India for both Current Trends and Sustainable Pathways. Similarly, water demand for crop production in the model is endogenously calculated based on irrigated cropland and livestock production and considers only blue water during the crop growing period. The current model framework accounts for lower water demand for agriculture overall as model validation and improvements in the model were beyond the scope of this exercise. Also, our findings on dietary patterns and consumption remain restricted to the national level as we are unable to account for sub-national and regional variations in dietary patterns across the country. In addition, the simulated processes were chosen based on their relevance for the global food system and may neglect important dynamics of high relevance for national food systems. For example, processes that may drive dietary patterns in India, such as religious affiliation, are not explicitly accounted for.

Moving ahead, while our analysis and assumptions have greatly benefitted from input from various stakeholders, we aim to continue to improve our assumptions to generate specific and actionable results through continued stakeholder engagement. Our Sustainable Pathway is already including highly ambitious targets for healthy diets, sustainable agricultural practices, and low emission targets. Through additional assumptions, we will be able to address additional sustainability objectives at national level are relevant for our stakeholders. In the present context of Covid-19, the focus on food systems and supply chains has become all the more relevant for policy makers and the general public.

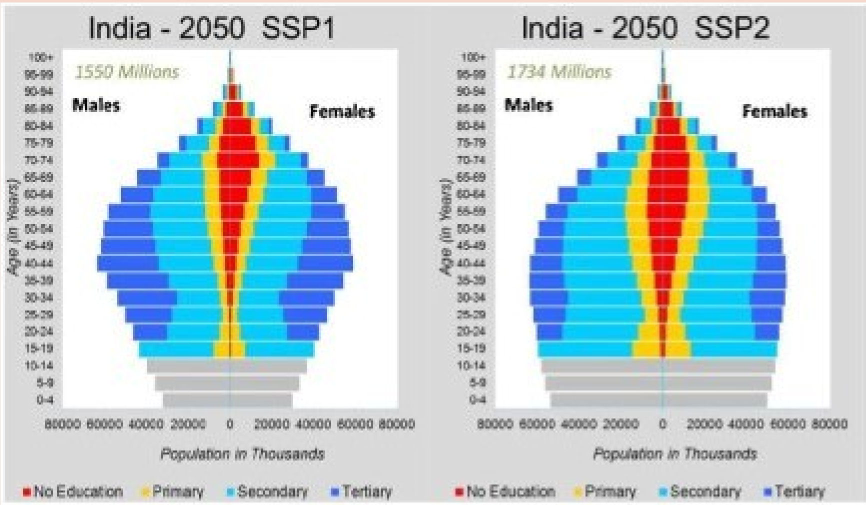
Annex 1. List of changes made to the model to adapt it to the national context

- MAgPIE is a recursive dynamic cost-minimization model of global land systems. The model simulates crop production, land-use patterns, water use for irrigation, and carbon stock changes at a spatial resolution of 0.5° × 0.5°. An additional feature of this model is the inclusion of international trade between defined world regions A detailed description of the modeling framework can be found in (Dietrich et al., 2019). The technical model description of the used version 4.1 is available at https://rse.pik-potsdam.de/doc/magpie/4.1/.
- MAgPIE uses spatially explicit biophysical information from the global gridded crop and hydrology Lund–Potsdam–Jena managed Land (LPJmL) model (Bondeau et al., 2007).
- To adapt the model in order to analyze options for sustainable food and land-use systems in India, we first conducted a validation process to tailor the model to national-level context and policies (e.g. improvement in productivity of pastures and grazelands).
- We have created two pathways “Current Trends” and “Sustainable” by setting the narratives around the Shared Socioeconomic Pathways (SSPs). Under the Current Trends, our assumptions are in line with SSP2, which is considered “Middle of the Road”, and for the Sustainable Pathway, our assumptions are in line with SSP1 which defines “Sustainability – Taking the Green Road” scenario (O’Neill et al., 2014; Popp et al., 2017; c.f. the underlying assumptions behind the scenarios in Section 10, Annex 2).
- In the Sustainable pathway, we have implemented the biofuel mandate of a 20% blending target in petrol and 5% in biodiesel according to India’s New Biofuel Policy (Ministry of New and Renewable Energy, 2018).
- For the purpose of FABLE Scenathon, we have implemented an exogenous trade setting for the trade adjustment of select commodities. The Scenathon (or “scenario marathon”) is an iterative process in which the FABLE country teams adjust their assumptions and pathways to ensure balanced trade flows and to aim towards achieving the global FABLE Targets.
- To convert the MAgPIE output to be compatible with the other FABLE models participating in the Scenathon we have disaggregated MAgPIE commodity groups into the FABLE Calculator commodity group by calculating the historical shares of each commodity within their respective product group by using FAOSTAT data for 2010 and 2015.
- We have implemented the FABLE biodiversity targets of “No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate” and “Protected areas cover at least 30% of global terrestrial land by 2030” by using evolution in the land cover category.

Annex 2. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)

Current Trends Pathway	Sustainable Pathway
The population is expected to reach 1.73 billion by 2050 based on our underlying assumption of SSP2 parameterization (Kc & Lutz, 2017). Currently, India's population is 1.31 billion and it is expected to reach approximately 1.4 billion by 2022. The projection suggests that India's population will continue to grow for several decades up to 1.5 billion in 2030 and 1.8 billion in 2050 (UN DESA, 2015).	The population is expected to reach 1.55 billion by 2050 based on our underlying assumption of SSP1 parameterization. The SSP1 parameterization is in line with more sustainable pathways that assume that investments in health and education will accelerate the demographic transition, leading to a relatively low world population (Kc & Lutz, 2017). Research indicates that under the SPP1 scenario for India, female education levels will be higher along with lower assumed education-specific fertility rates, thereby resulting in much lower birth rates.



Population of India by age, sex and educational attainment under SSP1 and SSP2 scenario (Source: Kc and Lutz, 2017).

LAND Constraints on agricultural expansion	
Current Trends Pathway	**Sustainable High Ambition Pathway**
We assume that deforestation will be halted beyond 2005. The assumption is based on several national policies that have been implemented (e.g. the Indian Forest Act and Indian Forest Conservation Act) and based on historical trends (FAO, 2020). Therefore, no agricultural land expansion into natural forests is allowed. Agricultural land can be increased by converting other natural vegetation areas that have lower carbon densities than natural forests. Areas under the industrial forestry sector are assumed to be constant and therefore cannot be converted into other land uses.	Same as Current Trends

LAND Afforestation or reforestation target (1,000 ha)	
We assume total afforested/reforested area will reach 21 Mha by 2030. These assumptions are based on India's Bonn Challenge Commitment (2014) whereby India has pledged to restore 13 Mha of degraded and deforested land by 2020, and an additional 8 Mha by 2030. According to Borah et al., 2017 India has brought an area of 9.8 Mha under restoration since 2011, meaning that work to restore these landscapes is already underway.	We assume total afforested/reforested area will reach 26 Mha by 2030. This assumption is based on India's additional commitment of 5 Mha in line with the existing Bonn Challenge commitment (2014). This new commitment was announced by the Government of India at the UN Summit in 2019 (Prime Minister's Office, 2019).

BIODIVERSITY Protected areas (% of total land)	
Current Trends Pathway	**Sustainable Pathway**
We assume that protected areas remain stable until 2050: by 2050 they represent 6% of total land. Indian protected areas were computed using the data from World Database on Protected Areas (UNEP-WCMC & IUCN, 2020). The assumptions are in line with India's commitment to the CBD.	Same as Current Trends

BIODIVERSITY Crop productivity for the key crops (in t DM /ha)

Current Trends Pathway

By 2030, crop productivity reaches:

- 4.5 tonnes DM per ha for rice
- 1.9 tonnes DM per ha for corn
- 6.7 tonnes DM per ha for soybean

We assume a moderate increase in crop productivity compared to 2010. This dynamic change in crop productivity is based on our assumptions of medium technological costs and medium interest rates (7%) that influence investments in yield-increasing technologies. The assumed investment horizon is provided by the interest rate, which is a risk-accounting factor associated with investment activities (Dietrich, Schmitz, Lotze-Campen, Popp, & Müller, 2014; Wang et al., 2016). Along with technological change, the change in crop yield is also driven by high use of fertilizers due to the underlying SSP2 parameterization and yield growth is proportional to the growth in fertilizers use (Valin et al., 2013; Mogollón et al. 2018). The elasticity of variable input including fertilizer use with respect to echnological change is 1.00 (Fricko et al., 2017) which means moderate use of yield improving technologies together with moderate use of fertilizer.

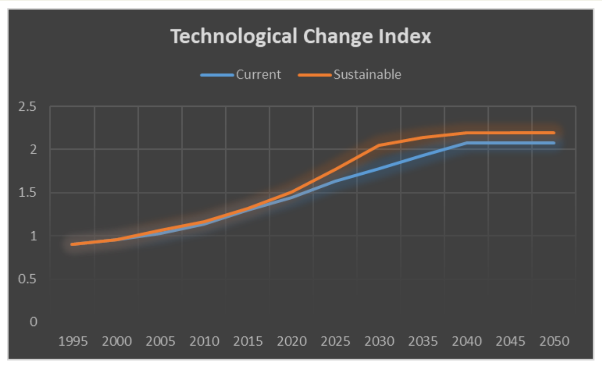
Sustainable Pathway

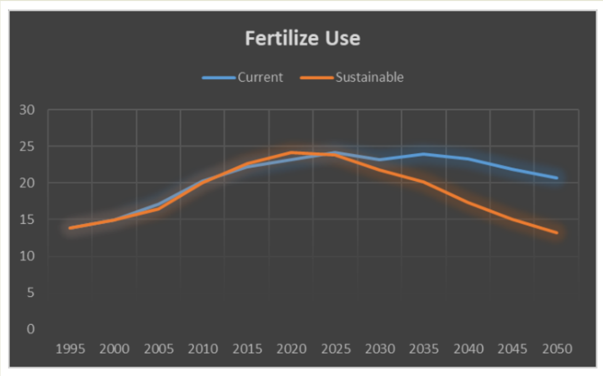
By 2030, crop productivity reaches:

- 6.5 tonnes DM per ha for rice
- 2.5 tonnes DM per ha for corn
- 7.8 tonnes DM per ha for soybean

We assume a high increase in crop productivity compared to 2010. This dynamic change in crop productivity is based on our assumptions of low technological costs and lower interest rates (4%). The assumed investment horizon is provided by the interest rate, which is a risk-accounting factor associated with investment activities (Wang et al., 2016). In addition, due to underlying SSP1 parameterization the yield growth is proportional to the growth in fertilizer use (Mogollón, Beusen, van Grinsven, Westhoek, & Bouwman, 2018; Valin et al., 2013). The elasticity of variable input including fertilizer use with respect to technological change is 0.75 (Fricko et al., 2017) which means high use of yield improving technology and low use of fertilizer.

Our assumptions are based on National Council of Applied Economic Research (2015) that suggests that due to technological innovation and diffusion through institutional arrangements, growth in yields will be high in the coming decades. In addition, several subsidies will reduce the cost of technologies and increase economies of scale. The study suggests that the area expansion for several cereal crops including wheat is going to be weak and that production and growth will mostly be driven by yield increases.





Difference in fertilizer use under the Current Trends (SSP2) and Sustainable pathways (SSP1)

BIODIVERSITY Livestock productivity	
Current Trends Pathway	**Sustainable Pathway**
We assume that by 2050, livestock productivity moderately increases based on improvements in feed basket content and livestock production systems. Following the methodology of (Wirsenius ,2000) feed conversion (total feed input per product output in dry matter) and feed baskets (demand for different feed types per product output in dry matter) are derived by compiling system-specific feed energy balances. To facilitate projections of feed conversion and feed baskets, we create regression models with livestock productivity annual production per animal in tonne fresh matter/animal/year as a predictor, which permits the construction of livestock feeding scenarios. Currently, feeding scenarios are derived based on exogenous livestock productivity scenarios consistent with the storylines of the Shared Socioeconomic Pathways (Weindl et al., 2017). We assume an SSP2 storyline which implies moderate growth in livestock productivity and related changes in feed baskets (Fricko et al., 2017,). Based on National Council of Applied Economic Research (2015), the increase in income levels, population, and urban space, as well as the increased use of livestock products will expand the production of livestock products in coming decades. Despite a major dependency on cereals, rising protein consumption will necessitate increasing livestock and dairy production. To meet the domestic protein demand, the Government of India is focusing on livestock intensification systems to improve yields in animal products (Planning Commission, 2012).	By 2050, livestock productivity increases at a higher rate compared to 2010 based on the improvement in feed baskets and livestock production systems. The feed conversion calculation is same as described in the Current Trends Pathway. We assume an SSP1 storyline which implies high growth in livestock productivity and related changes in feed baskets (Fricko et al., 2017). The extent to which growth in livestock production can be accelerated will depend on how technology, institutions, and policies address constraints facing the livestock sector. Production growth dependent on larger animal stocks is not sustainable in the long run, due to adverse effect on the carrying capacity of land and available resources; hence, future growth in production should essentially come from improvements in productivity. This will require overcoming feed and fodder scarcity and improvements in the delivery of animal health and breeding services. A key driver of growth will be the generation and dissemination of yield-enhancing and yield-saving technologies (Ministry of Agriculture and Farmer's Welfare, 2017).

BIODIVERSITY Pasture stocking rate	
Current Trends Pathway	**Sustainable Pathway**
By 2050, the average ruminant livestock stocking density per hectare will be higher compared to 2010 as we assume higher yields of pastureland. Several initiatives were taken to improve livestock feeding systems because, by 2025, India is likely to experience a fodder deficit of about 65% for green fodder and 25% for dry fodder (Indian Council of Agricultural Research, 2015; Ministry of Agriculture and Farmer's Welfare, 2017; Planning Commission, 2012).	Same as Current Trends

TRADE Share of consumption which is imported for key imported products (%)

Current Trends Pathway

By 2050, the share of total consumption which is imported is:

- 17% for corn
- 14% by 2050 for groundnut
- 10% by 2050 for poultry meat

Sustainable Pathway

By 2050, the share of total consumption which is imported is:

- 28% by 2050 for corn
- 21% by 2050 for dairy
- 21% by 2050 for poultry meat

TRADE Evolution of exports for key exported products (1,000 tonnes)

Current Trends Pathway

By 2050, the volume of exports is:

- 9,037 tonnes by 2050 for soybean
- 3,409 tonnes by 2050 for fibers
- 2,428 tonnes by 2050 for cotton lint

Based on our assumption of 10% trade liberalization for secondary and livestock products in 2030, 2050, 2100 and 20% for crops.

Sustainable Pathway

By 2050, the volume of exports is:

- 7,747 tonnes by 2050 for soybean
- 1,4370 tonnes by 2050 for oils cake
- 195 tonnes by 2050 for cotton lint

Based on our assumption of 10% trade liberalization for secondary and livestock products in 2030, 20% in 2050, 2100 and 20% in 2030, 30% in 2050, 2100 for crops.

FOOD Average dietary composition (daily kcal per commodity group)

Current Trends Pathway

By 2030, the average daily calorie consumption per capita is 2,260 kcal and is:

- 1,207 kcal from crops
- 363 kcal from livestock products
- 626 from secondary products

Our assumption is in the line with the SSP2 parameterization which assumes moderate consumption growth and an increasing share of livestock products in the dietary mix (Fricko et al., 2017). We assume that expected rise in per capita income, commercialization, and urbanization will cause a shift from main staples to high-value products, for example livestock products in India (Alae-Carew et al., 2019; Ritchie, Reay, & Higgins, 2018; Rosegrant, Leach, & Gerpacio, 1999), and substantial increases in projections for vegetable oils and sugar (Alexandratos, Nikos & Bruinsma, Jelle, 2012; Carriquiry et al., 2010)

Sustainable Pathway

By 2030, the average daily calorie consumption per capita is 2,286 kcal and is:

- 1,170 kcal from crops
- 385 kcal from livestock products
- 668 kcal from secondary products

We implemented a transition to a sustainable and healthy diet into the model's internal calculations of food demand, which are designed for long-term scenarios of food intake, dietary composition, body mass index distribution, body height and food waste. The food demand model is established based on a regression analysis with historical data to estimate consumption patterns using only changing GDP and population levels over time as drivers (Bodirsky et al., 2015; Dietrich et al., 2019). For the Sustainable Pathway we assume a linear convergence during the period 2020 and 2050 from model-internal calculations using the SSP1 parametrization of dietary patterns shifting according to recommendations for a healthy and sustainable diet described by the EAT-Lancet Commission (Springmann, 2019; Springmann et al., 2018).

FOOD Share of food consumption which is wasted at household level (%)

Current Trends Pathway

By 2030, the share of final household consumption which is wasted at the household level is 20%. This value is based on an exogenous food waste target that is approximately half of that of high-income countries.

These exogenous values are derived from FAO historical data and calibrated to FAO Food supply values globally.
In India, since food loss is mainly determined by the loss of fruits and vegetables during transportation and retail, we assume a moderate reduction in food loss and waste by 2050 under the SSP2 scenario (Fricko et al., 2017) as there is little available information on food waste at the household level.

Sustainable Pathway

By 2030, the share of final household consumption which is wasted at the household level is 10%. This value is based on an exogenous food waste target that is approximately a quarter of that of high-income countries. These exogenous values are derived from FAO historical data and calibrated to FAO Food supply values globally.

Under the SSP1 scenario, we expect a more sustainable use of food at the household level owing to changes in consumer behavior, better storage facilities, and improved education and awareness (Stehfest et al., 2019) as there is little available information on food waste at the household level.

India

BIOFUELS Targets on biofuel and/or other bioenergy use (Mt DM/Year)

Current Trends Pathway

By 2050, biofuel production accounts for:

- 79.63 Mt DM/year of sugarcane production
- 2.39 Mt DM/year of corn production
- 28.97 Mt DM/year of temperate cereal production

Based on our assumption that the demand for bioenergy will increase up to 2030 and remain stable thereafter. Energy demand is defined as total demand for first-generation bioenergy, which is mainly determined by public policy measures, and rises to about 6 EJ of final energy globally in 2030 and 0.5 EJ of final energy for the South Asian Region in 2030 (Lotze-Campen et al., 2014). India's average blending rate for ethanol in gasoline is expected to reach a record 5.8%, up from a previous record 4.1% in 2019 and considerably higher than historical levels. A surplus sugar season coupled with a stronger incentive to convert excess sugar to ethanol has helped oil-marketing companies procure upwards of 2.4 billion liters in 2019 (Aradhey, 2019)

Sustainable Pathway

By 2050, biofuel production accounts for:

- 540 Mt DM/year of sugarcane production
- 33.91 Mt DM/year of corn production
- 39.13 Mt DM/year temperate cereal production

Based on the implementation of India's New Biofuel Policy, 2018. The policy proposes an indicative target of 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel by 2030. Under these scenarios, we assume that the demand for ethanol will increase from 0.4 PJ/yr to 788 PJ/yr over the period from 2015 to 2030 and to 1838 PJ/yr in 2050. To meet the biodiesel mandate we assume that the demand for vegetable oils will also increase from 0.84 PJ/yr to 292 PJ/yr over the period from 2015 to 2030 and to 680 PJ/yr in 2050 with a continued increase after 2030. In our scenario we assume that demand will stabilize between 2030 and 2050 (Ministry of New and Renewable Energy, 2018)

CLIMATE CHANGE Crop model and climate change scenario

Current Trends Pathway

By 2100, global GHG concentration leads to a radiative forcing level of 6 W/m2 (RCP 6.0). Impacts of climate change on crop yields are computed by the crop model LPJmL (Bondeau et al., 2007; Müller & Robertson, 2014).

Sustainable Pathway

By 2100, global GHG concentration leads to a radiative forcing level of 6 W/m2 (RCP 2.6). Impacts of climate change on crop yields are computed by the crop model LPJmL (Bondeau et al., 2007; Müller & Robertson, 2014).

Annex 3. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on Map 1

FABLE classes	ESA classes (codes)
Cropland	Cropland (10,11,12,20), Mosaic cropland>50% - natural vegetation <50% (30), Mosaic cropland<50% - natural vegetation >50% (40)
Forest	Broadleaved tree cover (50,60,61,62), Needleleaved tree cover (70,71,72,80,82,82), Mosaic trees and shrub >50% - herbaceous <50% (100), Tree cover flooded water (160,170)
Grassland	Mosaic herbaceous >50% - trees and shrubs <50% (110), Grassland (130)
Other land	Shrubland (120,121,122), Lichens and mosses (140), Sparse vegetation (150,151,152,153), Shrub or herbaceous flooded (180)
Bare areas	Bare areas (200,201,202)
Snow and ice	Snow and ice (220)
Urban	Urban (190)
Water	Water (210)

Annex 4. Overview of biodiversity indicators for the current state at the ecoregion level[4]

	Ecoregion	Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with at > 10% natural vegetation within 1km²(%)
0	Rock and Ice	1981.607	27.1	63.4	33.5	66.5	4.582	93.3
218	Andaman Islands rain forests	514.522	5	68.8	6.3	93.7	11.262	91.2
222	Brahmaputra Valley semi-evergreen forests	5656.174	5.2	18.3	22.7	77.3	3688.655	25.3
226	Chin Hills-Arakan Yoma montane forests	15.518	0	72.5	0	0	0.188	100
228	East Deccan moist deciduous forests	34174.77	4.9	6.3	72.4	27.6	18539.109	26.2
233	Himalayan subtropical broadleaf forests	576.101	15.9	35.4	42.9	57.1	366.055	12.5
238	Lower Gangetic Plains moist deciduous forests	14617.61	3.1	6.4	45.4	54.6	12571.004	4.4
242	Malabar Coast moist forests	3471.677	3.6	3.8	30.5	69.5	1246.106	59.5
243	Maldives-Lakshadweep-Chagos Archipelago tropical moist forests	0.839	0	0		0	0.063	9.5
244	Meghalaya subtropical forests	4168.236	1.1	18.4	3.8	96.2	684.712	40.1
249	Mizoram-Manipur-Kachin rain forests	5822.178	4	49.6	7.6	92.4	470.292	47.3
252	Nicobar Islands rain forests	144.538	52.9	92.3	56.7	43.3	11.954	72.3
253	North Western Ghats moist deciduous forests	4830.426	4.9	6.7	65.1	34.9	2345.098	41
254	North Western Ghats montane rain forests	3100.352	17.2	24.1	62.5	37.5	607.07	69.3
261	Orissa semi-evergreen forests	2222.441	7.1	10.1	64	36	1760.293	10.4
270	South Western Ghats moist deciduous forests	2382.368	27.8	40.2	57.7	42.3	1022.4	31

4 The share of land within protected areas and the share of land where natural processes predominate are percentages of the total ecoregion area (counting only the parts of the ecoregion that fall within national boundaries). The shares of land where natural processes predominate that is protected or unprotected are percentages of the total land where natural processes predominate within the ecoregion. The share of cropland with at least 10% natural vegetation is a percentage of total cropland area within the ecoregion.

	Ecoregion	Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with at > 10% natural vegetation within 1km²(%)
271	South Western Ghats montane rain forests	2268.59	26.5	39.4	55.1	44.9	357.942	67.6
282	Sundarbans freshwater swamp forests	676.522	3.5	1.7	87	13	540.533	6.2
287	Upper Gangetic Plains moist deciduous forests	26367.93	1.3	2.3	38	62	24317.115	3.3
290	Central Deccan Plateau dry deciduous forests	24067.43	4.1	4.7	56.2	43.8	19066.507	11.2
292	Chhota-Nagpur dry deciduous forests	12269.22	6	6.8	80.2	19.8	8670.922	16
293	East Deccan dry-evergreen forests	2526.867	1.7	2.4	52.9	47.1	2241.722	7
295	Khathiar-Gir dry deciduous forests	26737.79	4.2	5.4	56.9	43.1	21266.776	13.2
296	Narmada Valley dry deciduous forests	17025.68	4.5	6.4	66.9	33.1	10854.944	26
297	North Deccan dry deciduous forests	5844.994	2.8	3.5	64.9	35.1	3870.024	20.1
298	South Deccan Plateau dry deciduous forests	8243.186	9.1	6.4	19.5	80.5	6469.961	9.7
302	Himalayan subtropical pine forests	3937.36	4.4	6.7	54.1	45.9	783.475	70.2
304	Northeast India-Myanmar pine forests	964.412	0	45.9	0.1	99.9	17.115	97.4
306	Eastern Himalayan broadleaf forests	5130.547	9.5	77.2	11.9	88.1	112.362	66.7
307	Northern Triangle temperate forests	6.379	0	98.8	0	0	0.068	100
308	Western Himalayan broadleaf forests	4664.288	6	17.6	29.3	70.7	876.715	64.2
309	Eastern Himalayan subalpine conifer forests	1265.683	5.8	90.7	6.3	93.7	12.141	93.7
310	Western Himalayan subalpine conifer forests	666.904	21.9	48.5	43	57	53.213	81.1
311	Terai-Duar savanna and grasslands	1193.908	9.8	13.7	65.2	34.8	734.683	20.4

India

	Ecoregion	Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with at > 10% natural vegetation within 1km²(%)
312	Rann of Kutch seasonal salt marsh	2395.042	78.9	74.6	93.9	6.1	167.378	63
314	Aravalli west thorn scrub forests	24441.65	2	3.9	37.3	62.7	20837.085	9.8
315	Deccan thorn scrub forests	33804.62	2.8	4.6	26.1	73.9	29566.782	11.1
316	Godavari-Krishna mangroves	642.768	13.6	21.1	53.1	46.9	415.004	15.1
318	Thar desert	16029.25	2	3.4	56.4	43.6	6807.855	28.6
320	Indus River Delta-Arabian Sea mangroves	261.584	3.5	14.3	21.2	78.8	147.409	30.2
323	Sundarbans mangroves	378.45	38.7	35.8	97.7	2.3	160.833	4.7
702	Northeast Himalayan subalpine conifer forests	535.269	7.7	92.4	8.3	91.7	5.961	99.6
750	Central Tibetan Plateau alpine steppe	108.192	0	74.1	0	0	0.038	100
751	Eastern Himalayan alpine shrub and meadows	1257.011	11.1	98.5	11.3	88.7	16.171	99
754	Karakoram-West Tibetan Plateau alpine steppe	5172.01	26.6	74.1	34.8	65.2	41.834	92.1
760	Northwestern Himalayan alpine shrub and meadows	2457.337	21.5	73.3	27.5	72.5	68.208	95.4
769	Western Himalayan alpine shrub and meadows	1353.641	23.2	66.3	27	73	54.275	97.2
770	Yarlung Zanbo arid steppe	0.151	0	100	0	0	0	0
814	Baluchistan xeric woodlands	2.235	0	0	0	0	2.092	8.3

Units

°C – degree Celsius

% – percentage

/yr – per year

cap – per capita

CO_2 – carbon dioxide

CO_2e – greenhouse gas expressed in carbon dioxide equivalent in terms of their global warming potentials

DM – Dry Matter

EJ – Exa Joule

g – gram

GHG – greenhouse gas

ha – hectare

kcal – kilocalories

kg – kilogram

kha – thousand hectares

km^2 – square kilometer

km^3 – cubic kilometers

kt – thousand tonnes

m – meter

Mha – million hectares

mm – milimeters

Mm^3 – million cubic meters

Mt – million tonnes

PJ – Peta Joule

t – tonne

TLU – Tropical Livestock Unit is a standard unit of measurement equivalent to 250 kg, the weight of a standard cow

t/ha – tonne per hectare, measured as the production divided by the planted area by crop by year

t/TLU, kg/TLU, t/head, kg/head- tonne per TLU, kilogram per TLU, tonne per head, kilogram per head, measured as the production per year divided by the total herd number per animal type per year, including both productive and non-productive animals

USD – United States Dollar

W/m^2 – watt per square meter

yr – year

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