**Report**

# Food systems transformation in Indonesia: Results on baseline and stylized scenarios from GLOBIOM

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# Abstract

As part of an effort to inform food system transformation in Indonesia and build on analytical and modelling work by BAPPENAS, FAO and others, this report contains the model description, business as usual trajectory and stylized scenarios coming from the GLOBIOM model. The report takes a food system approach where stylized scenarios follow three main policy levers, namely the healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability:

1. **Healthy diets** – In line with the RPJMN goal of improving the quality of Indonesian diets, this axis reflects a transition towards healthier diets in Indonesia through reducing food insecurity and increasing the consumption of products that are key to a healthy diet.
2. **Socioeconomic sustainability of agri-food supply** – In line with the RPJMN goal of increasing food availability, this axis reflects a transition towards increased and more sustainable agricultural production that meets the needs of a growing population by increasing local agricultural production and increasing the share of domestic production in national consumption.
3. **Environmental sustainability** – In line with the RPJMN goals of strengthening the environment, improving climate resilience, and promoting low carbon development, this axis reflects a transition towards environmental sustainability, achieved through policies that constrain land use and reduce food loss and waste, thereby reducing GHG emissions, reducing deforestation and preserving biodiversity.

One or two policy interventions are designed along each of the axes and compared in terms of the main flagship indicators: percentage undernourished, share of food calories produced domestically (%), total value added from agriculture, forest cover and GHG emissions. The scenarios modeled are: (1) 'POU': A target to increase food consumption towards reducing undernourishment to 2.5% by 2030 combined with a transition towards healthier diets; (2) 'INT': An intensification scenario leading to increased productivity on cropland through better cultivars and an increased use of water and fertilizers; (3) 'GHG050': A carbon tax of 50 USD/ton on agriculture and land use emissions; (4) 'CONS': an extension of the moratorium policy on primary forests and peatland conversion. In addition, different combinations of the individual policy interventions are made: a target on undernourishment combined with a moratorium on primary forests (CONS_POU), a moratorium on primary forests combined with agricultural intensification (CONS_INT), a target on undernourishment combined with agricultural intensification (INT_POU), and a combined moratorium on primary forests, target on undernourishment and agricultural intensification scenario (CONS_INT_POU).

**Model**

We use the Global Biosphere Management Model (GLOBIOM, Havlík et al. 2014), developed at the International Institute for Applied Systems Analysis (IIASA), to understand the effects of policy interventions on the three axes. GLOBIOM provides a national and sub-national level picture of food system performance within the agriculture and forestry sector in Indonesia, identifying and analysing synergies and trade-offs associated with policy interventions over the medium to long term, in this case 2030-2045. The model has been updated and refined using best available data and tailored to the context of Indonesia. A consistent land use-land cover map has been built using the best land cover map available, agricultural statistics and other available spatially explicit information on land use. The list of crops has been extended compared to the standard version of GLOBIOM to better represent the land use dynamics and demands for the main commodities in international markets. A comparison of the most important agricultural and land use items and indicators shows that GLOBIOM follows both

the trend and absolute changes of the land use, land use dynamics, GHG emissions, production, consumption, and trade over the historical reference period of 2000-2020 well.

**Business as usual results**

GLOBIOM's business as usual trajectory show that, due to the foreseen growth in GDP, production and value added, the percentage of undernourished decreases steadily over the time horizon, from 9% in 2020 to 5.7% in 2030 and 1.4% in 2045 under a no intervention scenario. Agricultural yields and value added measured in real terms continue to increase over the time horizon, by 13.8% in 2030 and 42% in 2045 compared to the 2020 value added. This is a lot smaller than the relative increase in real value added of 118% that GLOBIOM-Indonesia simulated over the 2000-2020 period.

Regarding the flagship indicators for the environment, emissions show a decrease compared to 2020, by 17% in 2030 and by 10% in 2045. This decrease in emissions is largely due to the sharp decrease in emissions from land cover change, mostly resulting from reduced deforestation and from the reduced draining of peatlands for agricultural conversion. Primary forests decrease by 2.4% in 2030 and 3.6% in 2045 compared to the 2020. Natural land decreases by 5.8% in 2030 and 17.4% in 2045. The land from these land covers shifts to agriculture, livestock and forestry production: plantation oil palm (+6.7% in 2030 and +18% in 2045), forest plantations (+9.5% in 2030 and +25.5% in 2045), cropland (+2.4% in 2030 and +10.9% in 2045) and a small increase in grassland for livestock production (+1.1% in 2030 and +7.6% in 2045).

**Scenario results**

Based on the stylized scenarios and their comparison regarding the main flagship indicators and the three axes, the following conclusions and policy recommendations can be drawn:

In the short term, to reach the goal of lower undernourishment and promoting healthier diets, it is particularly important to target and implement policy measures that directly impact consumers. Targeting consumers directly can lead to a reduction in the percentage of undernourished from 5.7% under the business as usual trajectory to 2.8% by 2030. Focusing on agricultural producers through the enhancement of yields will only lead to a reduction in the percentage undernourished to 5.3% by 2030.

Intensification measures may not be effective in reducing undernourishment and promoting healthier food choices, as the increased production is partly directed towards cash crops and exports[1]. Under the intensification scenario, production increases are concentrated in coffee and soy. Under the reduction in undernourishment scenario, production increases are observed primarily for rice, soy and sweet potatoes, crops that directly benefit consumption. Therefore, well-targeted policies towards not only reducing undernourishment but also improving diets will lead to more calorie and nutrient rich consumption patterns compared to an intensification scenario where the focus is purely on increasing agricultural production.

Scenarios focused solely on the environment result in slight increases in the percentage of undernourished individuals, especially in the longer term. This is because environmental policies that limit land cover conversion or put a price on emissions from agriculture and land use activities reduce the amount of productive land available for conversion to cropland and increase production costs.

Regarding the socio-economic sustainability of the agri-food system, we find that different crops will benefit from either agricultural intensification or support to consumers. Cash crops like coffee and crops

[1] It should be noted that GLOBIOM does not account for indirect impacts on enhanced food consumption through increased income and purchasing power from additional value added generated through the sales of commodity crops.

used to feed livestock such as soybeans will gain in terms of value added, by respectively 59.4% and 57.4% by 2030 under an intensification scenario. On the other hand, root crops like cassava and sweet potatoes, which are healthy staple foods, will gain in value added, by respectively 25.5% and 18.4% by 2030 under a scenario with higher demand for these types of crops (POU). Under a combined scenario with both POU and intensification, both cash crops and root crops will gain in value added. At the same time, food prices go down in the INT_POU scenario, leading to cost savings for the government in case of food subsidies to meet the targeted reduction in undernourishment.

Regarding environmental sustainability, a scenario focusing only on a decrease in undernourishment leads to an increase in the cropland extent and in emissions. Cropland expansion is driven by the additional demand for certain crops (+0.5mln ha compared to the base in 2030 and +0.49mln ha compared to the base by 2045).
If primary forests are subject to a moratorium, other potentially biodiverse-rich land covers, like natural lands are likely to be converted more. Combining scenarios can mitigate negative emissions effects compared to a business-as-usual scenario, but may not achieve individual goals (e.g. no reduced deforestation under CONS-INT-POU). In both the short and long term, a conservation scenario is the most effective in "saving" primary forests (+1.9% or nearly 1 million hectares (0.97) by 2030 and +1.8% or 1.2 million ha by 2045) compared to a carbon tax (+0.3% or 147,000 hectares by 2030 or +1.4% or 665 thousand ha by 2045). However, a conservation scenario also leads to a reduction in natural land (-0.6% or 146,000 hectares), which is not covered by the moratorium. A conservation and intensification scenario leads to the largest gains in primary forests (+2.3% or 1.2 million hectares by 2030 and up to 2 million ha by 2045) and natural land (+1.1% or 276,000 hectares by 2030 or 786 thousand ha by 2045). When also combining these two objectives with a target on reducing undernourishment, it becomes possible to reduce emissions, particularly those caused by changes in land cover, without increasing the percentage of undernourished people (see Figure 1).

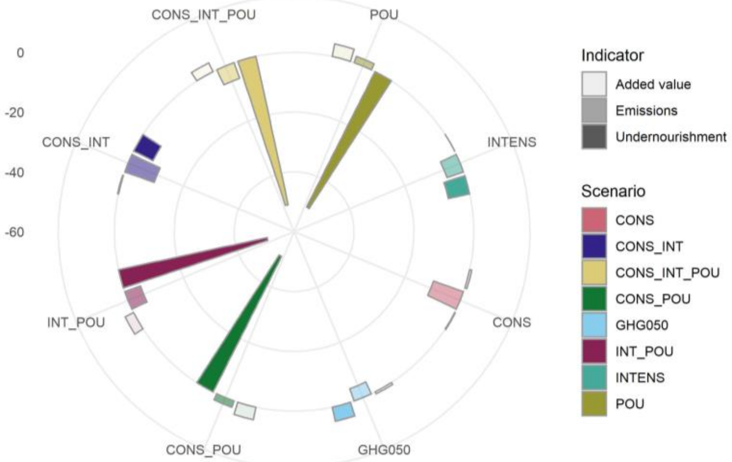


*Figure 1:* Spider diagram of results by flagship indicator and main policy intervention. Changes are reported in percentage change of the policy intervention in 2030 compared to the baseline in 2030.

The analysis of policy interventions and its outcomes primarily focuses on the national level. However, implementing these interventions across Indonesia, being an archipelago, could lead to increased transaction costs, such as higher food distribution expenses. Currently, most of the food production occurs in Java. Initial findings from GLOBIOM suggest that targeting these food producing hotspots can yield quick wins in terms of e.g. food production and food availability. Nonetheless, regions outside of Java have the highest rates of undernourishment, indicating the need for further research to explore regional variations in meeting policy objectives.

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# Food systems transformation in Indonesia: Results on baseline and stylized scenarios from GLOBIOM

## Highlights/policy recommendations

i) This report uses the Global Biosphere Management Model (GLOBIOM) to understand the effects of interventions on healthy diets, socio-economic sustainability and agri-food supply, and enverionmental sustainability in Indonesia.

ii) We updated and refined the GLOBIOM model for Indonesia by using the best available data on land use, agriculture, and forestry sectors for the country.

iii) The model is fine-tuned to calibrate well the historical patterns of deforestation, emissions and trajectories in the agricultural sector and is thereby able to predict the future dynamics of the agriculture and land use sectors.

iv) The baseline shows a decrease in emissions over the 2020-2045 period compared to the past two dacades, due to a decrease in agriculture-induded deforestation. However, land cover conversions still occur, with a decrease in primary forests and natural land going towards agriculture, livestock and forestry production.

v) Baseline results further show a slowdown in the increase in value added from agriculture and forestry activies.

vi) Due to the foreseen growth in GDP, production and value added, the percentage of undernourished decreases steadily over the time horizon, from 8.9% in 2020 to 5.7% in 2030 and further to 1.4% in 2045. However, without additional policies this may leave some negative impacts on the environment.

vii) The stylized scenarios show that in the short term, to reach the goal of low level of undernourishment and promote healthier diets, it is particularly important to target and implement policy measures that directly impact consumers. Targeting consumers directly can lead to a reduction in the percentage of undernourished from 5.7% under the baseline to 2.8% by 2030. Focusing on agricultural producers through the enhancement of yields will lead to only slightly reduced percentage of undernourished - to 5.3% by 2030.

viii) An intensification scenario may not be effective in reducing undernourishment and promoting healthier food choices, as the increased production is partly directed towards cash crops and exports. Under an intensification scenario, especially coffee and soy production increase, whereas increases are observed for rice, soy and sweet potatoes under a reduction in undernourishment scenario. Therefore, well-targeted policies towards not only reducing undernourishment but also increasing diet patterns will lead to a different diet compared to an intensification scenario where the focus is purely on increasing production.

ix) Scenarios focused solely on conservation will result in slight increases in the percentage of undernourished individuals, especially in the longer term.

x) Regarding the socio-economic sustainability of the agri-food system, we find that different crops will benefit from either agricultural intensification or support to consumers. Combined scenarios may help to bring benefits regarding value added for both cash crops and food crops, and at the same time lead to cost savings for the government through food price decreases.

xi) If primary forests are subject to a moratorium, other potentially biodiverse-rich land covers, like natural land, may be converted. Combining scenarios can mitigate negative emissions effects compared to a business-as-usual scenario, but may not achieve individual goals (e.g. no reduced deforestation under CONS-INT-POU). Further, it is possible to reduce emissions, particularly those caused by changes in land cover, without increasing the percentage of undernourished people, when combining policy interventions around different axes.

xii) The analysis of policy interventions and its outcomes primarily focuses on the national level. However, implementing these interventions across Indonesia, being an archipelago, could lead to increased transaction costs, such as higher food distribution expenses. Currently, most of the food production occurs in Java. Initial findings from GLOBIOM suggest that targeting these hotspots can yield quick wins in terms of food production and environmental conservation. Nonetheless, regions outside of Java have the highest rates of undernourishment, indicating the need for further research to explore regional variations in meeting policy objectives.

# Introduction

Tropical regions are at the center of current climate and biodiversity policy pledges and will play a key role on the attainment of Sustainable Development Goals throughout the 21st century (Swamy et al. 2018). These areas display some of the highest productive potentials globally, and thus are pivotal to food and fiber production, as well as food security. At the same time, tropical regions house the largest share of the global biodiversity (Hill et al. 2019) and terrestrial carbon stocks (Pan et al. 2011). These features give rise to potential trade-offs among environmental, human and economic objectives of the land use sector, where economic growth in rural areas and expansion of agriculture and forestry, targeted at food security and income generation, might occupy areas previously covered by biodiversity and carbon-rich primary forests. This is evidenced by current deforestation frontiers in Indonesia, where the land use sector is responsible for a large share of GHG emissions and biodiversity loss, due to the conversion of primary forest cover (Hoang and Kanemoto 2021). Integrative approaches to land stewardship are therefore urgently needed, to reconcile these trade-offs are and reverse the trends in environmental degradation, while promoting social welfare and contributing to the attainment of SDGs.

Indonesia is among the countries that experienced the most profound changes in land use during the past decades. Recent trends in the country's economic growth were supported by natural resources exploitation, driven by both an accelerated population growth and growing world demand for some of its key commodities (Khatun et al. 2017; Wang et al. 2020). The high population growth is likely to increase the demand for agricultural products that are key for the country's food self-sufficiency, such as rice and maize. Furthermore, economic growth will likely drive a change in diets, such as increased consumption of animal-based products, altering production systems and land requirements for food production (e.g. Popp et al. 2017). Political leaders have increasingly cited food self-sufficiency as a major motivation to increase domestic production and reduce the countries import dependency, especially for key staple crops, such as rice. At the same time, world demand of some of Indonesia's cash crops has seen rapid increases over the past decades, most notably for oil palm, but also rubber, coffee, and cocoa.

The development of the forestry and agricultural sectors in Indonesia have contributed to the improvement of local livelihoods and consolidated the role of the country in international commodity markets. At the same time, negative impacts to the environmental integrity have been linked to the expansion of forestry and agricultural frontiers into natural forests (e.g. Tsujino et al. 2016). As Indonesia is still facing high deforestation rates, the potential trade-offs associated to the rising agricultural demands has been extensively debated (e.g. Austin et al. 2019; Pendrill et al. 2019). Indonesia is a mega-diversity country with a large share of endemic species and displays large carbon stocks in both living biomass and soils (Murray et al. 2015). Hence, the loss of primary forest cover and peat drainage pose a threat to global climate and biodiversity goals.

In this context, as a response to the environmental impacts caused by the expansion of agriculture and forest sector, the country committed to reduce GHG emissions by 29% by 2030, compared to baseline and declared a moratorium on conversion of primary forests and peatlands in 2010. Among the primary strategies to reduce the pressure on primary forests caused by the expansion of agricultural frontiers and forest management are the improvement in management practices and production technologies. Specifically, agricultural intensification with the use of improved genetic material and higher input levels have been proposed to reduce the deforestation levels in the tropics (e.g. Koh et al. 2010; Tegegne et al. 2016). Hence, agricultural intensification can contribute to the achievement of the policy targets related to self-sufficiency in food production in Indonesia. Recent analyses show that there is still a substantial potential for improving crop yields in the country, especially rice and maize (Rosa et al. 2018; Agus et al. 2019) Kubitza et al. (2018) report that the improved land tenure in Indonesia has

incentivized owners to improve management practices, leading to agricultural intensification and reduction of pressure over primary forests.
The increase in agricultural productivity, however, is not a silver bullet to reduce the pressure over natural forests and other natural lands. Garret et al. (2018) highlights that the effectiveness of intensification alone to spare natural land depend on the interconnectedness of the focal regions with global markets and the elasticity of the demand, where increases in productivity may reduce global prices and, in turn, increase the demand. Integrative approaches, hence, may be required to resolve the trade-offs arising from land use and land use change in the future, especially in tropical regions, where the pressure on land conversion is particularly severe. At the one hand, sustainable development goals (SDGs) and national policies require an expansion of agricultural production to address undernourishment and food production concerns. Concurrently, the biodiversity and climate crisis demand an expansion of protected areas and limits on the loss primary forests and other valuable habitat types.
In this project we take a food system approach where we focus on a comprehensive and complementary ‘technical’ (economic-ecological) analysis of the critical aspects of food system transformation in Indonesia. As part of an effort to inform food system transformation in Indonesia and build on analytical and modelling work by BAPPENAS, FAO and others, this report contains the model description, baseline and stylized scenarios of one of three distinct economic models, GLOBIOM, to generate complementary analysis and insights that will help Indonesian policymakers turn their commitments into technically sound and politically feasible solutions. The stylized scenarios follow the three main policy levers outlined in the concept note ‘A novel modelling approach to support governance innovation for food system transformation in Indonesia’, namely the healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability, including climate change.

# Scenario framework

To investigate the effects of different policies and integrated approaches aimed to achieve food production to secure a reduction in undernourishment and a transition towards healthy diets with environmental integrity, we designed a series of interventions, based on current policy mechanisms and pledges in Indonesia (Table 1). As a counterfactual we implemented a baseline scenario, considering the business-as-usual (BAU) land management practices and policies currently in place in Indonesia, with no shifts in production systems and mitigation efforts.
We designed the interventions along three main policy levers outlined in the concept note ‘A novel modelling approach to support governance innovation for food system transformation in Indonesia’, namely the healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability, including climate change:

4. **Healthy diets** – In line with the RPJMN goal of improving the quality of Indonesian diets, this axis reflects a transition towards healthier diets in Indonesia through reducing food insecurity and increasing the consumption of products that are key to a healthy diet, such as fruits and vegetables, fish and animal proteins (as set out in the RPJMN).
5. **Socioeconomic sustainability of agri-food supply** – In line with the RPJMN goal of increasing food availability, this axis reflects a transition towards increased and more sustainable agricultural production that meets the needs of a growing population by increasing local agricultural production and increasing the share of local production in national consumption.
6. **Environmental sustainability, including climate change** – In line with the RPJMN goals of strengthening the environment, improving climate resilience and promoting low carbon development, this axis reflects a transition towards environmental sustainability, achieved through policies that constrain land use and reduce food loss and waste, thereby reducing GHG emissions

(in line with Indonesia's global commitments), reducing deforestation and preserving biodiversity (both key objectives of the RPJMN).

Using GLOBIOM, we design one or two interventions along each of the axes and compare them in terms of the main flagship indicators; Prevalence of Undernourishment (PoU), Share of food calories produced domestically (%), total value added from agriculture, forest cover and GHG emissions. The interventions and targets are specified in Table 1.

*Table 1. Definition of the stylized scenarios applied in GLOBIOM-Indonesia*

| **Axis** | **Definition of intervention** | **Scenario abbreviation** |
|---|---|---|
| Baseline | Business as usual, no explicit change in agricultural management assumed. No explicit moratorium policies assumed other than those calibrated in the baseline. Population and GDP growth and diets according to SSP2 | NoCC |
| Healthy diets | Undernourishment target towards 2.5% at national level in 2030 combined with a transition towards EAT-Lancet diets. | PoU |
| Socio-economic sustainability of agri-food | Intensification scenario through the increased use of water and fertilizers for main crops in Indonesia based on the process-based crop model EPIC-IIASA. | INT |
| Environmental sustainability, including climate change | Carbon tax of 50 USD/ton | GHG050 |
| | Extension of the moratorium policy on primary forests and peatland conversion. | CONS |
| Combination scenarios | Undernourishment target to reach 2.5% at national level in 2030 (POU) combined with an extension of the moratorium policy on primary forests and peatland conversion (CONS) | CONS_POU |
| | Extension of the moratorium policy on primary forests and peatland conversion (CONS) combined with an intensification scenario (INTENS) | CONS_INT |
| | Undernourishment target to reach 2.5% at national level in 2030 (POU) combined with an intensification scenario (INTENS) | INT_POU |
| | Extension of the moratorium policy on primary forests and peatland conversion (CONS) combined with an intensification scenario (INTENS) and undernourishment target to reach 2.5% at national level in 2030 (POU) | CONS_INT_POU |

# Methods

We use the Global Biosphere Management Model (GLOBIOM, Havlík et al. 2014), developed at the International Institute for Applied Systems Analysis (IIASA), to understand the effects of policy decisions on healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability in Indonesia. We updated and refined the model using best available data and tailored the model to the context of Indonesia.

## GLOBIOM

GLOBIOM is a global partial equilibrium bio-economic model integrating the agricultural and forestry sectors in a bottom-up setting based on detailed grid cell information (Havlík et al. 2014). The originality of GLOBIOM comes from representing drivers of land use change at two different geographical scales. Land related variables, such as land use change, crop cultivation, timber production and livestock numbers vary according to local conditions, including environmental and economic characteristics, such as soil, climate and production costs. Final demand, processing quantities, prices, and trade are computed at the regional level. In GLOBIOM, regional factors influence how land use is allocated at the local level. Local constraints influence the outcome of the variables defined at the regional level. This ensures full consistency across multiple scales. Land use activities - crop, livestock, forest and short-rotation tree plantations - and land use change are represented at the grid cell level in Indonesia. This results in spatial units 1501 units in the country, where land use and land use change are endogenously computed.
The food and timber demand are driven by population growth, economic (GDP) growth and food diets, which are taken as exogenous inputs and included at the regional/national level in the model. However, the final demand for each region is endogenously computed in GLOBIOM, according to the price level and the share of local versus imported goods to describe how the food/fibers demand varies according to the evolution of the relative competitiveness of each region and the corresponding transmission of prices to the producers (tariffs, transportation costs). Demand and international trade are represented at the level of the economic regions/countries based on the spatial equilibrium modelling approach (Takayama and Judge 1964).

## GLOBIOM-Indonesia

Indonesia has been the focus of specific model developments aimed at deriving a more accurate representation of the current land use, land use dynamics, GHG emissions, production, consumption, and trade. A consistent land use-land cover map has been built using the best land cover map available, agricultural statistics and other available spatially explicit information on land use. Internal transportation costs were computed based on the infrastructure network and included in the model, based on the distance to the closest market for each product and the hourly cost of transportation. The list of crops has been extended compared to the standard version of GLOBIOM in Indonesia to better represent the land use dynamics and demand for the main commodities in international markets. Finally, production systems have been refined depending on the priorities of each region, e.g. by distinguishing large scale and smallholder oil palm plantations in Indonesia. More information on these can be found hereafter.

## ***Spatial resolution***

All the spatial input data of GLOBIOM are compiled at the simulation unit level, which are polygons between 5 and 30 arcmin which is equivalent to about 86 and 302 thousand hectares respectively at the equator. The polygons encompass cells of 5 arcmin with similar soil, altitude, slope characteristics and agro-ecological zone inside a country (Skalsky et al., 2008). This results into 4963 simulation units in Indonesia.

## ***Agricultural statistics***

Statistics have been collected at two different administrative units: the province level which is the first administrative unit and the regency and city level which correspond to the second administrative unit level and is further referred to as *kabupaten*, which is the Indonesian name for regencies. There have been many new administrative units which have been created over the years in Indonesia. This is especially challenging when one works with time series as the new administrative units cannot be compared anymore with previous years. That might also lead to some issues to re-organize the data collection in the new administrative units resulting in some inconsistencies and breaks in the statistics time series over time. According to the Global Administrative Unit Layers (GAUL) dataset from the Food and Agriculture Organization (FAO), there were 318 *kabupaten* in 2000 in Indonesia but 442 *kabupaten* in 2010 which is equivalent to a 40% growth in the number of *kabupaten* in ten years. Figure 1 shows in orange the kabupatens which have been created during or after 2000. Consequently, we have decided to first re-aggregate all the statistics at the administrative level of 2000 which is the most aggregated one and corresponds to the base year of the model before comparison and harmonization with other datasets.

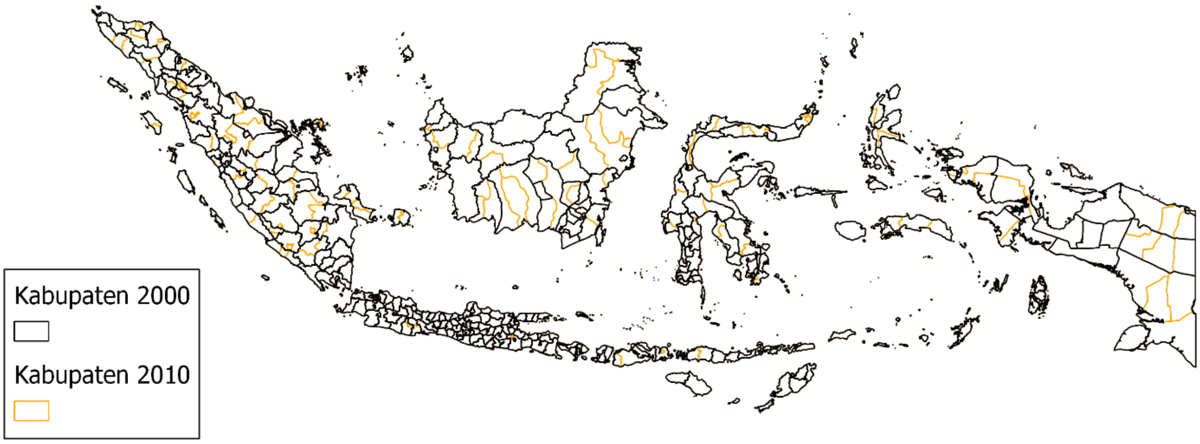



*Figure 2 Kabupaten in 2000 and Kabupaten created between 2000 and 2010*

Statistics for area and production for 19 crops over 2000-2009 and for the number of heads and production for six animal types at *kabupaten* level for the whole Indonesia were downloaded from the Ministry of Agriculture portal[2]. Several quality checks on the agricultural statistics data were performed.

## *Land cover map*

A reliable land cover map is essential to determine current repartition of different vegetation types, analyze competition for land amongst products and forecast future land use changes. In this study, the GLC2000 land cover map, which is used in the standard version of GLOBIOM, is replaced by the ICRAF land cover map for the year 2000.

The standard land information layer in GLOBIOM is split into eight land cover classes: (1) Mature forests not used for timber or agriculture; (2) Managed natural forests for timber production; (3) Short rotation tree plantations for timber production; (4) Cropland including both annual and perennial crops; (5) Grazed pasture; (6) Other natural land which refers to non-forest non productive land; (7) Wetland; and (8) Not relevant land including urban and bare land.

[2] https://aplikasi.pertanian.go.id/bdsp/index.asp

To adjust the model to the context of Indonesia, we expand and redefign the land cover classes. Following the ICRAF land cover map, we aggregate the ICRAF land cover classes into the following categories listed in Table 2.

### Table 2: Land cover deliniation used in GLOBIOM based on ICRAF 2000 land cover map

| ICRAF land cover map | New aggregation with GLOBIOM |
|---|---|
| Undisturbed forest | Primary, real pristine forests |
| Undisturbed swamp forest | |
| Undisturbed mangrove | |
| Logged over forest | Managed, secondary forests. Can be further divided into logged and not logged |
| Logged over swamp forest | |
| Logged over mangrove | |
| Cropland | Cropland (combination of annual crops and tree crops) |
| Others monoculture | |
| Rubber agroforest | |
| Others agroforest | |
| Grass | Grassland (grassland used for grazing, not natural grassland) |
| Rubber monoculture | Rubber monoculture |
| Oil palm monoculture | Plantation oil palm |
| Teak plantation | Plantation forests (short rotation plantations) |
| Pulp plantation | |
| Other forest plantation | |
| Shrub | Natural land |
| Others cleared land | |
| Settlement | Not relevant |
| Waterbody | |
| Cloud and shadow | |
| No Data | |

Compared to the standard GLOBIOM delineation, we add plantation oil palm and rubber monoculture as separate land cover classes. Large-scale oil palm plantations have been added as a separate land cover class because there are quite different constraints and costs related to the establishment of large-scale oil palm plantations compared to smallholder fields and they have been a main driver of land use change over the past two decades. Maps of large-scale oil palm plantations are available, which are generally more accurate as they focus on only one land cover rather than aiming to give a complete picture of land allocation. We therefore opted for large-scale oil palm plantations from Gunarso et al. (2013) for Sumatra and Papua for 2000 and from Gaveau et al. (2016) for Kalimantan for 2000 to delineate the large-scale oil palm land class. Both use visual detection of satellite images to delineate the plantations.

## *Agricultural products*

There are 11 crops that are included by default in GLOBIOM and are of relevance in the context of Indonesia: oil palm, rice, sugarcane, cassava, maize, potatoes, sweet potatoes, soybean, cotton, beans and groundnuts. We also have collected information on rubber, cocoa, coconut, coffee, candlenut, pepper and vanilla, in terms of demand and production costs. We do not know the spatial location of agricultural activities inside each *kabupaten*. Hence, to reconcile agricultural statistics and the land

cover map, we compute the cultivated area by crop for each simulation unit using a downscaling mechanism (You and Wood 2006). The total area for each crop for each *kabupaten* is given by the statistics, whereas the maximum cropland in each grid cell is given by the ICRAF land cover map.
Four main animal types are included: cattle, pigs, sheep and goats and poultry. In GLOBIOM-Indonesia, all main animal types are incorporated. We do not have information on the area used for grazing in Indonesia. Consequently, we compute the pasture area by combining information on the number of ruminants, grazing requirements (estimated from the RUMINANT model) and forage productivity (estimated from EPIC model).
The harvested area of oil palm can be different from the planted area because there is a time lag of several years (usually 3 years) before the palm trees produce its first fruits and because of potentially damaged trees. BPS provides information on the oil palm area which is immature and damaged. This was considered in the model by introducing a harvest coefficient that expresses the development of the oil palm productivity over time.

## *Forest products*

For the forest sector, GLOBIOM-Indonesia was expanded to account for different intensities of forest management, as well as to allow timber production of timber from forest plantations (e.g. Teak plantations). A typical rotation system in permanent production (natural) forest in Indonesia lasts 30-35 years. There is almost never a second rotation in production forests and in many cases, forest concessions have been converted to oil palm concessions or timber plantations in the past.

## *Emissions*

To calculate below and above-ground carbon biomass released from deforestation, we focus on the carbon contents in equilibrium states of the different land cover classes. Various sources have focused on measuring carbon contents in different land cover classes at different locations. We implemented the maps of Kindermann et al. (2008), the pan-tropical biomass maps from NASA (Saatchi et al. 2011) and WHRC (Baccini et al. 2012) in GLOBIOM-Indonesia. Because Kindermann et al. (2008) is not considered very suitable for the tropics, we have replaced it with the numbers from (Baccini et al. 2012) for Indonesia. Since we do not have (Baccini et al. 2012) at the global level, we keep the numbers of Kindermann et al. (2008) for the rest of the world. Below and above-ground carbon biomass is then calculated as the sum of the carbon values from these maps over the deforested locations, converted to Mt $CO_2$ per year.
Margono et al. (2014) estimated that 2.6 million ha of forest in wetland have been converted over 2000–2012 i.e. 43% of total deforestation. Drainage of peat soils leads to their decomposition, due to which it releases greenhouse gasses (GHG) for several decades. In the assessment of GHG emitted from peatland conversion, we limit our focus on oil palm in Indonesia. The peatland map from the Research and Development Agency of the Ministry of Agriculture is used to calculate the share of each land use class in peatland in each simulation unit. To estimate the emissions from new peatland drainage over time, the hectares of forest or other natural land which are converted towards large scale oil palm plantations are multiplied by the share of peatland in that location. In the case of peatland drained because of smallholder oil palm plantations expansion, the share of oil palm in cropland is multiplied by the share of peatland converted to cropland in a certain grid cell.
Based on Valin et al. (2014) we assume that peatland continues to emit greenhouse gasses over a period of 20 years against a value of 60.8 $tCO_2$ ha-1 yr-1. The areas of peatland conversion are cumulated over a period of 20 years. Based on Miettinen et al. (2012) we assume that 22% of the

conversion towards large scale oil palm plantations happened on peatlands in Sumatera and 11% in Borneo. Furthermore, we make the assumption that 50% of this area will continue to emit for 10 years (i.e. it would have been planted in 1990) and 50% for 20 years (i.e. it would have been planted in 2000).
Further emissions considered are those resulting from crop and livestock production and other land use change. Carbon biomass from crop cultivation is based on the average carbon stock in crops from EPIC and multiplied by the share of the year the crop is on the field (0.25 for seasonal crops and 1 for annual crops). For rice, the 2000 emission factor of 4.44 t$CO_2$ ha for Indonesia from FAOSTAT is considered. Carbon biomass is also considered for the main tree crop plantations such as oil palm, cocoa, coffee and rubber. The carbon stock default value for palm oil tree from IPCC (2006) is 68 tons C, or 249 tons of $CO_2$ per ha for a mature plantation (136 tons dry matter above ground biomass x 0.5 ton carbon per dry matter ton as for woody biomass; see IPCC AFOLU Guidelines Chap 5, Table 5.3). However, a typical rotation period for palm oil is 25 years and palm trees are continuously growing. Therefore, the IPCC value needs to be corrected to account for the growth curve. Khasanah et al. (2012) consider based on several field studies an average of 40 tC/ha on the life-cycle on a plantation, using growth profiles consistent with IPCC values for mature plantations. Therefore, the estimate of 40 tC/ha or 147 tons of $CO_2$ per ha appears appropriate for above biomass of palm plantations in the model. For computing below-ground biomass, we use the IPCC below to above-ground biomass ratio of 0.2 (subtropical humid forest; above biomass lower to 125 t dry matter per ha), leading to a total carbon biomass of 48 tC/ha or 176 tons of $CO_2$ per ha. For the moment, we apply the same rate to rubber and cocoa trees. The change in carbon biomass is then calculated as the carbon stock value multiplied by the area of change of the respective land use, converted to Mt $CO_2$ per year.

# Validation of the model results over the historical period

We start our result section by assessing changes in deforestation, emissions as well as production, consumption and trade for the major agricultural commodities in Indonesia under the baseline scenario and comparing them with statistics over the historical period. We continue analyzing the effects of a business as usual and different scenarios on healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability.

## Comparison to FAO statistics

We compare the four most important crops for human consumption - corn, rice, soy beans and wheat - and the four most important commodity crops – cocoa, coffee, oil palm and rubber - in Indonesia. Over the 2000-2020 period, strong increases in consumption are observed for all main staple and commodity crops. Where soy and rice show modest increases in consumption of 10-20 percent, wheat increases by about 60 percent and corn consumption almost doubles over the 2000-2010 period. GLOBIOM follows both the trend and absolute consumption increases well.
The increase in consumption - and therefore agricultural demand – is partly coming from an expansion in production and partly coming from increased imports. Production of both corn and rice steadily go up; corn production triples over the 2000-2020 period – from 8.8 mln tons to 25.8 mln tons as projected by GLOBIOM.  The rice production increase does not go as fast, from a 14 percent increase in 2020 to an almost stable situation compared to 2000. In the case of rice, Indonesia’s trade position steadily changes from a small nett exporter to a small nett importer.

A large increase in imports is reported especially for soy beans. On the other hand, exports of commodity crops have increased as well; besides the well-known case of oil palm, cocoa and rubber experienced rapid increases over the past two decades. Imports of two other important staple crops soy beans and wheat increased faster. In the case of soybeans, where imports almost double, this can be related to a large increase in meat consumption and production over the past two decades. Soybeans are an important feedstock for livestock production. In the case of wheat, the steady increase in consumption comes directly from imports, since wheat is not a crop that Indonesia produces itself. Imports therefore almost double from 3.5 to 6.7 million tons over the 2000-2020 calibration/validation period.

Where the increase in staple crop production generally does not keep up with the rise in consumption, all commodity crops show a large increase in area and production. Besides the increase in oil palm, which increases almost 5-fold over the 2000-2020 period, also natural rubber (+240%), cocoa (doubling) and to a lesser extent coffee (+130%) show large increases in production and resulting area of cultivation.

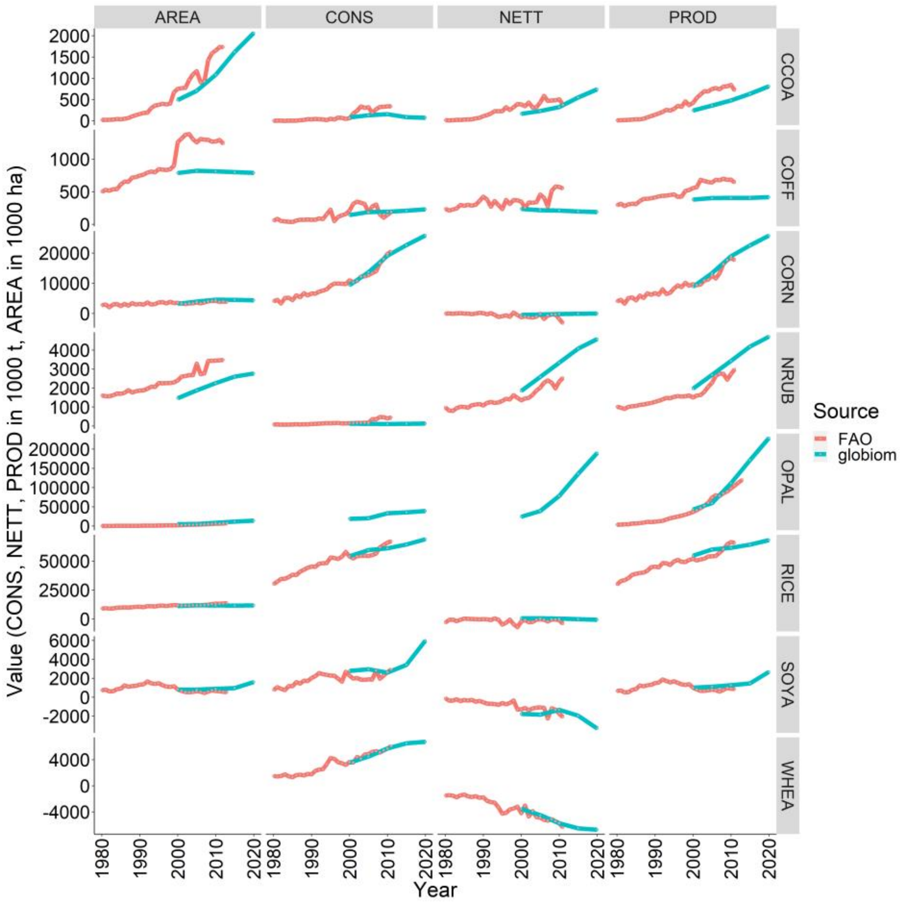



*Figure 3[3]: GLOBIOM baseline over the 2000-2020 period compared with the historical evolution of harvested area in 1000 ha (AREA), total consumption (CONS), nett trade (NETT) and production (PROD) in 1000 tons over the 1980-2020 period according to FAO statistics.*

[3] Crop abbreviations: CCOA = cocoa, COFF = coffee, CORN = corn, NRUB = natural rubber, OPAL = oil palm (fresh fruit bunch), RICE = rice, SOYA = soy beans, WHEA = wheat.

## Deforestation and land cover change

The increases in crop production and area lead to decreases in other land covers, most notably forest land. Deforested area in GLOBIOM is calculated as the sum of all land use changes from primary forests and managed forests to other land uses. Many studies have assessed historical deforestation in Indonesia, with results varying between 4.5 Mha and 14 Mha cumulated deforestation over the period 2000-2010 (Margono et al. 2014; Busch et al. 2015). The reasons for the differences are not so clear but they could be related to the different accounting of tree plantations as part of forests or not, the definition of forest which is adopted, the satellite images used and the algorithms to process them. Here we use two specific land cover products to validate the changes in the main land covers over the 2000-2020 period, the ICRAF land cover maps of 2000 and 2010, and the Restore+ remote sensing land cover map of 2018. Total primary forest area starts from exactly the same amount in 2000, 77mln ha, and is decreasing in both the land cover products and GLOBIOM. The projected decrease goes faster in the land cover products compared to GLOBIOM. GLOBIOM shows a 23.1 mln ha decrease in forest area over the 2000-2020 period, whereas remote sensing products predict a deforestation of 32.1 mln ha. Given that only the agriculture, forestry and bioenergy sectors are represented in GLOBIOM, it's likely that the remainder of the deforestation is caused by other sectors such as mining, settlement expansion and discrepancies in local productivities. Additionally, the trend in deforestation in Indonesia has shown a steady decline over the past years (Gilbert 2022). The decrease in primary forests can be partly attributed to an increase in logging activities and conversion to managed forests (12.3mln ha projected in GLOBIOM compared to 11.6mln ha in the remote sensing data over 2000-2020), an increase in oil palm plantation areas (10 mln ha in GLOBIOM compared o 9 mln ha in the remote sensing data), an increase in forest plantation areas (1.1 mln ha in GLOBIOM compared to 1.9mln ha in the remote sensing data) and a small increase in cropland (1.9 mln ha in GLOBIOM). The remote sensing products showed a decrease in cropland over time; however, this is due to the different classification of what belongs to cropland between the different products. For remote sensing products it is often difficult to separate agroforestry areas from plantations and annual crops. The ICRAF land cover map accounted large unproductive plantation areas in cropland, whereas this was separated out in the Restore+ land cover map. As rubber plantations are also accounted for separately in GLOBIOM's land cover classification the cropland extent matches well between GLOBIOM and remote sensing products for the year 2020.

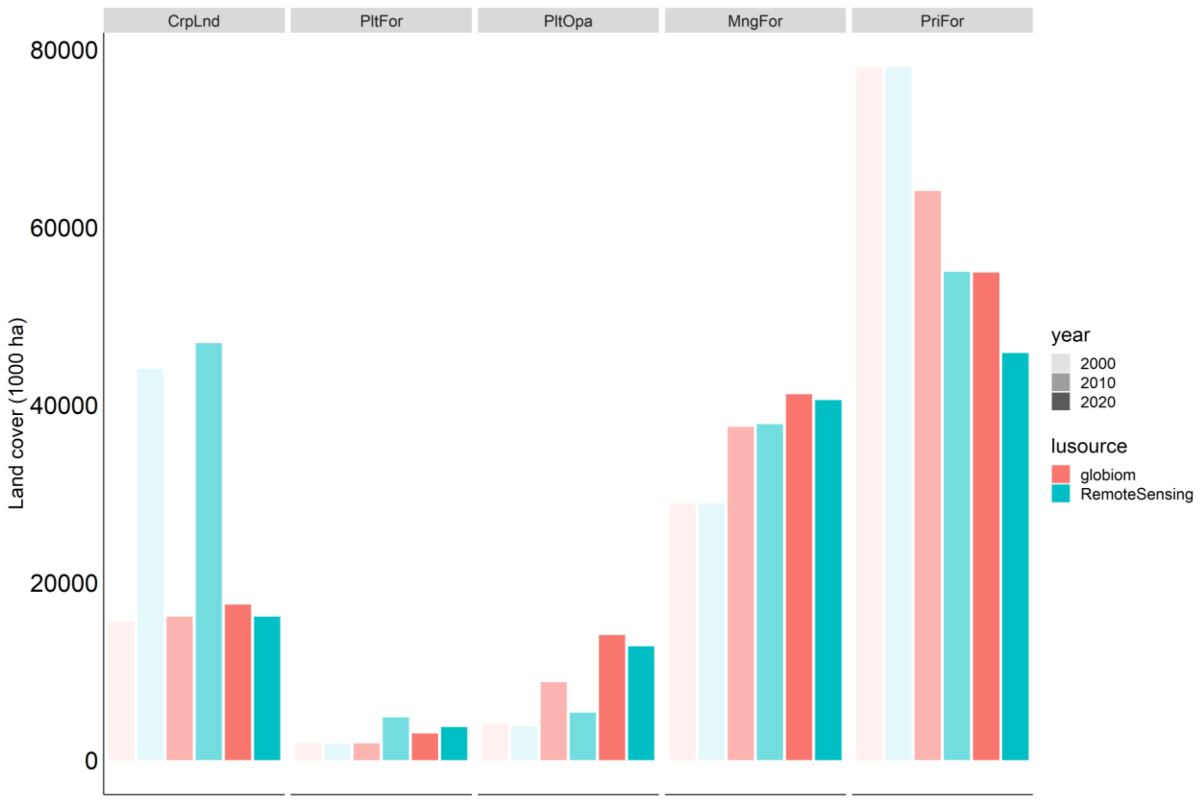
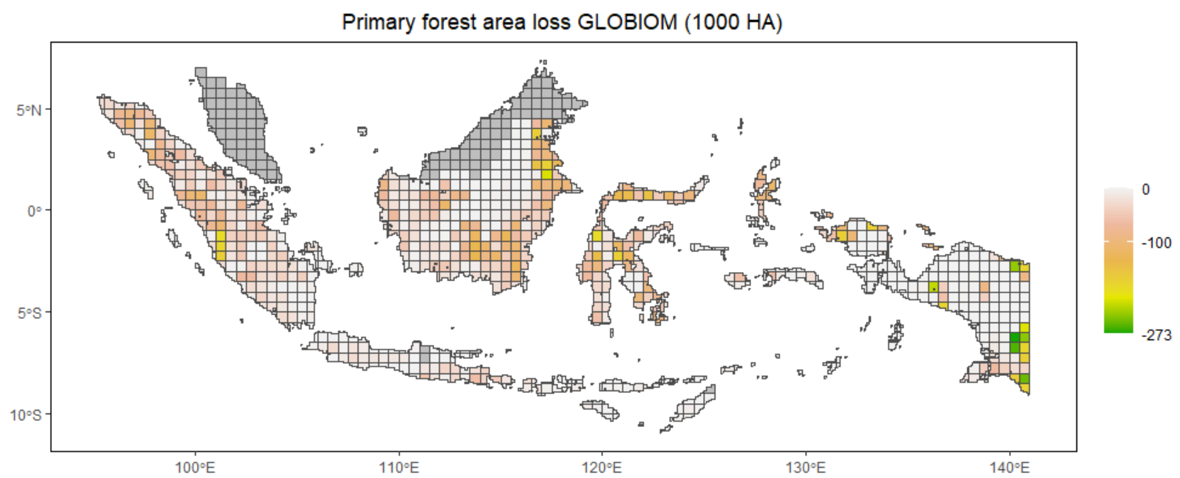



*Figure 4: Extend of cropland, plantation forests, plantation oil palm, secondary forests and primary forests compared between GLOBIOM and remote sensing products over 2000-2020 period..*

## Land cover change spatially

The updating of the land cover map, harmonization with the agricultural statistics as well as calibration of the trends over 2000-2020 leads to spatial land use changes that follow well the change in primary forest area and plantation oil palm. Primary forest area loss in both GLOBIOM and the remote sensing data has been especially high in West Sumatra, Mid and East Kalimantan and the South-East of Papua. Sumatra and the South part of Kalimantan are the areas that have experienced tha largest oil palm expansion over the past two decades.



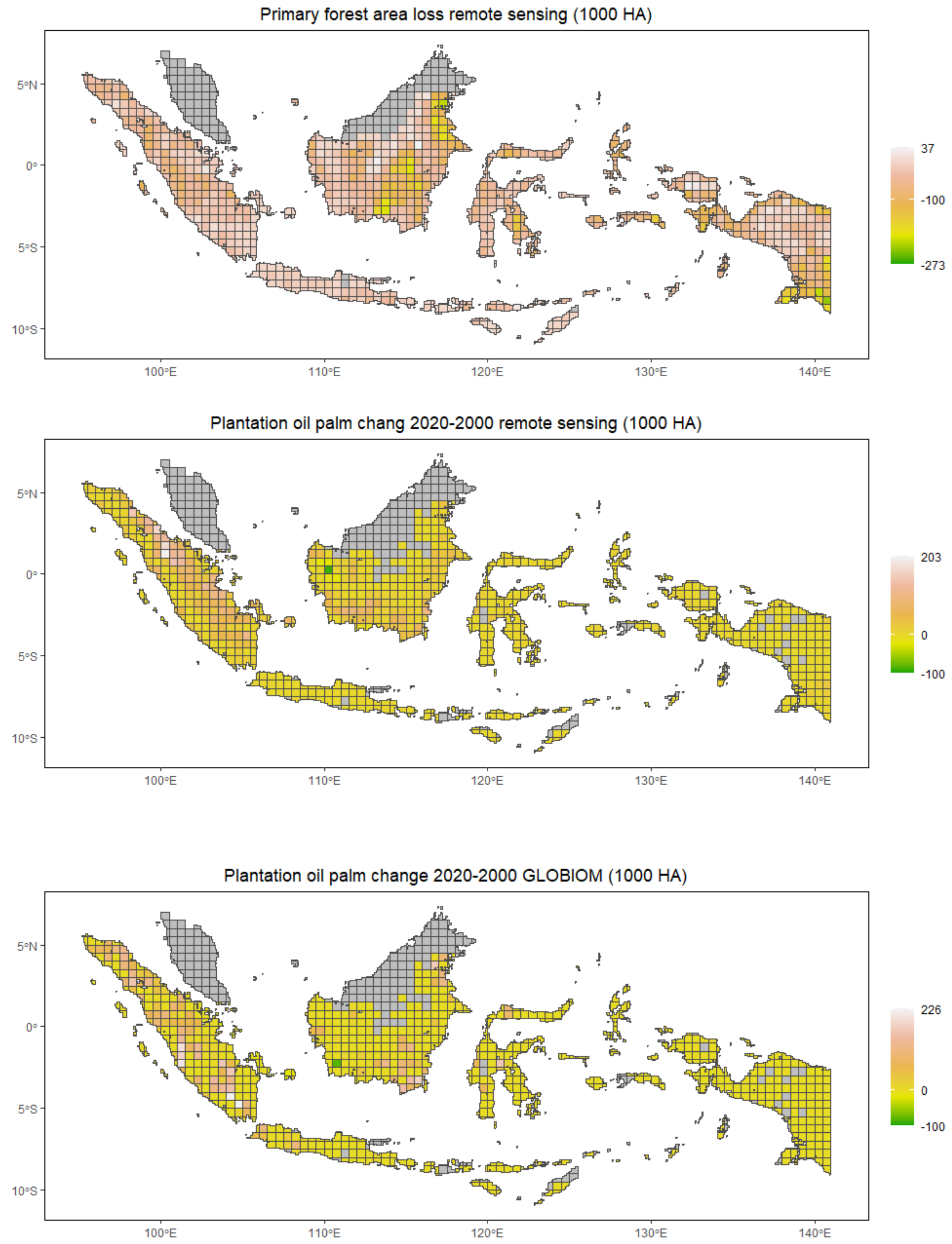



*Figure 5: Change in primary forest area and plantation oil palm in 1000 ha at the 0.5 degree grid level in Indonesia, compared between GLOBIOM-Indonesia and remote sensing products.*

## Emissions

By adding the land cover and land use changes, we can compare the total emissions in the agriculture, forestry and other land use classes (AFOLU) between GLOBIOM and the Biennial Update Report (BUR) of Indonesia (Figure 6). Especially for 2010 and 2015 total emissions compare well between GLOBIOM and the BUR. Total emissions from AFOLU are 524 in the BUR in 2010 (457 according to GLOBIOM) and 468Mt CO2eq according to the BUR in 2015 (604 according to GLOBIOM). These emissions do not include the BUR categories peat fire, other agriculture, non-other land to other land and non-settlement to settlement, however. Especially emissions from peat fires have proven to be high and very variable, ranging from 180 in 2010 to 333 in 2005 and 464 Mt CO2 eq in 2015 in the BUR. Major differences between the BUR and GLOBIOM can however be observed for two categories, non-cropland to cropland and peat decomposition. Where the BUR attributes a much higher level of emissions to peat decomposition, GLOBIOM attributes a much higher level of emissions to the land cover conversion towards cropland. Reasons for these could be different classifications of what can be counted as cropland or deforestation (e.g. related to plantations), and a different accounting of the per hectare carbon lost from land cover conversion or peat decomposition.

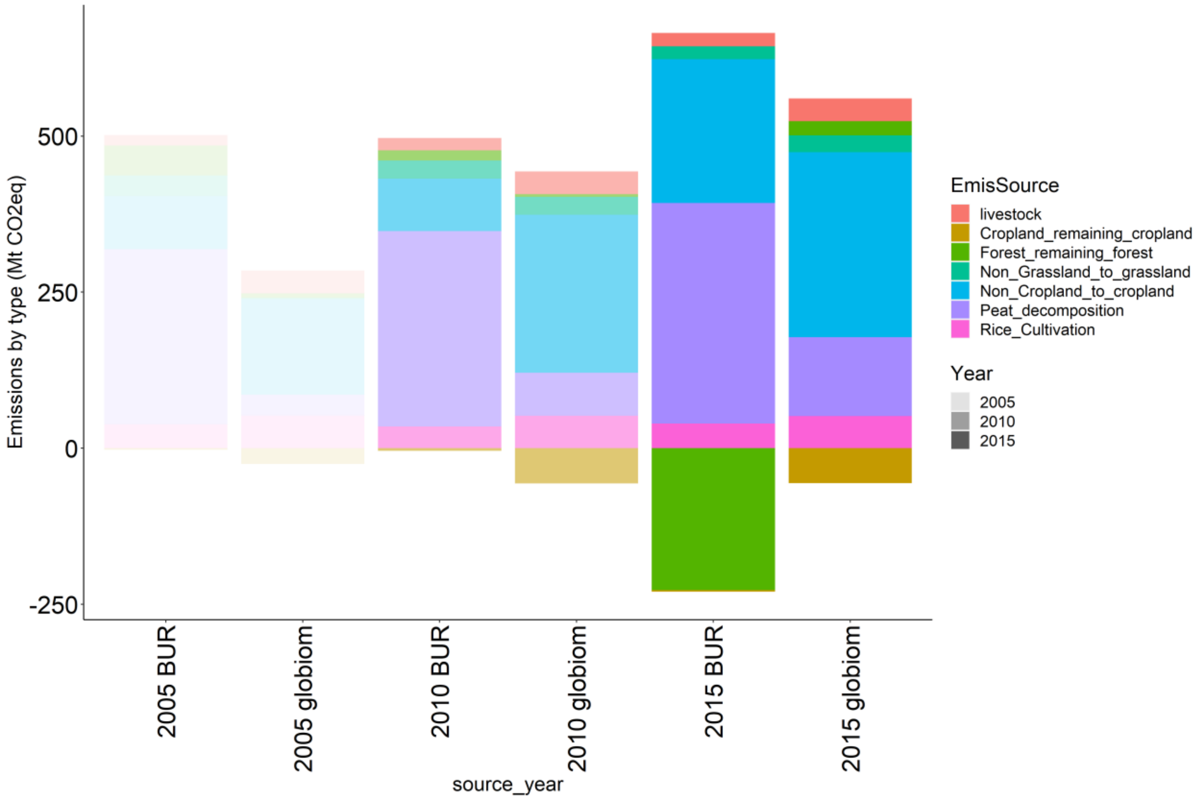



*Figure 6: Average annual AFOLU emissions in Mt CO2eq compared between GLOBIOM-Indonesia and the Biennial Update Report (BUR) for 2005, 2010 and 2015 by main source of emissions.*

# GLOBIOM-Indonesia Baseline

Figure 7 shows the baseline evolution of the main flagship indicators that were selected in this project (GHG emissions, area of forests, undernourishment prevalence, share of food calories produced domestically and value added of production). Regarding the flagship indicators for the environment, emissions show a decrease as of 2020, by 17% in 2030 compared to 2020 and 10% by 2045 compared

to 2020. This decrease in emissions is largely due to the sharp decrease in emissions from land cover change, and then mostly deforestation, and consequently the conversion of peatlands decreases as well. Total emissions amount to 484Mt CO2eq in 2030 and 527Mt CO2eq in 2045. Especially deforestation is reduced, conversion away from natural land continues to occur (see Figure 8). There are smaller increases related to agricultural management observed, however. $N_2O$ emissions from cropland management increase by 9.3% in 2030 compared to 2020 and 27.9% in 2045 compared to 2020. CH4 emissions from rice cultivation show smaller increases of 3.2% in 2030 and 9.4% in 2045 compared to 2020.
Land cover conversions do still occur; however, at a decreased rate. Primary forests decrease by 2.4% in 2030 and 5.3% in 2045 compared to the 2020 situation. Natural land decreases by 5.8% in 2030 and 17.4% in 2045. The decreases in these land covers shift to the land covers for agriculture, livestock and forestry production; plantation oil palm (+6.7% in 2030 and +18% in 2045), forest plantations (+9.5% in 2030 and +25.5% in 2045), cropland (+2.4% in 2030 and +10.9% in 2045) and a small increase in grassland for livestock production (+1.1% in 2030 and +7.6% in 2045) (see Figure 8).

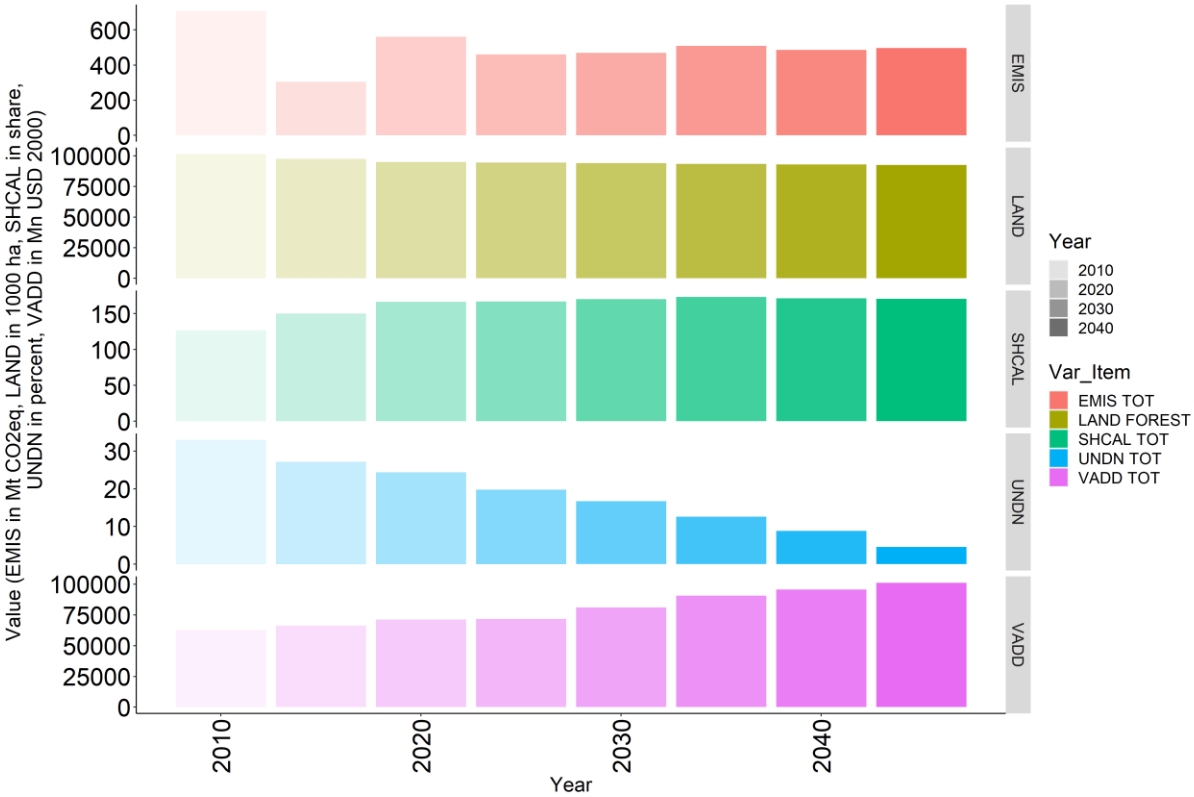



*Figure 7: Baseline results for the flagship indicators over the period 2010-2045. Emissions (EMIS) in Mt CO2eq, Forest land (LAND) in 1000 ha, food calories produced domestically (SHCAL) as share, undernourishment (UNDN) as percentage, value added in million USD 2000.*

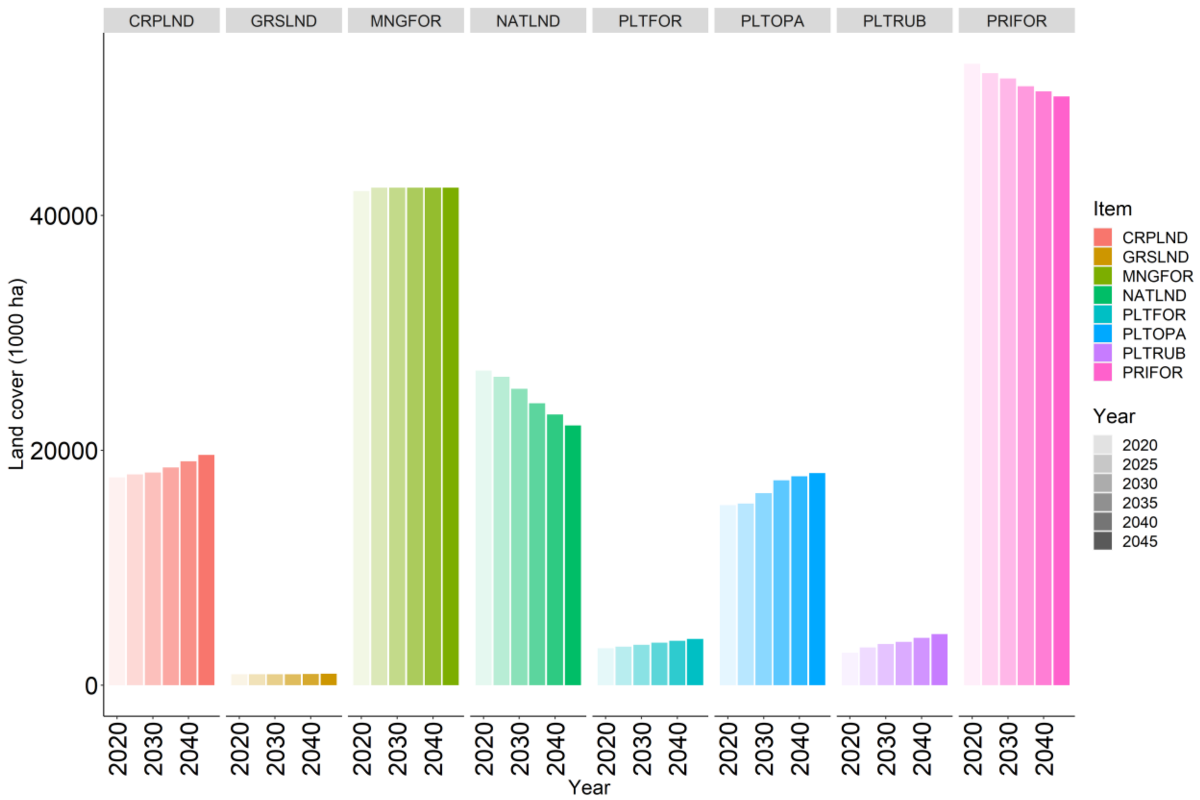



*Figure 8: Change in land cover extent in 1000 ha over the 2020-2045 period.*

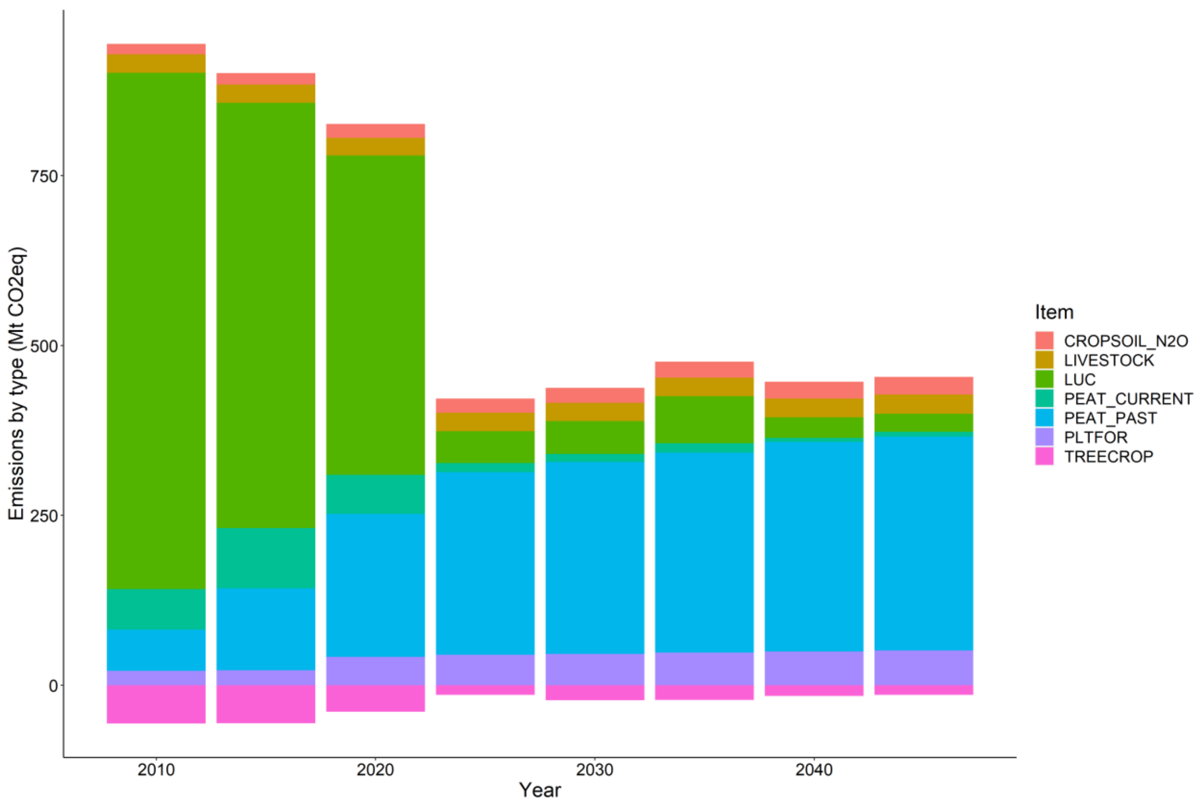



*Figure 9: Change in emissions in Mt CO2eq over the 2020-2045 period.*

The slowdown in the deforestation rate can be mostly attributed to a slowdown in the world demand for certain commodity crops, such as oil palm, of which Indonesia is a large exporter, combined with a projected increase in yields that is due to plantations reaching maturity and further intensification and expansion in other regions.

The evolution of agricultural production and the competition for natural resources is dependent not only on changing demands within Indonesia but also in the rest of the world. Oil crops have been the most rapidly expanding crop group in terms of production and consumption, driven by a relatively high-income elasticity, an increase in diets and an increasing use of biofuel crops. Amongst oil crops, especially oil palm has increased rapidly. Between 1990 and 2009 global palm oil production quadrupled whereas soybean production doubled (Villoria et al. 2013). We take the recently released OECD-FAO Agricultural Outlook 2022-2031 projections on oilseeds and oilseed products to define the trajectories for future production and consumption. The outlook projects that by 2031 the consumption of other oilseeds will be increase to 188 Mt, representing an increase by 12% from the 167Mt consumed in 2022. It is expected that Indonesia and Malaysia will continue to be the main producers and exporters of oil palm and the aggregate vegetable oils group (OECD/FAO, 2022). For the period until 2045, for almost all regions except for some in Asia and Africa, we observe a declining growth rate in total demand, which is mostly due to the projected decrease in the growth rate of population and GDP towards 2050 under SSP2. The increase in global oil palm demand, but at a declining rate, is combined with a situation in Indonesia where large areas of oil palm plantations consist of relatively young trees that have still to reach a peak in their productivity. The increases in Indonesia's production and export required to meet the growing world demand therefore do not require the same amount of land expansion from oil palm plantation as they have over the 2000-2020 period. Oil palm plantation areas increase from 15.3mln ha in 2020 to 16.3 mln ha in 2030 (7% increase compared to 2020) and subsequently to 18mln ha in 2045 (18.4% increase compared to 2020). This leads subsequently to a 23.9% and 58.5% increase in production in 2030 and 2045 compared to 2020. The export position of oil palm increases even faster, by 31.6% in 2030 and 70.5% in 2045 compared to the 2020 situation.

In general, area expansion changes more for commodity than for staple crops. Rubber and cocoa experience quite large changes in both area and production, of 17% and 45% increase in area and production for cocoa in respectively 2030 and 2045 and 27% and 57.8% in area and 37.3 and 85.1% in production in 2030 and 2045 for natural rubber. The change in area and production goes almost directly to increased exports for the two commodity crops. The staple crops corn, rice, soybeans and wheat show a more differentiated picture. Rice consumption goes up by 16% in 2030 and 33.2% in 2045 compared with the 2020 levels, but production and area don't follow suit, leading to a doubling of imports by 2030. Imports also increase for soybeans and wheat. Wheat is a crop that cannot be grown in Indonesia. Therefore, a higher consumption must directly come from larger imports; by 8.5% in 2030 and 17.6% in 2045. Soybean imports increase also due to the large increase in in livestock production and consumption. The only staple crop for which the trade position improves is corn. Consumption increases in the baseline; imports go down to almost zero and production increases mostly because of increased intensification (Figure 10).

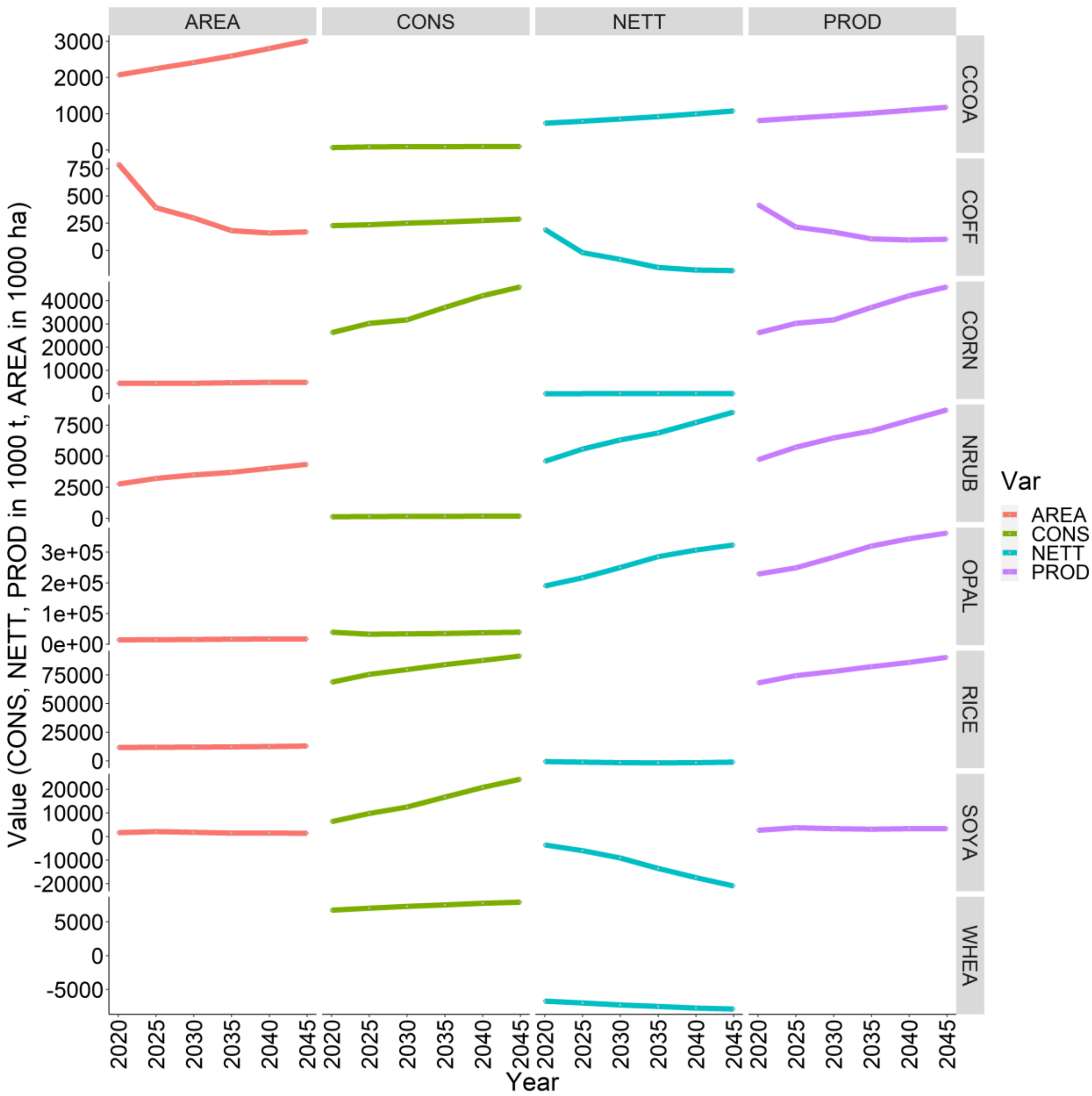



*Figure 10: GLOBIOM baseline of harvested area in 1000 ha (AREA), total consumption (CONS), nett trade (NETT) and production (PROD) in 1000 tons for the main commodity crops cocoa (CCOA), coffee (COFF), natural rubber (NRUB), and oil palm (OPAL), and the main staple crops corn (CORN), rice (RICE), soy beans (SOYA) and wheat (WHEA) over the period 2020-2045.*

The slowdown in the export boom of main agricultural commodities also results in a slowdown in terms of an increase in value added from agriculture and forestry activities. Total value-added increases by 13.8% in 2030 and 42% in 2045 compared to the 2020 situation. This is a lot smaller than the relative increase of 118% in value added that GLOBIOM-Indonesia simulated over the 2020-2000 period.

Figure 10 showed that besides an increase in some of the main commodity crops, the main staple crops increased in area and production, but often not enough to compensate for the demand increase, leading to larger import volumes.

Besides commodity crops, the agricultural area cultivated also goes to the country's own food production. When breaking down the share of food calories produced domestically by group in Figure 11 the large increase in oilseeds production becomes obvious. Between 2020 and 2030 this increases further from 438 to 464% of consumption, whereafter it stays stable until 2045. Indonesia is less selfsufficient in the other food groups, ranging between 29 and 106% in 2030 and 42 to 123% in 2045. Especially milk and ruminant meat rely heavily on imports, with about 35% of the food calories for milk produced domestically in 2030 and 48% of the calories from ruminant meat produced domestically. The share of cereals production in total consumption stays relatively constant around 92% over the period.

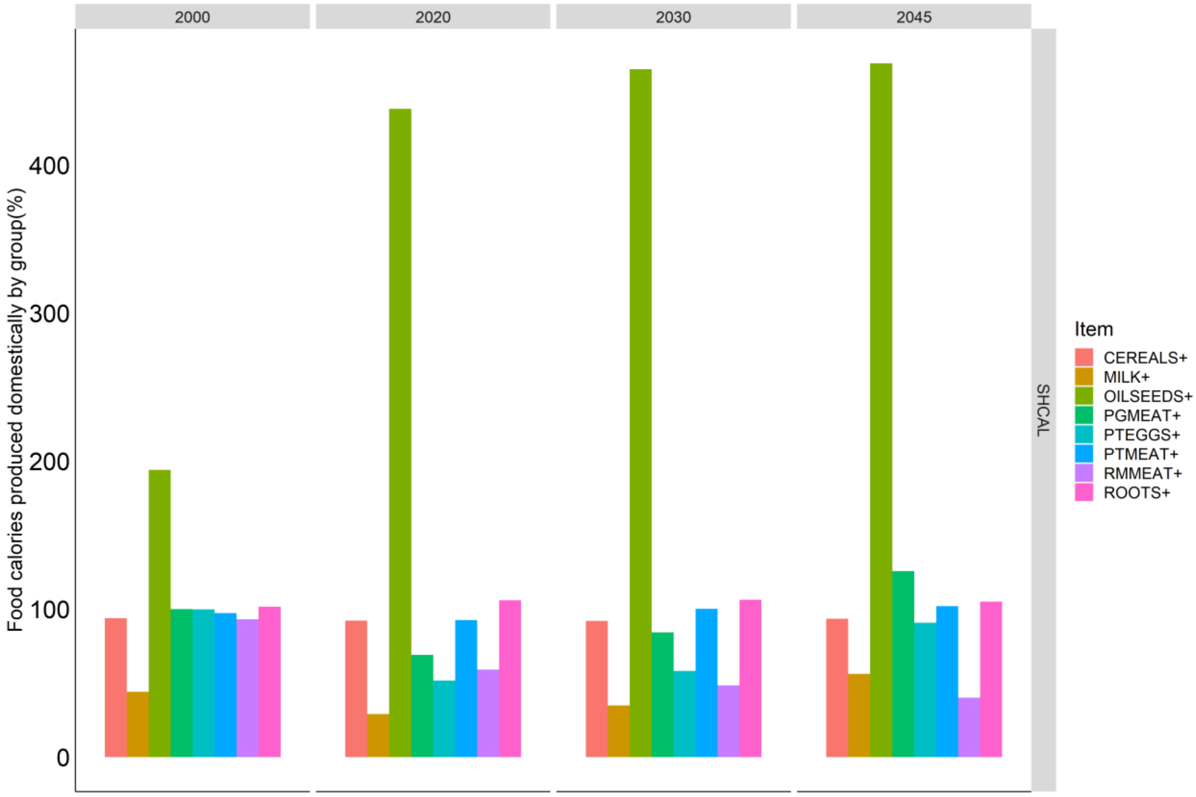



*Figure 11: Percentage of food calories produced domestically by product group.*

Due to the foreseen growth in GDP, production and value added, the percentage of undernourished decreases steadily over the time horizon, from 8.9% in 2020 to 5.7% in 2030 to 1.4% in 2045 under a no intervention scenario.

## Scenario Results

To analyze the impact of different policies on each of the axes we designed at least one specific intervention around each axis. Under the axis of healthy diets, we assume a policy that converges towards 2.5% of the population that still lives under undernourishment in 2030 combined with a transition towards EAT-Lancet diets. Under the axis of socioeconomic sustainability of agri-food supply we assume a scenario where productivity goes up through the application of high nutrient and water inputs for current cultivars. Under the environmental sustainability axis, we assume two separate type of interventions. First, a continuation of the oil palm and peat moratorium under a conservation scenario; second, a carbon price of 50 USD per ton. In addition, we assume crossings of the different scenarios

Figure 12 shows a diagram of the outcomes by main flagship indicator and scenario. The changes are reported in percentage change of the respective policy intervention compared to the baseline in 2030. Table A1 shows absolute value for each main indicator the baseline in 2020, 2030 and 2045 and the percentage changes between the main policy intervention and the baseline for 2030 and 2045.

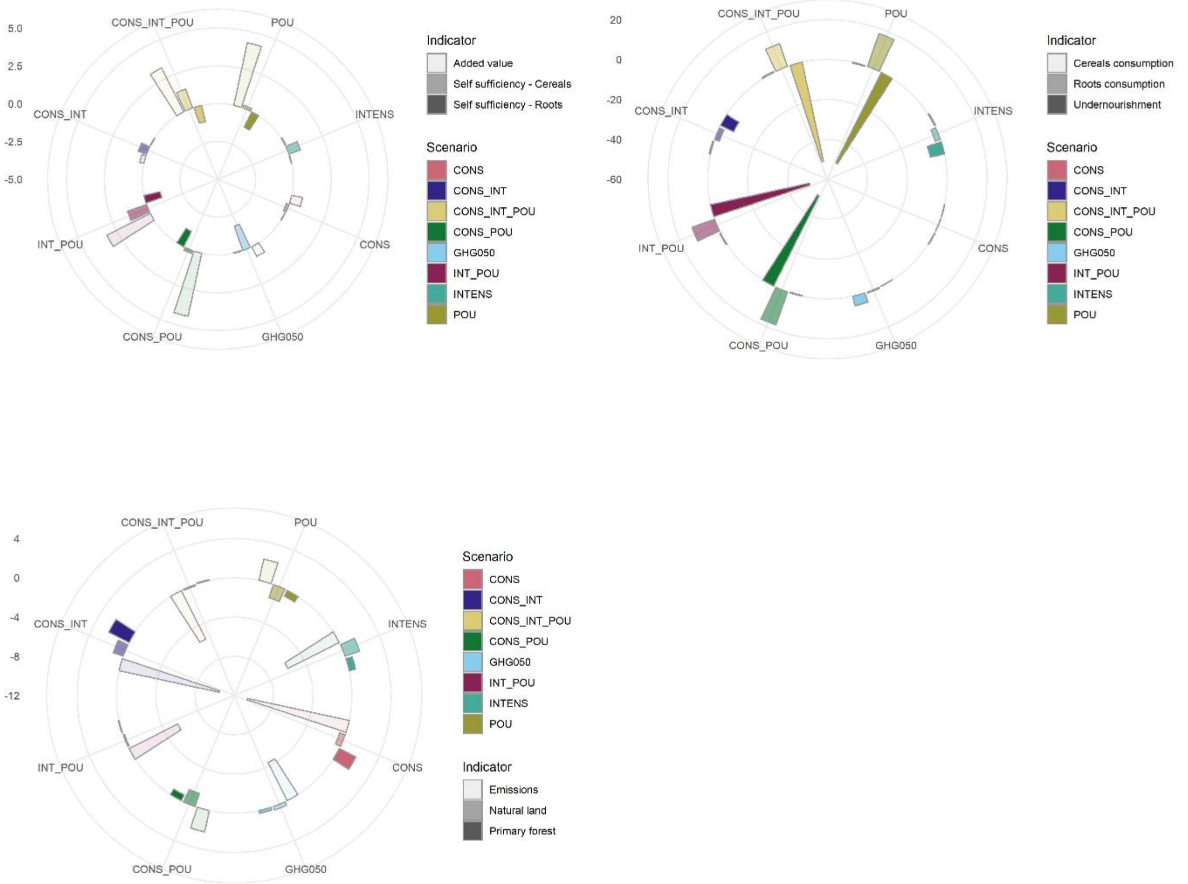



*Figure 12: spider diagram of results by flagship indicator and main policy intervention. Changes are reported in percentage change of the policy intervention in 2030 compared to the baseline in 2030.*

## Healthy diets

Under a baseline scenario the population undernourished decreases from 9% or 24.4mln inhabitants to 5.7% or 16.7mln inhabitants in 2030 and further to 1.4% or 4.5mln inhabitants by 2045. **In the short term (2030), to reach the goal of undernourishment and promoting healthier diets, it is particularly important to target and implement policy measures that directly impact consumers. In the long term (2045), environmental policies, especially in the form of a carbon tax may result in a slight increase in the percentage of undernourished individuals due to reduced agricultural production and increased food prices.** _Implementing either an intensification scenario or an undernourishment target will result in a decrease in the percentage of

undernourished individuals by 2030, with the former achieving an additional 7.3% reduction and the latter achieving a 50.8% reduction compared to the baseline. By 2045, these scenarios will have achieved similar levels of reduction, with a 20.8% reduction for intensification and a 37.2% reduction for undernourishment targets (from 5.7% of undernourished under the baseline in 2030 to 5.3% under an intensification scenario and 2.8% under an undernourishment target). By 2045 this gets closer to each other: -20.8% for an intensification scenario versus -37.2% for a POU, or 1.4% under the business as usual, 1.1% under the intensification scenario and 0.9% under the POU.
Scenarios focused solely on conservation will result in slight increases in the percentage of undernourished individuals, with a 0.3% increase under a conservation scenario and a 4.9% increase under a carbon tax scenario by 2030 (respectively 5.7 and 5.9% of undernourished). By 2045, the increase in undernourishment will be 6.7% under a conservation scenario and 18.6% under a carbon tax scenario (respectively 1.5 and 1.7% of undernourished). This is because environmental policies that limit land cover conversion or put a price on emissions from agriculture and land use activities reduce the amount of productive land available for conversion to cropland and increase production costs. Therefore, meeting the additional food demand will require changes in management on existing cropland.
**An intensification scenario may not be very effective in reducing undernourishment and promoting healthier food choices, as the increased production is partly directed towards cash crops and exports.** Further, well-targeted policies towards not only reducing undernourishment but also increasing diet patterns will lead to a different diet compared to an intensification scenario where the focus is purely on increasing production. For instance, a reduction in undernourishment coupled with the adoption of the EAT-Lancet diet can increase the consumption of root vegetables by 17.5% while reducing the intake of meat products (by -4.7% for ruminant meat to -9.4% for poultry meat). On the other hand, an intensification scenario mainly boosts cereal consumption, which is already high in Indonesia.

## Socio-economic sustainability of agri-food supply

GLOBIOM projects increased yields for the three main crops (corn, palm oil and rice) by 2030 and a slight increase in value-added from agriculture and forestry to increase by 14% between 2020 and 2030. In terms of the share of food calories produced domestically, GLOBIOM projects the share of local cereals production in total cereals consumption to stay relatively constant between 2020 and 2030, at around 63%.
Within the agricultural sector, the agricultural items that are expanding, either in terms of area and production or in terms of export position or domestic consumption are dependent on the axis around which the intervention is focused.
An emphasis on reducing undernourishment can boost the value added in agriculture, with a 3.2% increase expected under an intensification and undernourishment strategy, and a 4.2% increase under a scenario focused on reducing undernourishment compared to the baseline in 2030. As the difference in the percentage of undernourished between the baseline and the undernourished target is not so large anymore by 2045, also the difference in the value added becomes marginal. A carbon tax does however still lead to a decrease in the percentage of undernourished by 2.2%. In GLOBIOM, the value added in agriculture is dependent on two factors; the impact of the scenario on production and the impact of the scenario on prices. Under a production increase, it may be that the increase in supply leads to a decrease in prices and therefore may not directly increase the total value added of producer.
**An undernourishment scenario may lead to an increase in food prices due to the higher demand for agricultural products, a cost that has to be borne by the government in well-targeted policies in order to reach the desired level of undernourishment reduction.**

**Combining an undernourishment target with agricultural intensification can also result in cost savings for the government, as the additional production will lead to lower food prices. Different crops will benefit from either agricultural intensification or support to consumers.** Cash crops like coffee (+59.4%) and crops used to feed livestock such as soybeans (+57.4%) will gain in terms of value added under an intensification scenario. On the other hand, root crops like cassava (+25.5%) and sweet potatoes (+18.4%), which are healthy staple foods, will gain in value added under a scenario with higher demand for these types of crops (POU). Under a combined scenario with both POU and intensification, both cash crops and root crops will gain in value added. However, an undernourishment scenario will lead to a decrease in value added for livestock products.

**An increased demand for healthy foods leads to a slight reduction in self-sufficiency but not in an absolute decrease in production** (see Figure 13). In all scenarios aimed at reducing undernourishment, self-sufficiency decreases due to higher demand for specific products. When combined with an intensification scenario, the self-sufficiency rate only slightly increases (by -2.4% to -2.2% compared to the baseline by 2030). This is because intensification benefits different crops than those required under a healthy undernourishment scenario. Environmental policies, such as a conservation scenario and carbon tax, do not directly affect self-sufficiency in the short term (-0.2% compared to the baseline by 2030 in both cases). Additionally, as the difference in total production and consumption between scenarios decreases by 2045 compared to 2030, so does the difference in self-sufficiency.

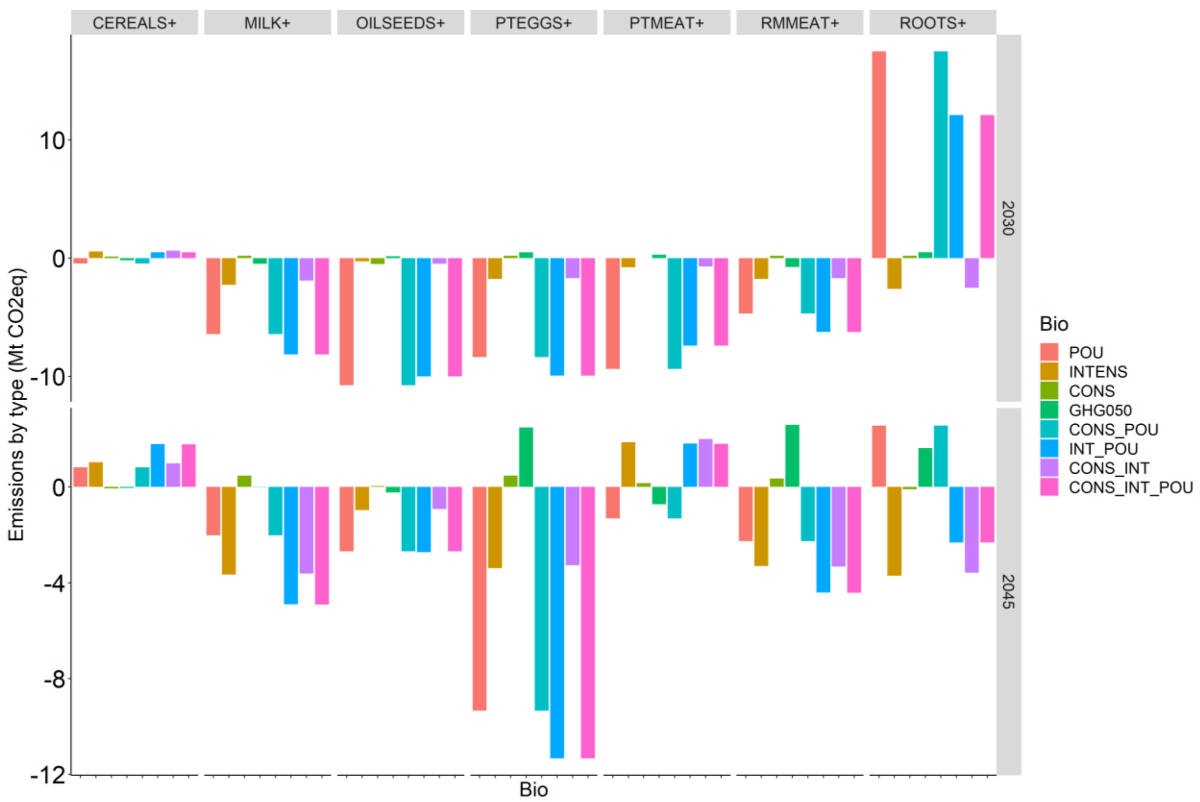



*Figure 13: Percentage change in food calories produced domestically by food group compared to the baseline by 2030.*

## Environmental sustainability

Compared to 2020 levels of **GHG emissions**, GLOBIOM projects Indonesia's overall GHG emissions to be 16.5% lower in 2030 and -11.3% lower in 2045, mostly due to a significant decrease in emissions from land cover change and from reduced deforestation. However, both MIRAGRODEP and GLOBIOM project a slight increase in GHG emissions from agriculture between 2020 and 2030. GLOBIOM projects $N_2O$ emissions from cropland management to increase by 8.9% between 2020 and 2030 and by 28.4% between 2020 and 2045. GLOBIOM also projects CH4 emissions from rice cultivation to increases by 2.2% in 2030 and 10% in 2045, compared to 2020 levels.

GLOBIOM projects a slowing in the rate of deforestation in Indonesia, mostly attributed to a slowdown in the world demand for certain commodity crops, such as oil palm, of which Indonesia is a large exporter, combined with a projected increase in yields that is due to plantations reaching maturity and further intensification and expansion in other regions. However, GLOBIOM still projects a decrease in **primary forest cover** from 2020 levels of 2.4% by 2030 and 5.3% by 2045, as land use conversion continues for oil palm plantations (+6.7% in 2030 and +17.9% in 2045), forest plantations (+9.5% in 2030 and +25.5% in 2045), cropland (+2.4% in 2030 and +10.9% in 2045) and a small increase in grassland for livestock production (1.1% in 2030 and + 7.6% in 2045).

**A pure POU scenario leads to cropland increase and an increase in emissions.** Cropland especially expands under a reduction in undernourishment scenario, due to the extra demand for certain crops (by 3% compared or +0.5mln ha to the base in 2030 and 2.5% or +0.49mln ha by 2045). An intensification scenario slightly increases cropland towards 2045 (+0.8% or 164 thousand ha compared to the baseline).

**If primary forests are subject to a moratorium, other potentially biodiverse-rich land covers, like natural land, may be converted. Combining scenarios can mitigate negative emissions effects compared to a business-as-usual scenario, but may not achieve individual goals (e.g. no reduced deforestation under CONS-INT-POU).** In both the short and long term, a conservation scenario is the most effective in "saving" primary forests (+1.9% or nearly 1 million hectares (0.97) by 2030 and +1.8% or 1.2 million ha by 2045) compared to a carbon tax (+0.3% or 147,000 hectares by 2030 or +1.4% or 665 thousand ha by 2045). However, a conservation scenario also leads to a reduction in natural land (-0.6% or 146,000 hectares), which is not covered by the moratorium. A conservation and intensification scenario leads to the largest gains in primary forests (+2.3% or 1.2 million hectares by 2030 and up to 2 million ha by 2045) and natural land (+1.1% or 276,000 hectares by 2030 or 786 thousand ha by 2045). However, under a combined conservation, intensification, and POU scenario, cropland increases (+2.7% or close to 0.5 million hectares) without altering the extent of forest or natural land compared to the baseline by 2030. By 2045 this scenario does lead to an increase of 700 thousand ha of primary forests and almost 1 million ha of natural land compared to the baseline. This finding is similar to that of an intensification and POU scenario. Since the conservation scenario does not cover all forest areas, the increased demand for cropland from the POU target may encroach on those areas not covered by the moratorium.

**It is possible to reduce emissions, particularly those caused by changes in land cover, without increasing the percentage of undernourished people, when combining policy interventions around different axes.** This has its impacts on emissions. The impact on emissions varies depending on the scenario. The most significant increase in emissions (+2.2%) occurs when combining the POU and CONS_POU scenarios, while all other scenarios lead to a decrease in greenhouse gas emissions. Therefore, intensification and environmental policies can both contribute to reducing emissions.

The conservation scenario, or a combination of conservation and intensification, results in the largest emissions reductions (-10.4% by 2030 compared to the baseline), while a carbon tax by 2045 leads to a reduction of -8.5% (compared to -4.2% under a conservation scenario). However, when these scenarios are combined with the POU target, emission reduction falls to -5.6% by 2030, and it disappears if not also combined with an intensification scenario. Land cover change contributes the most significant emissions reductions (-75% under a conservation scenario by 2030, and up to -55% by 2045 compared to the baseline). A POU scenario has a notable effect on emissions from rice cultivation (+10% by 2030).

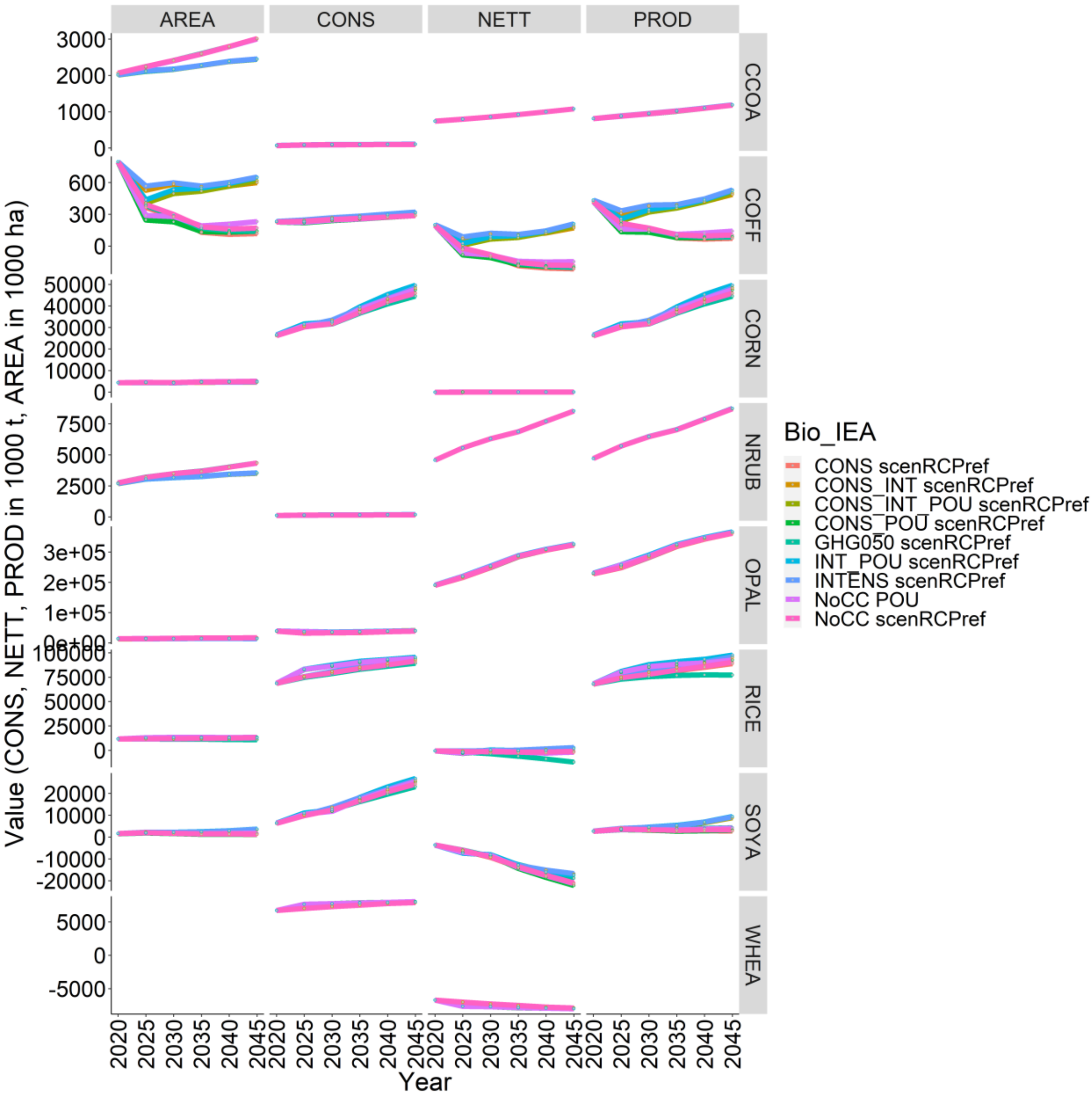



*Figure 14: Evolution in harvested area in 1000 ha (AREA), total consumption (CONS), nett trade (NETT) and production (PROD) in 1000 tons over the 2020-2045 period by scenario and main crop*

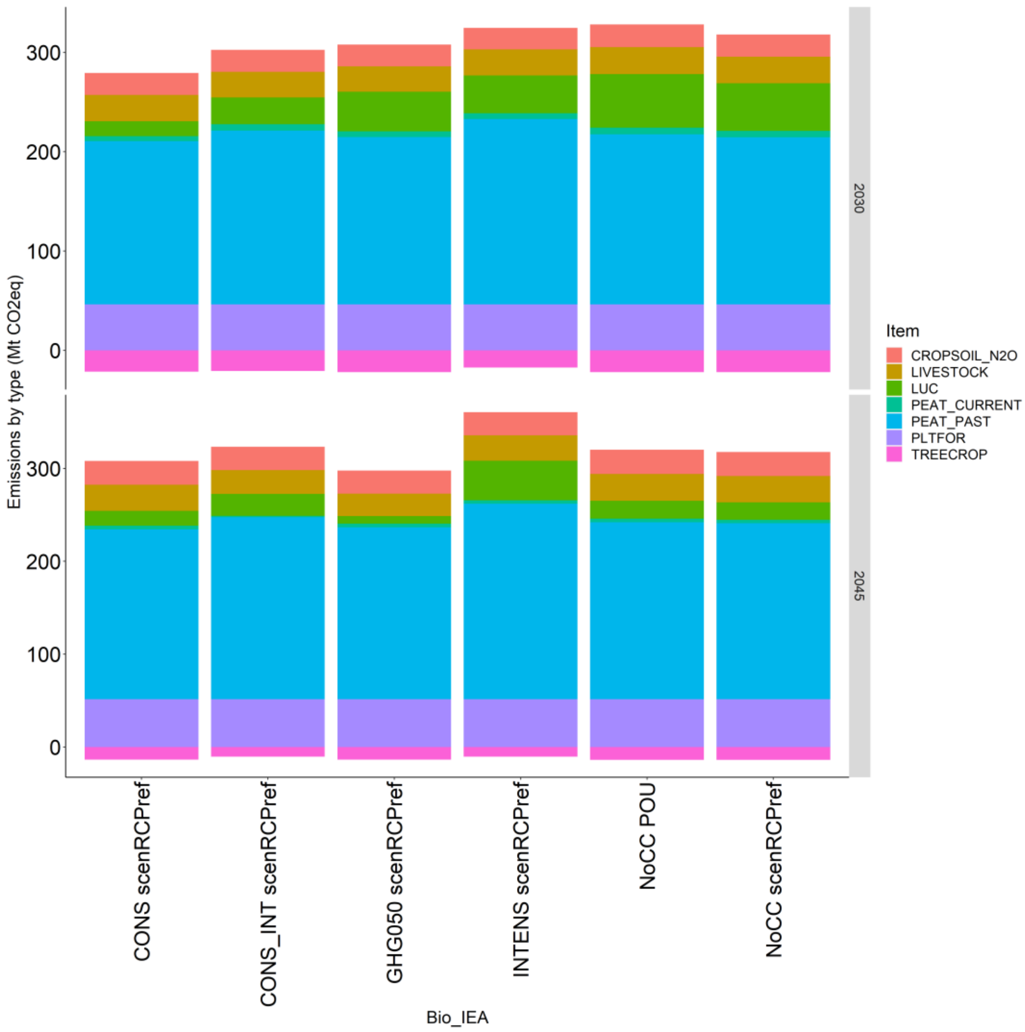



*Figure 15: Emissions by type and scenario in 2030 and 2045 in Mt CO2eq*

## Distributional aspects

The spatial scale of implementation of the scenarios around each of the axes differs per scenario. The target on undernourishment under the healthy diet scenario is implemented at the national level, meaning that geographically differentiated factors such as access to markets are not considered in the model to reach those targets. The conservation and intensification policy are however spatially explicit; preserving primary forests and peatlands is forced in the model locally. The degree of intensification that can be achieved is determined by the crop model EPIC-IIASA that takes soil, altitude and slope properties into account to determine the difference between potential and current production at a gridded level. A GHG price is partly local in its policy as the price is set at the national level but the emission reduction that can be achieved is determined at the grid level as biomass and fertilizer use are accounted for in a gridded way.

Figure 16 and Figure 17 show how these differences may play out at the gridded level. Compared to the BAU, an intensification scenario leads to the largest area of primary forest loss and a conservation policy preserves the largest area of primary forests. In total, the difference between these two scenarios is 1.8mln ha of primary forest land. The conservation policy that is forced in at the gridded level leads to small losses throughout the country under an intensification policy compared to a conservation policy. However, because of the forest extent, larger areas of forests are 'saved' in Kalimantan and Papua. A reduction in undernourishment leads to the largest increase in the area of rice cultivation compared to a BAU, whereas a carbon tax leads to the largest decrease. The scenario focused on reducing undernourishment follows a target. Therefore, large, concentrated increases in rice area cultivation can be found in Java, and smaller increases in Sumatra and Sulawesi. In these areas rice cultivation is most profitable. However, it also leads to a decrease in rice areas in Kalimantan and Papua. This might have consequences for the accessibility of inhabitants in Kalimantan and Papua to the additional food production, and therefore the distribution of the population undernourished. This points towards the need for national policies and targets to have on the ground implementation.

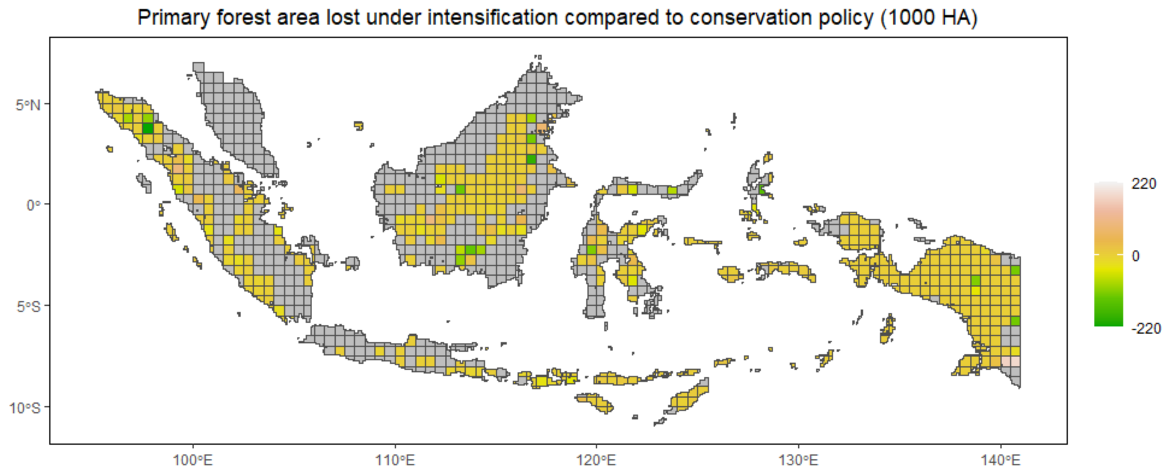



*Figure 16: Primary forest area lost under an intensification scenario compared to a conservation scenario in 1000 ha by 2045.*

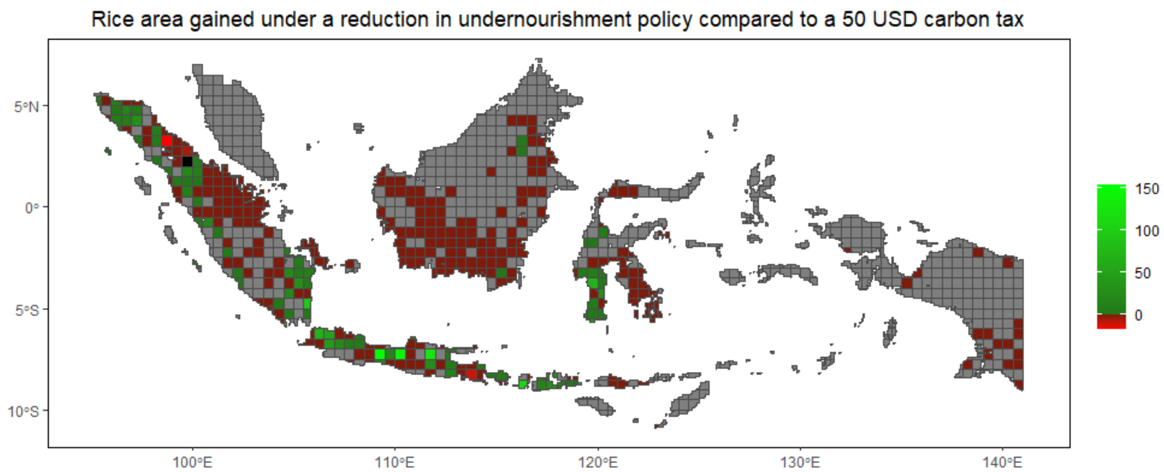



*Figure 17: Rice area gained under a reduction in undernourishment policy compared to a 50USD carbon tax in 1000 ha by 2045.*

## Conclusion

Tropical regions, including Indonesia, are vital for food and fiber production, biodiversity and carbon storage. At the same time, these regions have set important goals and targets such as a reduction of undernourishment and nutrition-related diseases such as stunting and a transition towards healthy diets. The expansion of agriculture and forestry can lead to trade-offs between economic growth, social welfare, and environmental preservation. As part of an effort to inform food system transformation in Indonesia and build on analytical and modelling work by BAPPENAS, FAO and others, this report contains the model description, baseline, and stylized scenarios of one of three distinct economic models used in the project, GLOBIOM, to generate complementary analysis and insights that will help Indonesian policymakers turn their commitments into technically sound and politically feasible solutions. This report designed interventions along three main policy levers outlined in the concept note 'A novel modelling approach to support governance innovation for food system transformation in Indonesia', namely the healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability, including climate change. The Global Biosphere Management Model (GLOBIOM, Havlík et al. 2014) was used to understand the effects of interventions on healthy diets, socio-economic sustainability of agri-food supply and environmental sustainability in Indonesia.

We updated and refined the model using best available data and tailored the model to the context of Indonesia to accurately represent the current land use, land use dynamics, GHG emissions, production, consumption, and trade. This leads the model to produce a national trajectory that follows well what is reported in FAO statistics and spatial land use changes from remote sensing products.

Without any policies, the baseline shows a decrease in emissions over the 2020-2045 period, particularly due to a decrease in agriculture-induced deforestation. The slowdown in deforestation is mainly due to a slowdown in the increase in world demand for certain commodity crops like oil palm and an increase in yields due to plantation maturity and intensification. However, land cover conversions still occur, with a decrease in primary forests and natural land going towards agriculture, livestock, and forestry production. The slowdown in the world demand of some of the main agricultural commodities of which Indonesia is a key exporter also results in a slowdown in the increase in value added from agriculture and forestry activities. Cropland still shows a steady increase, which is partly due to other commodity crops such as cocoa and rubber and partly due to crops for domestic food production. Due to the foreseen growth in GDP, production and value added, the percentage of undernourished decreases steadily over the time horizon, from 9% in 2020 to 5.7% in 2030 and further to 1.4% in 2045.

The stylized scenarios show that regarding healthy diets, a target on a reduction of undernourishment helps to reduce the percentage of undernourished from 5.7% under the baseline to 2.8% by 2030. Further, an intensification scenario enhances food availability and reduces undernourishment, while a carbon tax makes food production more costly and increases undernourishment. Regarding the socio-economic sustainability of agri-food, the value added in agriculture is dependent on the impact of the intervention on production and prices. In terms of environmental sustainability, environmental policies are the only policies that help reduce deforestation compared to the business-as-usual scenario. Regarding environmental sustainability, a scenario focusing only on a decrease in undernourishment leads to cropland increase and an increase in emissions. Cropland expansion is driven by the extra demand for certain crops (+0.5mln ha compared to the base in 2030 and +0.49mln ha compared to the base by 2045).

If primary forests are subject to a moratorium, other potentially biodiverse-rich land covers, like natural land, may be converted. Combining scenarios can mitigate negative emissions effects compared to a business-as-usual scenario, but may not achieve individual goals (e.g. no reduced deforestation under CONS-INT-POU). In both the short and long term, a conservation scenario is the most effective in "saving" primary forests (+1.9% or nearly 1 million hectares (0.97) by 2030 and +1.8% or 1.2 million ha by 2045) compared to a carbon tax (+0.3% or 147,000 hectares by 2030 or +1.4% or 665 thousand ha by 2045). However, a conservation scenario also leads to a reduction in natural land (-0.6% or 146,000 hectares), which is not covered by the moratorium. A conservation and intensification scenario leads to the largest gains in primary forests (+2.3% or 1.2 million hectares by 2030 and up to 2 million ha by 2045) and natural land (+1.1% or 276,000 hectares by 2030 or 786 thousand ha by 2045). When also combining this with a target on reducing undernourishment, this shows that is possible to reduce emissions, particularly those caused by changes in land cover, without increasing the percentage of undernourished people, when combining policy interventions around different axes.

By combining different scenarios, it may be possible to mitigate the negative effects of emissions, but it is important to consider the potential for encroachment and leakage to achieve the desired outcomes.

The analysis of policy interventions and its outcomes primarily focuses on the national level. However, implementing these interventions across Indonesia, being an archipelago, could lead to increased transaction costs, such as higher food distribution expenses. Currently, most of the food production occurs in Java, while the key biodiversity and carbon hotspots are on islands like Kalimantan. Initial findings from GLOBIOM suggest that targeting these hotspots can yield quick wins in terms of food production and environmental conservation. Nonetheless, regions outside of Java have the highest rates of undernourishment, indicating the need for further research to explore regional variations in meeting policy objectives.

Table A1: Absolute value for each main indicator the baseline in 2020, 2030 and 2045 and the percentage changes between the main policy intervention and the baseline for 2030 and 2045.

| **Absolute values** | | | | **Scenario results 2030** | | | | | | | | **Scenario results 2045** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline value 2020 | Baseline value 2030 | Baseline value 2045 | CONS | INTENS | POU | GHG050 | CONS_INT_POU | INT_POU | CONS_INT | CONS_POU | CONS | INTENS | POU | GHG050 | CONS_INT_POU | INT_POU | CONS_INT | CONS_POU |
| **Healthy diets** | | | | | | | | | | | | | | | | | | | |
| Desirable dietary pattern - kcal cap/day | 2518 | 2637 | 3045 | 2637 | 2658 | 2963 | 2624 | 2963 | 2963 | 2658 | 2963 | 3033 | 3083 | 3142 | 3012 | 3142 | 3142 | 3083 | 3142 |
| Desirable dietary pattern - g prot/day | 61.0 | 68.2 | 83.0 | 68.2 | 68.8 | 72.6 | 67.8 | 73.3 | 73.3 | 68.8 | 72.6 | 82.7 | 84.5 | 84.6 | 81.8 | 85.4 | 85.4 | 84.5 | 84.6 |
| Desirable dietary pattern - g fat/day | 40.6 | 46.5 | 56.4 | 46.4 | 46.8 | 49.0 | 46.4 | 49.3 | 49.3 | 46.8 | 49.0 | 82.7 | 84.5 | 84.6 | 81.8 | 85.4 | 85.4 | 84.5 | 84.6 |
| Prevalence of undernourishment (%) | 0.1 | 5.7 | 1.4 | 5.7 | 5.3 | 2.8 | 5.9 | 2.8 | 2.8 | 5.3 | 2.8 | 1.5 | 1.1 | 0.9 | 1.7 | 0.9 | 0.9 | 1.1 | 0.9 |
| **Socio-economic sustainability of agri-food supply** | | | | | | | | | | | | | | | | | | | |
| Value added in (Mn USD 2000) agriculture | 71259 | 81121 | 101179 | 81724 | 81164 | 84563 | 81695 | 83754 | 83724 | 81344 | 84586 | 101498 | 102018 | 100994 | 98951 | 100130 | 100078 | 101371 | 101008 |
| Self-sufficiency - CEREALS+ (%) | 0.9 | 92.2 | 93.4 | 92.1 | 93.0 | 92.4 | 90.6 | 93.5 | 93.5 | 92.7 | 92.4 | 92.9 | 96.0 | 92.7 | 85.9 | 95.6 | 95.6 | 95.8 | 92.8 |
| Self-sufficiency - ROOTS+ (%) | 1.1 | 106.5 | 105.3 | 106.5 | 106.5 | 105.3 | 106.5 | 105.4 | 105.4 | 106.5 | 105.3 | 105.2 | 104.7 | 105.2 | 105.1 | 105.0 | 105.0 | 104.7 | 105.2 |
| Self-sufficiency - OILSEEDS+ (%) | 4.4 | 464.3 | 467.6 | 464.9 | 462.7 | 494.8 | 466.4 | 488.8 | 488.8 | 460.9 | 494.8 | 468.0 | 469.0 | 470.4 | 481.7 | 473.2 | 473.4 | 468.0 | 470.4 |
| Self-sufficiency - RMMEAT+ (%) | 0.6 | 48.6 | 40.3 | 48.4 | 48.8 | 48.0 | 45.6 | 48.0 | 48.0 | 48.5 | 48.0 | 39.8 | 40.2 | 40.5 | 33.5 | 40.4 | 40.4 | 39.7 | 40.5 |
| Self-sufficiency - PTMEAT+ (%) | 0.9 | 100.1 | 102.0 | 100.1 | 102.9 | 96.3 | 99.9 | 99.6 | 99.6 | 102.9 | 96.3 | 101.8 | 105.2 | 105.2 | 100.5 | 106.6 | 106.6 | 104.7 | 105.2 |
| Self-sufficiency - PTEGGS+ (%) | 0.5 | 58.2 | 90.7 | 58.2 | 58.2 | 44.7 | 58.2 | 44.7 | 44.7 | 58.2 | 44.7 | 90.7 | 90.7 | 67.5 | 90.7 | 67.5 | 67.5 | 90.7 | 67.5 |
| Self-sufficiency - MILK+ (%) | 0.3 | 35.1 | 56.4 | 35.1 | 34.8 | 28.9 | 34.4 | 28.8 | 28.8 | 35.0 | 28.9 | 55.6 | 52.4 | 46.8 | 41.2 | 44.3 | 44.3 | 52.1 | 46.8 |
| **Environmental sustainability** | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Forest cover (mln ha) | 94.9 | 93.4 | 92.5 | 94.4 | 94.4 | 93.7 | 94.2 | 94.1 | 94.1 | 94.7 | 93.7 | 93.2 | 93.4 | 92.2 | 93.2 | 93.2 | 93.2 | 94.0 | 92.2 |
| Primary forest cover (mln ha) | 52.9 | 51.0 | 50.1 | 52.6 | 52.0 | 51.3 | 51.8 | 51.7 | 51.7 | 52.9 | 51.3 | 51.3 | 51.0 | 49.8 | 50.8 | 50.8 | 50.8 | 52.1 | 49.8 |
| Natural land (mln ha) | 26.8 | 25.2 | 22.1 | 25.1 | 25.6 | 24.9 | 25.3 | 25.2 | 25.2 | 25.5 | 24.9 | 21.8 | 23.1 | 21.9 | 22.8 | 23.1 | 23.1 | 22.9 | 21.9 |
| Cropland expansion (mln ha) | 17.7 | 18.1 | 19.6 | 18.0 | 18.1 | 18.7 | 17.9 | 18.6 | 18.6 | 18.1 | 18.7 | 19.4 | 19.8 | 20.1 | 18.3 | 20.0 | 20.0 | 19.6 | 20.1 |
| GHG emissions (Mt CO2eq/yr) | 561.3 | 470.6 | 498.0 | 420.7 | 443.0 | 481.1 | 450.3 | 444.5 | 444.5 | 421.5 | 481.1 | 477.0 | 487.2 | 498.5 | 455.4 | 482.4 | 482.4 | 462.0 | 498.5 |

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