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The Food and Land Use Coalition

2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems

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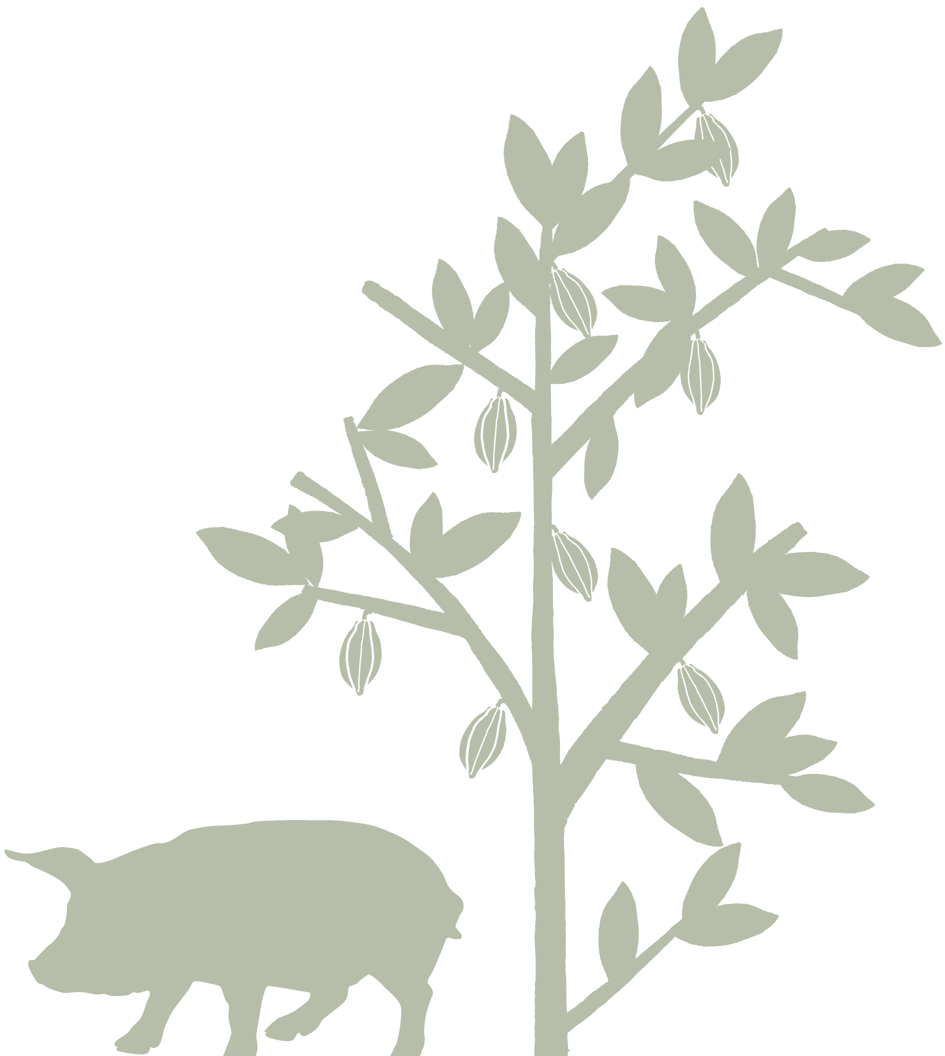
2020 Report of the FABLE Consortium

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



Malaysia

Wai Sern Low[1*], Andrew Chiah Howe Fan[1], Jeremy Jiang Shen Lim[1], Danesh Prakash Chacko[1], Jit Ern Chen[1], Chun Sheng Goh[1]

[1]Jeffrey Sachs Center on Sustainable Development, Sunway University, Kuala Lumpur, Malaysia.
*Corresponding author: waisernl@sunway.edu.my

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 Malaysia. 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 based on publicly available government reports and academic literature in consultation with national stakeholders and experts and modeled them with the FABLE Calculator (Mosnier, Penescu, Thomson, and Perez-Guzman, 2019).

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 Malaysia's Nationally Determined Contribution (NDC), and Forest Reference Emission Level (FREL) treat the FABLE domains. According to the NDC, Malaysia has committed to reducing its **GHG emissions intensity of GDP** by 45% by 2030 compared to 2005. This includes emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include the Central Forest Spine (CFS) initiative, the Heart of Borneo (HoB) initiative, and expanding the implementation of good agricultural practices, intensifying research and development for improving agricultural production under the Eleventh Malaysia Plan. Under its current commitments to the UNFCCC, Malaysia does not mention biodiversity conservation.

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

	Total GHG Mitigation					Mitigation Measures Related to AFOLU (Y/N)	Mention of Biodiversity (Y/N)	Inclusion of Actionable Maps for Land-Use Planning[1] (Y/N)	Links to Other FABLE Targets
	Baseline		Mitigation target		Sectors included				
	Year	GHG emissions (Mt CO_2e/yr)	Year	Target					
NDC (2016)	2005	288.7	2030	Reducing its GHG emissions intensity of GDP by 45% by 2030	Energy, Industrial Processes, Waste, Agriculture, Land Use, Land Use Change and Forestry (LULUCF)	Y	N	N	Forests, water, and food security
FREL (2019)	2005 - 2015	-205	2016 - 2025	Not Available	Deforestation, Sustainable Management Forest, and Conservation activities	N	N	N	Forests

Note. The NDC "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)
Sources. Malaysia (2016) for NDC and Malaysia (2019) for FREL

1 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 2016, as listed on the CBD website (CBD, 2020) which are related to at least one of the FABLE Targets. In comparison with FABLE Targets, the NBSAP targets identify specific areas of concern but tend not to set concrete targets.

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

NBSAP Target	FABLE Target
(4) **By 2025, our production forests, agriculture production and fisheries are managed and harvested sustainably.**	**DEFORESTATION:** Zero net deforestation from 2030 onwards
(6) **By 2025, at least 20% of terrestrial areas and inland waters, and 10% of coastal and marine areas, are conserved through a representative system of protected areas and other effective area-based conservation measures.**	**BIODIVERSITY:** At least 30% of global terrestrial area protected by 2030
(4) **By 2025, our production forests, agriculture production and fisheries are managed and harvested sustainably.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(7) **By 2025, vulnerable ecosystems and habitats, particularly limestone hills, wetlands, coral reefs and seagrass beds, are adequately protected and restored.**	
(8) **By 2025, important terrestrial and marine ecological corridors have been identified, restored and protected.**	

Brief Description of National Pathways

Among possible futures, we present two alternative pathways for reaching sustainable objectives, in line with the FABLE Targets, for food and land-use systems in Malaysia.

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by medium population growth (from 32.7 million in 2020 to 40.7 million in 2050), limited constraints on agricultural expansion, no afforestation target, medium productivity increases in the agricultural sector, and slow shifts in diets consistent with SSP2 (see Annex 1). This corresponds to a future based on current policy and historical trends that would also see considerable progress with regards to shifting away from land exploitation to manufacturing and service sectors for economic growth. Moreover, as with all FABLE country teams, we embed this Current Trends Pathway in a global GHG concentration trajectory that would lead to a radiative forcing level of 6 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. Our model includes the corresponding climate change impacts on crop yields by 2050 for rice and corn (see Annex 1).

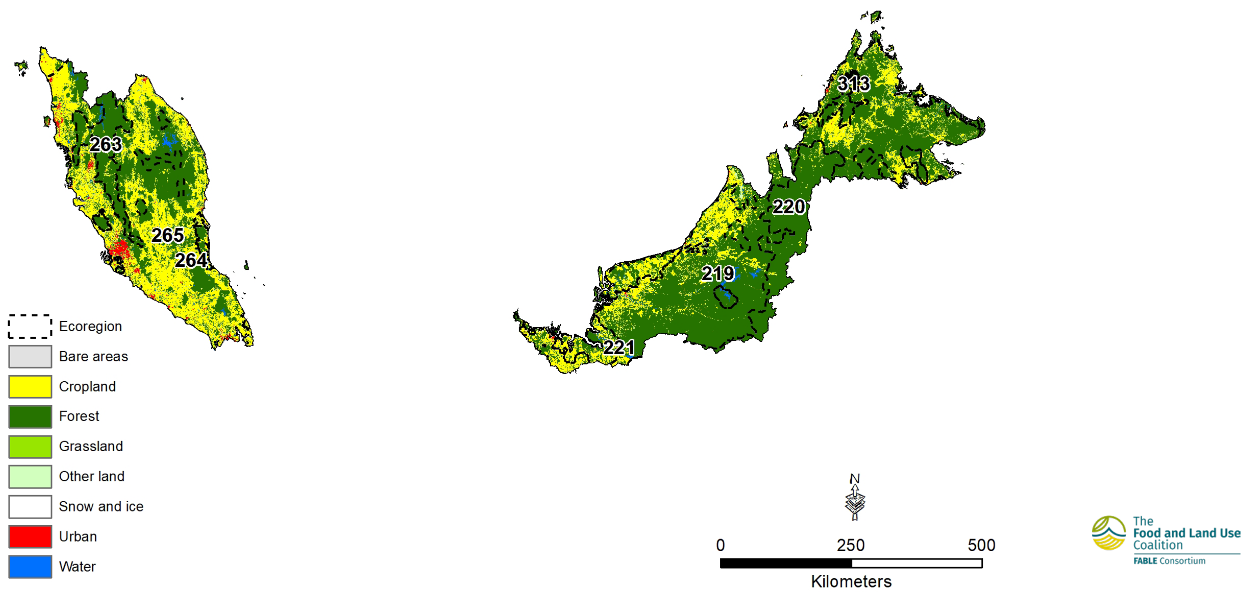
Our Sustainable Pathway represents a future in which significant efforts are made to adopt sustainable policies and practices and corresponds to a high boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would have higher agricultural productivity and lower deforestation (see Annex 1). This corresponds to a future based on the successful implementation of various national technological and innovation policies that would also see considerable progress with regards to achievement in technological breakthrough, leading to lower dependence on primary agricultural expansion. With the other FABLE country teams, we embed this Sustainable Pathway in 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 2012, Malaysia was covered by 66% forest, 21% cropland, 1% urban, and 12% other natural land as determined from the FABLE Calculator. Agricultural land is roughly evenly distributed in Peninsula Malaysia and more concentrated in the coastal regions of Sabah and Sarawak state. The largest contiguous forested zones are found in Sabah and Sarawak as well as the regions adjacent to the Taman Negara National Park and the Titiwangsa Mountain Range that runs on a North to South axis along the center of Peninsular Malaysia (Map 1). The primary threats to biodiversity in Malaysia have been the expansion of oil palm estates into forested zones (2.1.3 International Union for Conservation of Nature (IUCN) threat classification) and logging activities (5.3.2 IUCN threat classification).

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



Note. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 2.
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)

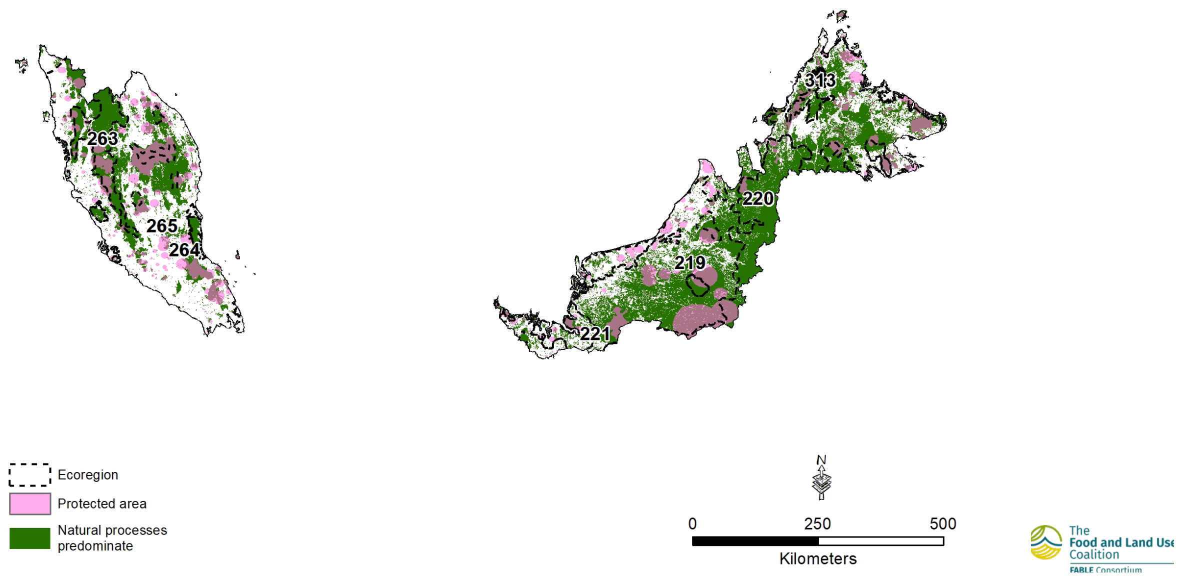
We estimate that land where natural processes predominate[2] accounted for 62% of Malaysia's terrestrial land area in 2010 (Map 2). The Southwest Borneo freshwater swamp forests in Sarawak holds the greatest share of land where natural processes predominate, followed by Peninsular Malaysian montane rain forests and Kinabalu montane alpine meadows in Sabah (Table 3). Across the country, while about 7 Mha of land are under formal protection, falling short of the 30% zero-draft CBD post-2020 target, only 25% of land where natural processes predominate is formally protected. The Borneo lowland rain forests and Borneo montane rain forests in Sabah and

2 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".

Sarawak are still at risk of logging and conversion to cropland. There have been recent positive tendencies though (Borneo Post Online, 2019): In Sarawak, the Chief Minister has committed to stop issuing new permits for new oil palm plantations. In Sabah, a jurisdictional approach has been adopted to achieve a state-wide RSPO certification by 2025, leveraging on existing laws and regulations (van Houten & de Koning, 2018). The commitment was brought to the State Cabinet in 2015 jointly by The Sabah Forestry Department, the Natural Resource Office, and LEAP (Land Empowerment, Animals, People), a civil society organization, and the RSPO secretariat.

Approximately 68.2% of Malaysia's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively "biodiversity-friendly" croplands, leaving some space for natural vegetation, are most widespread in Peninsular Malaysian rain forests, followed by Borneo lowland rain forests and Borneo peat swamp forests. The reason for regional differences in extent of "biodiversity-friendly" croplands is not known, but can potentially be explained by the requirement for suitable soil conditions for oil palm cultivation, which requires acidic, well drained alluvial soils where there are no extensive slopes exceeding 15% grade. In other words, oil palm grows less optimally on hilly terrain, which is where most of this natural vegetation is left to grow.

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



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.
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)

Table 3 | Overview of biodiversity indicators for the current state at the ecoregion level[3]

	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 >10% Natural Vegetation within 1km² (%)
219	Borneo lowland rain forests	13,215	17.7	58.7	23.8	76.2	1,527	78.4
220	Borneo montane rain forests	3,823	16.4	87.6	17.9	82.1	90	82.4
221	Borneo peat swamp forests	1,901	19.0	26.2	20	80	467	72.7
263	Peninsular Malaysian montane rain forests	1,651	31.5	94.0	32.8	67.2	36	82
264	Peninsular Malaysian peat swamp forests	363	4.4	55.2	3.3	96.7	106	69.8
265	Peninsular Malaysian rain forests	10,921	17.1	33.3	30.6	69.4	3,544	64.2
268	South China-Vietnam subtropical evergreen forests	0	100.0	0.0			0	
273	Southwest Borneo freshwater swamp forests	1	1.0	100.0	1	99	0	100.0
281	Sundaland heath forests	57	24.8	31.3	15.6	84.4	16	71.8
284	Tenasserim-South Thailand semi-evergreen rain forests	240	9.2	21.3	23.3	76.7	140	20.8
313	Kinabalu montane alpine meadows	60	78.5	90.4	86.6	13.4	5	54.3
319	Indochina mangroves	0	0.0	0.0			0	
321	Myanmar Coast mangroves	42	0.0	82.9	0	0	3	93
322	Sunda Shelf mangroves	726	32.3	55.4	39.7	60.3	89	79.8

Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); cropland, natural and semi-natural vegetation – ESA CCI land cover 2015 (ESA, 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)

3 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.

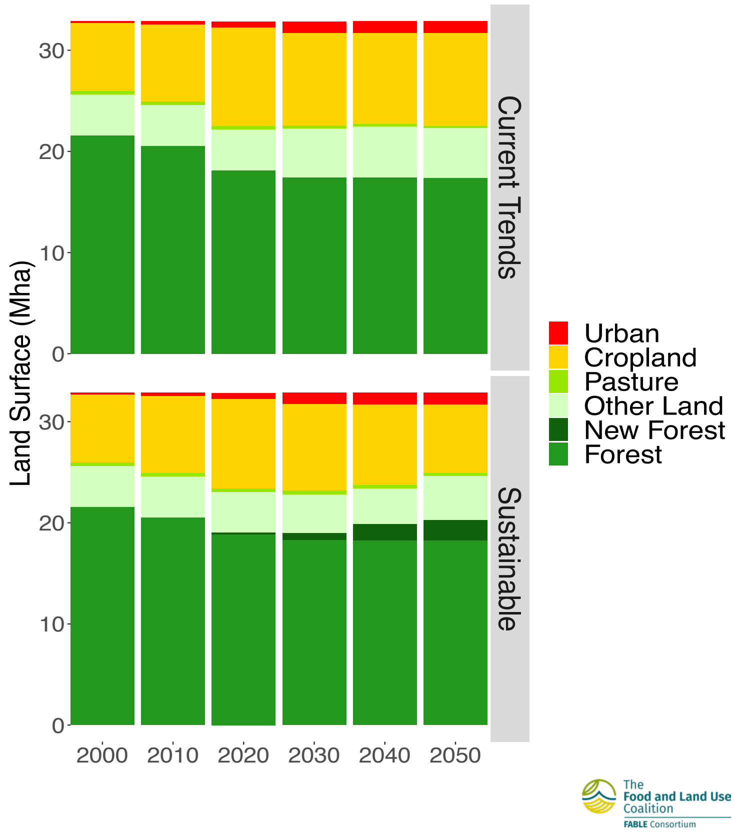
Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions, including no constraints on land conversion beyond protected areas and no afforestation by 2025 (see Annex 1).

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result from an increase of cropland area and a decrease of forest area compared to 2000-2010. This trend will stop over the period 2030-2050: cropland area and forest area stabilize (Figure 1). The expansion of the planted area for oil palm, rice, and cocoa explains 98% of total cropland expansion between 2010 and 2030. For oil palm, most of the expansion is export-oriented, with about 4% of palm oil produced being consumed locally. For rice, the expansion is due to increasing local food demand. Finally, for cocoa, the expansion is due to increasing local food demand and increasing exports. Pasture expansion is mainly driven by the increase in internal demand while livestock productivity per head increases and ruminant density per hectare of pasture remains constant over the period 2020-2030. Between 2030-2050, main land cover change is explained by increased internal demand due to increase in average food intake per capita as well as increasing exports of palm oil products. This results in a reduction of land where natural processes predominate by -6% by 2030 and by -3.5% by 2050, both compared to 2010, respectively.

In the Sustainable Pathway, assumptions on deforestation and protected areas have been changed to reflect the Malaysian government's commitment

Figure 1 | Evolution of area by land cover type and protected areas under each pathway

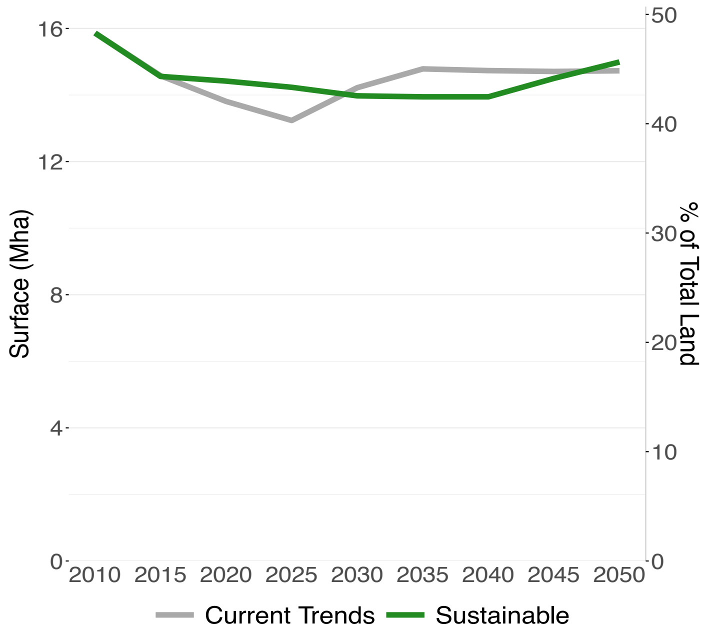


Source: Authors' computation based on ESA CCI (2017) for the area by land cover type for 2000.

to ban expansion of oil palm acreage beyond 6.5 Mha by 2023 (Yusof, 2019). The main assumptions include the prevention of deforestation by 2023 and constraints on the expansion of agricultural land beyond its current area (see Annex 1) (Ministry of Natural Resources and Environment, 2016).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Malaysia in the Sustainable Pathway: (i) complete halting of deforestation, (ii) reduction of loss of land where natural processes predominate, (iii) stabilization of agricultural land area, and (iv) no reforested/afforested land. In addition to the changes in assumptions regarding land-use planning, these changes compared to the Current Trends Pathway are mainly explained by stopping forest conversion to export-oriented oil palm plantations. This leads to a stabilization in the area where natural processes predominate: the area stops declining by 2035 and increases by 3% between 2045 and 2050 (Figure 2).

Figure 2 | Evolution of the area where natural processes predominate



The Food and Land Use Coalition FABLE Consortium

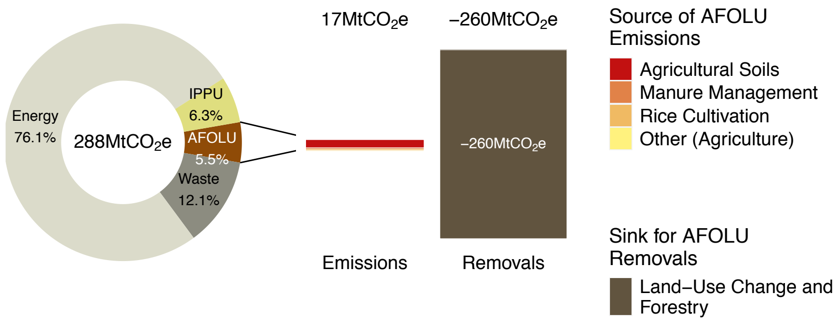
GHG emissions from AFOLU

Current State

The Agriculture, Forestry, and Other Land Use (AFOLU) sector is a critical component of the Malaysian plan to address climate change largely due to the extent of carbon sinks in the region such as forests and peatlands. The effort to balance economic concerns, food security, and the preservation of the country's vast carbon sinks remains a point of debate to this day. In particular, peatlands pose a unique challenge due to the lack of national data available.

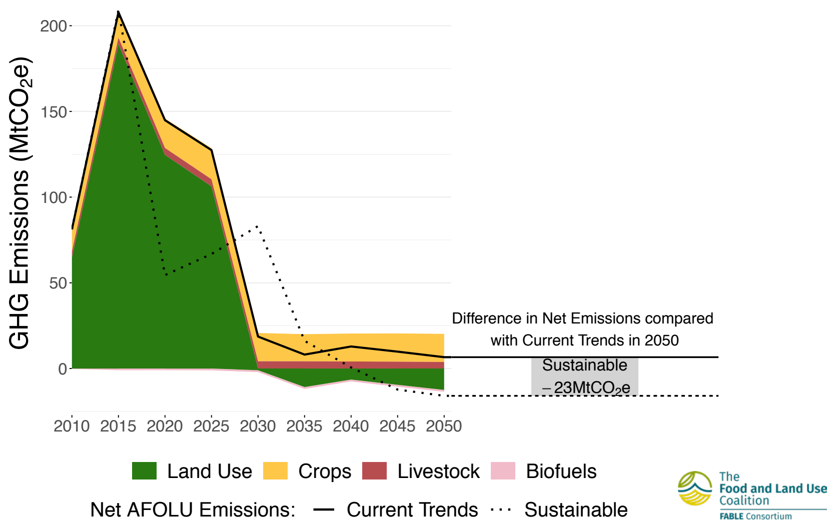
Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 5.5% of total emissions in 2011 (Figure 3). Agricultural soils are the principle source of AFOLU emissions, followed by manure management, rice cultivation, and field burning of agricultural residues. This can be explained by the projected increase in palm oil plantations to meet both external demand as well as fulfill domestic trade targets. This increase in planted area corresponds to increased fertilizer use which has historically contributed to increases in GHG emissions from the agricultural sector (Ministry of Energy, Science, Technology, Environment and Climate Change, 2018).

Figure 3 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2011



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

Figure 4 | Projected AFOLU emissions and removals between 2010 and 2050 by main sources and sinks for the Current Trends Pathway



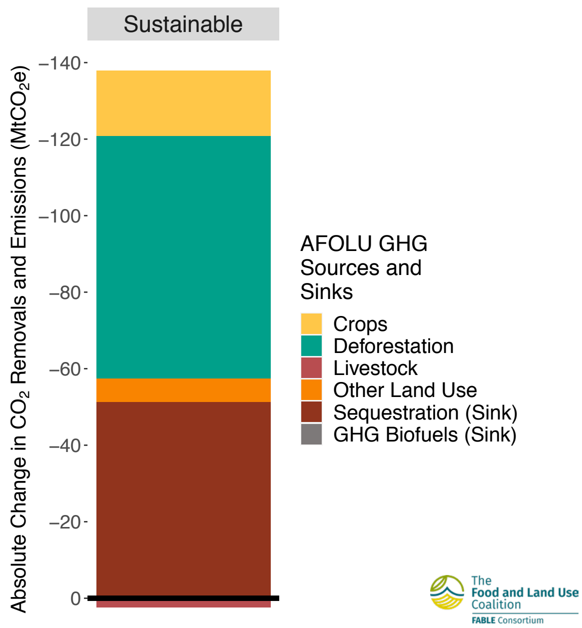
Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU decrease to 18.6 Mt CO_2e/yr in 2030, before declining to 6.6 Mt CO_2e/yr in 2050 (Figure 4). In 2050, cropland is the largest source of emissions (16 Mt CO_2e per year) while there is also significant carbon sequestration from vegetation (-12.5 Mt CO_2e/yr). Over the period 2020-2050, the strongest relative increase in GHG emissions is computed for livestock (8%) while a reduction is computed for deforestation (110%).

In comparison, the Sustainable Pathway leads to a reduction of AFOLU GHG emissions by 341% (Figure 4). The potential emissions reductions under the Sustainable Pathway is dominated by a reduction in GHG emissions from land-use change (Figure 5). The change in assumptions made for cropland expansion as well as afforestation targets are the most important drivers of this reduction.

Compared to Malaysia's commitments under UNFCCC (Table 1), our results show that the targets can easily be met even under the current trends scenario. This result could be particularly important when considering options for enhancing our future commitments in the subsequent NDCs. One particular criticism that can be made is the usage of GHG intensity per GDP to measure the target. This makes achieving the target much simpler as the GDP of the country is expected to grow steadily over the period and hence may present a much more positive view of the country's achievements than is warranted.

Figure 5 | 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

Malaysia continues to be plagued by the burden of malnutrition and non-communicable diseases. While the data shows that Malaysia is largely on track by way of caloric, protein and fat consumption, its health outcomes remain poor. The prevalence of stunting and obesity among its population is high relative to other upper middle-income countries (UNICEF, 2018). Our analysis shows that there remain imbalances in Malaysian diets that need to be addressed, particularly the overconsumption of sugar, eggs, and poultry, and the under-consumption of nuts, pulses, fruits, and vegetables.

The "Triple Burden" of Malnutrition

Undernutrition	Micronutrient Deficiency	Overweight/ Obesity
2.5% of the population was undernourished in 2017. This share has decreased since 2008 (-4.2%) (World Bank, 2017).	35.5% of women (Institute for Public Health, 2015) and 6.6% of children under 12 suffer from anemia (Poh et al., 2013), which can lead to maternal death.	17.7% of adults, and 11.9% of children were obese in 2015 (Institute for Public Health, 2015). These shares have increased since 2006 (Institute for Public Health, 2006).
20.7% of children under 5 were stunted and 11.5% wasted in 2016 (Institute for Public Health, 2016).	2.5% of male and 4.5% of female children 5 years old and younger are deficient in vitamin A (Khor, 2005), which can notably lead to blindness and child mortality. 48.2% are deficient in iodine, which can lead to developmental abnormalities (Selamat et al., 2010).	30% of adults were overweight in 2015 (Institute for Public Health, 2015), and 10% of children were overweight in 2013 (Salleh, 2017). This share has increased since 2006 (Institute for Public Health, 2006).

Disease Burden due to Dietary Risks
73% of deaths are attributable to non-communicable diseases (NCDs) which are linked to dietary risks (Institute for Public Health, 2015), or approximately 364 deaths per year per 100,000 people (WHO, 2016).
17.5% of the population suffers from diabetes (Institute for Public Health, 2015) and 35% from cardiovascular diseases (Institute for Public Health, 2017), which can be attributable to dietary risks.

Table 4 | Daily average fats, proteins and kilocalories 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)	2,804 (2,085)	2,805 (2,092)	2,802 (2,092)	2,805 (2,096)	2,816 (2,096)
Fats (g) (recommended range	84 (62-93)	84 (62-94)	82 (62-93)	84 (62-94)	84 (63-94)
Proteins (g) (recommended range	78 (70-245)	78 (70-245)	78 (70-245)	78 (70-245)	78 (70-246)

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.

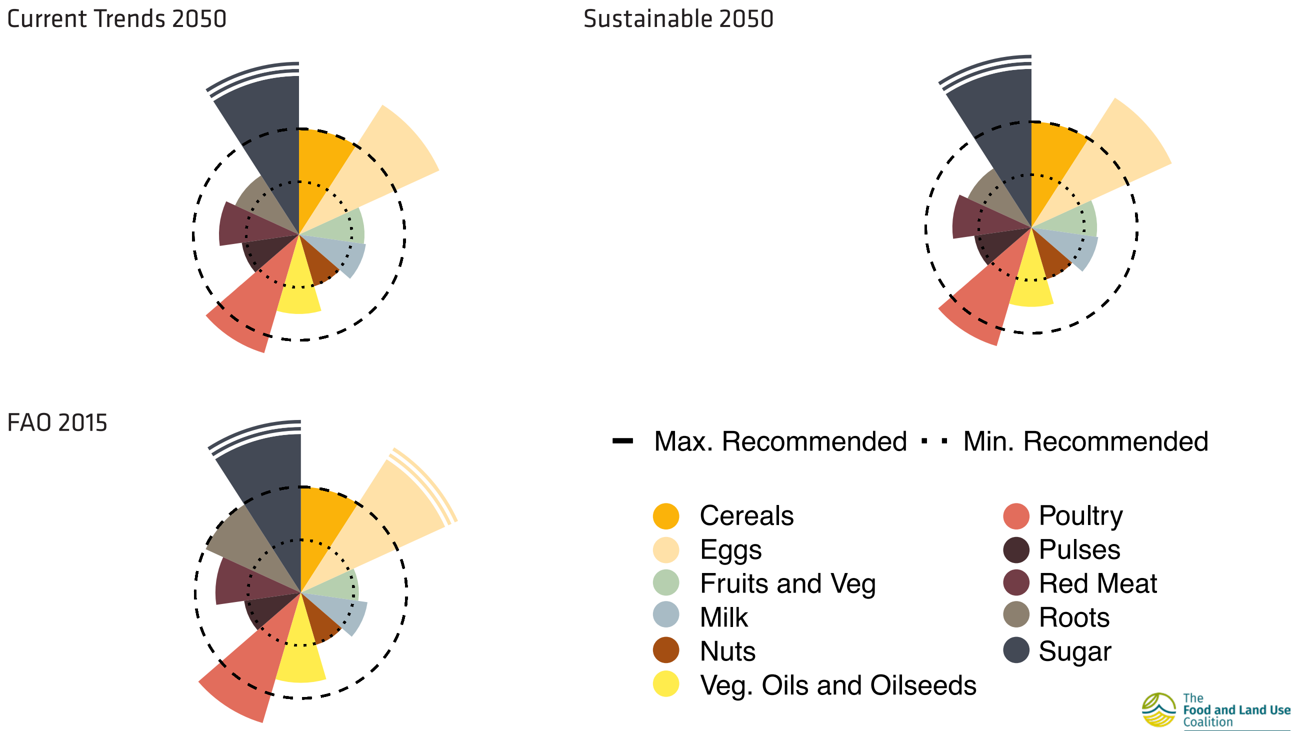
Pathways and Results

Under the Current Trends Pathway, compared to the average Minimum Dietary Energy Requirement (MDER) at the national level, our computed average calorie intake is 34.1% higher in 2030 and 33.8% higher in 2050 (Table 4). The current average intake is mostly satisfied by cereals and sugar, and animal products, which represent 18% of the total calorie intake. We assume that the consumption of animal products, animal fat, fish, fruits, and vegetables will increase, while oilseeds and vegetable oils, poultry, red meat, and roots consumption will decrease. Compared to the EAT-Lancet recommendations (Willett et al., 2019), sugar, eggs and poultry are over-consumed while nuts, pulses, fruits and vegetables are under-consumed in 2050 (Figure 6). The intake of fat and protein per capita are within the dietary reference intake (DRI).

Under the Sustainable Pathway, we assume that diets will transition towards SSP1 (Sustainability). The ratio of the computed average intake over the MDER increases to 33.9% in 2030 and 34.3% in 2050 under the Sustainable Pathway. Compared to the EAT-*Lancet* recommendations, only the consumption of eggs, poultry and sugar remains outside of the recommended range with the consumption of all the remaining categories are within the recommended range in 2050 (Figure 6). Moreover, the fat and protein intake per capita fall within the dietary reference intake (DRI) in 2030, showing no improvement compared to the Current Trends Pathway.

The National Plan of Action for Nutrition of Malaysia III (2016-2025) outlines a host of facilitating and enabling strategies (Ministry of Health, 2016) that will be particularly important to promote this shift in diets. Addressing nutritional deficiencies, obesity and other diet-related non-communicable diseases have been given due attention considering national health outcomes. With specific strategies targeted at women, children, and the general population, solutions range from awareness campaigns, to food fortification, to policies governing food advertising.

Figure 6 | Comparison of the computed daily average kilocalories intake per capita per food category across pathways in 2050 with the EAT-Lancet recommendations



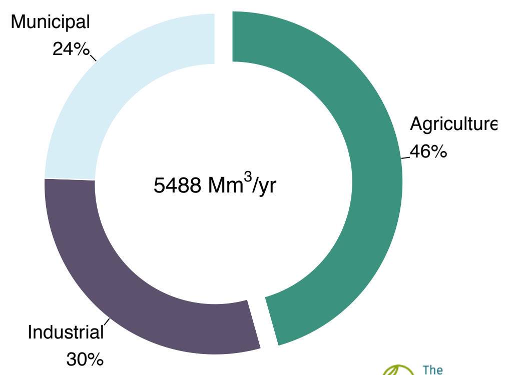
Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings), therefore different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended 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 and eggs indicate that the average kilocalorie consumption of these food categories is significantly higher than the maximum recommended.

Water

Current State

Malaysia is characterized by equatorial climate with high uniform temperatures with 2,875 mm (FAO, 2017) average annual precipitation that mostly occurs over the period of November – March and May – October (Zakaria, Craig, Ooi, & Thomas, 2020). The agricultural sector represented 46% of total water withdrawals in 2005 (World Bank, 2020; Figure 7). Moreover in 2009, 5.4% of agricultural land was equipped for irrigation (FAO, 2011). The three most important irrigated crops, rice, other vegetables, and other products, account for 87%, 11%, and 2% of the total harvested irrigated area, respectively.

Figure 7 | Water withdrawals by sector in 2005

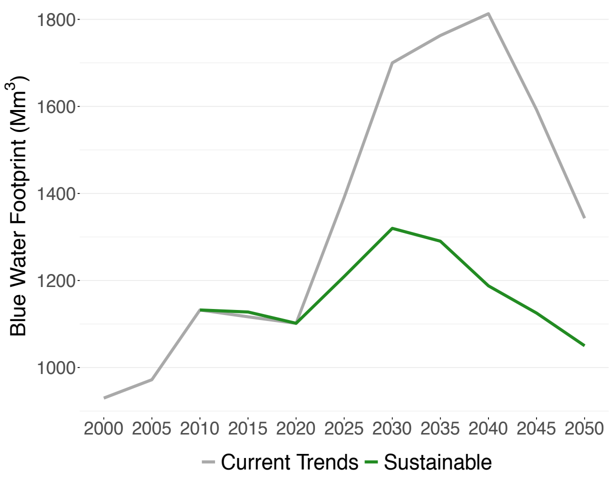


Source. Adapted from World Bank (2020)

Pathways and Results

Under the Current Trends Pathway, annual blue water use increases between 2000-2015 (930 Mm^3/yr and 1,117 Mm^3/yr), before reaching 1,700 Mm^3/yr and 1,343 Mm^3/yr in 2030 and 2050, respectively (Figure 8), with rice accounting for 81% of computed blue water use for agriculture by 2050[4]. In contrast, under the Sustainable Pathway, blue water footprint in agriculture reaches 1,320 Mm^3/yr in 2030 and 1,050 Mm^3/yr in 2050, respectively.

Figure 8 | Evolution of blue water footprint in the Current Trends and Sustainable Pathways



4 We compute the blue water footprint as the average blue fraction per tonne of product times the total production of this product. The blue water fraction per tonne comes from Mekonnen and Hoekstra (2010a, 2010b, 2011). In this study, it can only change over time because of climate change. Constraints on water availability are not taken into account.

Resilience of the Food and Land-Use System

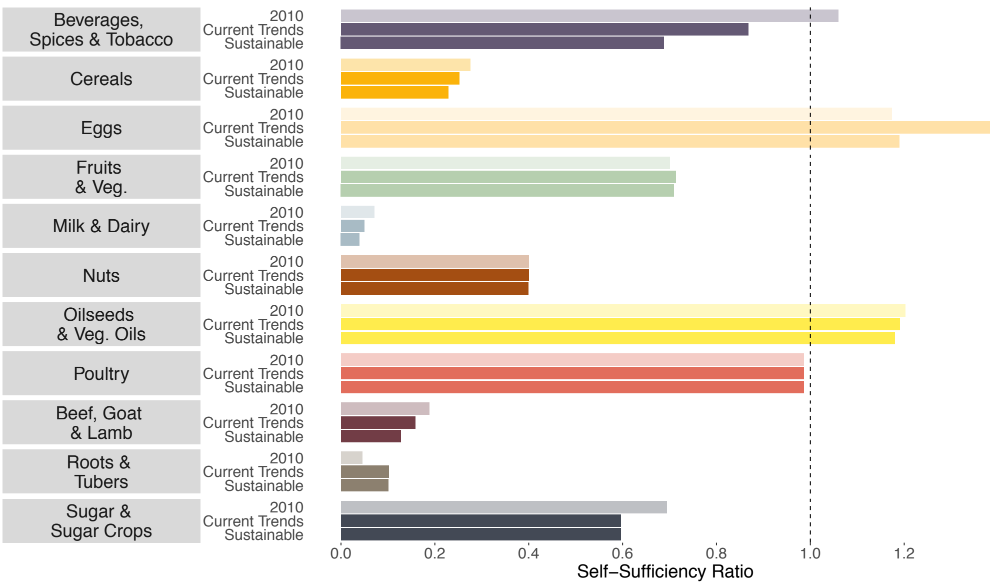
The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Malaysia's resilience to agricultural-trade and supply disruptions across pathways: the 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

Malaysia's level of self-sufficiency is low because key product groups such as cereals, milk and dairy, beef, goat, and lamb are significantly reliant on imports. Among cereals product groups, rice is a particularly important component since it was consumed by 89.8% of the population in 2014 (Ministry of Health, 2014). In 2010, 40% of rice was imported, hence a significant source of the population's energy source is dependent on external sources (FAO, 2013).

Under the Current Trends Pathway, we project that Malaysia would be self-sufficient in eggs, oilseeds, and vegetable oils in 2050, with self-sufficiency levels by product group remaining stable for most products from 2010 – 2050 (Figure 9). The product groups where the country depends on the most on imports to satisfy internal consumption are cereals, milk and dairy, beef, goat, and lamb and this dependency will continue until 2050. Similarly, under the Sustainable Pathway, Malaysia remains self-sufficient in eggs, oilseeds and vegetable oils, representing stable self-sufficiency levels. This is explained by Malaysia's food production system whereby production of wheat is not suitable to be grown locally, while milk, beef, mutton and lamb local production remains low despite numerous governmental initiatives, hence demand is expected to continue to significantly rely on imports (Sundaram and Gen, 2019).

Figure 9 | 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.

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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:

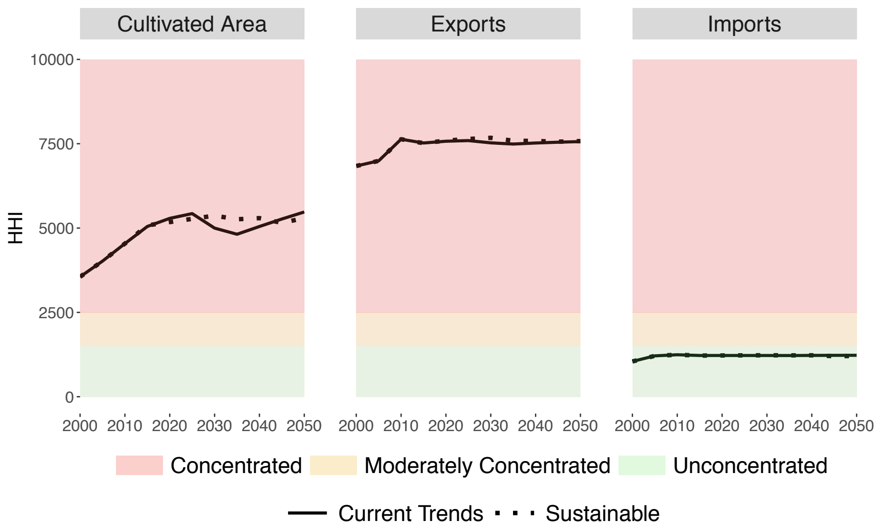
- **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- **Exports and imports:** 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.

According to the HHI, Malaysia has a very high concentration of exports and planted area. This is because Malaysia's agriculture policy is highly skewed towards palm oil. In 2010, palm oil represented 55.8% of all crop exports measured by tonnage and 66.2% of all crop acreage (FAO, 2013). Malaysia's imports on the other hand are diversified. This means that Malaysia not only has low self-sufficiency, but Malaysia's low self-sufficiency applies to a wide variety of product groups.

Similarly, under the Current Trends and the Sustainable Pathways, we project high concentration of crop exports and low concentration of imports and high concentration in the range of crops planted in 2050, trends which increase over the period 2010 - 2050. This indicates low levels of diversity across the national production system and exports (Figure 10).

Figure 10 | Evolution of the diversification of the cropland area, crop imports and crop exports of the country using the Herfindahl-Hirschman Index (HHI).



Discussion and Recommendations

Since the beginning of 21st century, Malaysia has observed large-scale deforestation mainly in its Bornean states, i.e. Sabah and Sarawak. The land-use changes in both states mark an unprecedented, vivid example of land exploitation to jumpstart economic development. The changes began with rampant logging (legal and illegal) and were followed by the expansion of oil palm plantations. In 2000-2020, about 2.6 Mha of new oil palm plantations were established throughout Malaysia, with 0.5 Mha in Sabah and 1.3 Mha in Sarawak. The total land with oil palm plantations has almost doubled in the last 20 years, reaching almost 6 Mha in 2020 compared to 3.4 Mha in 2000. While the expansion of the cash crop has brought in significant revenue for the country, it also involved large-scale conversions of forests and peatlands which are rich in carbon stock and biodiversity.

Currently, the conventional exploitative land-based economy in Malaysia is facing a predicament: how to maintain economic growth without causing further environmental impacts and also repairing the damage done in the past. One of the benefits of the collaborative approach in FABLE has been to clearly demonstrate that all sectors are closely inter-related. Particularly for the case of Malaysia, changes in food consumption patterns and trade patterns can have significant impacts on domestic agricultural expansion and forested areas. Palm oil cultivation, in particular, has an outsized impact on forest cover, given the lack of other land cover types to convert from. Indeed, it can be seen using the FABLE Calculator tool that under the Current Trends Pathway that an increase in external demand for palm oil translates to rapid loss of forest cover before 2030, after which it is assumed that no further deforestation will occur. We modeled here a 116% increase in palm oil exports between 2000 and 2015 and can observe, as mentioned above, a loss of 2.6 Mha of forest cover (or 12% loss from 2000) within the same period; most of which can be attributed to palm oil expansion given no other major crop has seen such growth.

In recent years, palm oil has been the single largest crop export by tonnage for Malaysia (greater than 50%). From 1990 to 2010, palm oil production grew robustly at a rate of 3.1% per year, however in the Current Trends Pathway, we forecast that the annual growth for the 2010-2050 period will slow down to 1.8% per year, as global demand is anticipated to be much more tepid and exports are adjusted to follow import demand in the FABLE Calculator. A solution to the country's land exploitation dilemma begins by searching for **new sources of income to reduce the dependency on palm oil export**. From an environmental perspective, capping oil palm expansion would significantly avoid further forest loss in the country. On the contrary, extending palm oil plantations even more in order to increase exports would lead to more land use change, deforestation and biodiversity loss, and potentially excessive water consumption. A combination of coherent policies across ministries are needed to address the problems embedded in the AFOLU sector.

For the Sustainable Pathway, we estimate that the total global demand for palm oil, for the 2010-2050 period, will fall a further 8.4% per year vis-à-vis the Current Trends Pathway due to slower global population growth and increased productivity of local substitutes. This forecast follows closely with the trend of declining global demand for commodities, and the increasing wages of foreign laborers which makes Malaysia gradually lose its comparative advantage in furthering oil palm expansion. Therefore, our Sustainable Pathway is based on the assumptions that instead of clearing more land to produce more palm oil for a slowing demand, seeking new sources of revenues, such as investing more in downstream activities for high value-added products will be the focus of the land-based sectors. That is why we anticipate that there will be about 0.9 Mha more forests by 2050 in the Sustainable Pathway.

At a macro level, the country has been **transforming from an agriculture-based economy into a manufacturing and services centered economy**. In 1990, agriculture already decreased to 15% of GDP compared to 44% in 1960. The share further halved to 7% by 2018, with the services sector emerging as the most significant sector contributing 53% of GDP (World Bank, 2018). Moving forward, Malaysia - with its relatively small landmass - needs to enhance the skills of its workforce so that it can successfully transform its economy from developing status to advanced status, where growth and prosperity depend on human capital and ingenuity rather than wanton exploitation of land and nature.

However, the country may have to rethink its land-use strategy, especially considering **reinventing its model of food supply-demand**. In 2018, Malaysia's food import bill was 50 billion MYR, and our food trade deficit totaled 18.6 billion MYR in 2016 (Murad, 2020). Despite repeated calls to increase Malaysia's self-sufficiency levels, government initiatives to reach those targets have continually fallen short. New and innovative approaches to local food production will need to be developed. Given the rapid urbanization trend across the whole country, urban farming may potentially address food security as well as create new business opportunities. Food security policies should do more than just address "dietary energy undernourishment", but also be oriented towards micronutrient deficiencies and diet related non-communicable diseases. Lastly, while there has been growing awareness of the scale of Malaysia's food waste problem, a more multisectoral approach must be implemented to optimize our food systems, including supply chain efficiency and consumer behaviors, rather than viewing it purely in terms of solid waste management.

It is, however, important for policymakers to realize that utility-based development strategies with wealth creation as the center of policymaking may prevent further degradation but are likely inadequate to repair the previous environmental damage. **Effective restoration strategies** need to be put in place on top of the previously mentioned actions. Some areas, however, should be given top priority to conservation. For example, restoring riparian buffers are necessary not only to mitigate land conversion impacts on biodiversity and water quality but also to ensure long-term viability of agricultural activities by slowing rates of riverbank erosion and lateral channel migration. Also, restoring patches of degraded land surrounded by ecological important areas may substantially improve habitat connectivity which can be critical for the survival of many species.

The interconnected nature of economic productivity and conservation means that no single strategy or policy can be a perfect solution, although some can be more practical and effective than the others within different periods of time, or acceptable by different stakeholders. These inadequacies demand optimally combining the different strategies to reach both ends. This requires a structural thinking in policymaking to manage the entire system. Based on scientific findings of the FABLE Consortium, there is also a need to **co-produce and tailor more knowledge to local specificities**, to model with more granularity the synergies and trade-offs in different areas and contexts in order to communicate, manage, and implement effective national and sub-national policies to achieve a Sustainable Pathway. Engagement with policymakers and others key stakeholders in various forms of communications will be the key upcoming mission for the FABLE Malaysia team.

Our recommended policy improvements are that, as we advance towards 2050, **policies to accelerate Malaysia's transition to the secondary and tertiary sectors, especially bio-based industries and eco-tourisms that leverage on the vast resources in the country are needed to compensate for the reduction in income from agricultural commodities, palm oil in particular**. However, due to uneven development across the country, Malaysia's 5-year national development plan from 2015 to 2020, still places the development of agriculture commodities as one of its key priorities. Moving forward, the federal and state governments should be bold in transforming its agricultural policies and working closely together, so that private investors have the stability and confidence needed to change their investments and reallocate their capital to more sustainable sectors. From an environmental perspective, the reduction in palm oil exports in the Sustainable Pathway, creates the opportunity to increase forest cover by around 0.9 Mha by 2050, which would contribute significantly to Malaysia's carbon-sink capacity. Hence, wise land use planning is needed to **sustainably reforest our land** so that Malaysia can exemplarily deliver on its commitments to the Paris Climate Agreement.

From the perspective of biodiversity policies, current policies are ineffective because they are formulated without adequate data. For example, **the lack of a clear breakdown of forest areas by ecotype and comparison of the loss of areas in each ecotype**, has resulted in policies which are too general and that overlook niche ecosystems which can have significant biodiversity value. Also, **the absence of systemic spatial mapping data** has led to ineffective habitat connectivity policies which risk failure to achieve the outcomes defined in the 8th NBSAP Target of restoring and protecting terrestrial ecological corridors by 2025. Therefore, the dearth of quality data in the biodiversity policy space needs to be addressed with utmost urgency.

Food security is another policy space which requires significant policy improvement. Sundaram et al. (2019) have noted the **need for a cross-ministry, comprehensive national food policy document** as the current policy infrastructure is fragmented and ineffective. Specifically, the National Agro-Food Policy (2011-2020) focuses on food security while the National Plan of Action of Nutrition III (2016-2025) focuses on nutrition. Policy **implementation and outcome monitoring must also be strengthened**, as many well designed and well-intended policies are failing to deliver on their intended outcomes. For example, since the launch of the National Strategic Plan for Food Waste Management in Malaysia, no progress has been reported since nor has it been included in other policy documents (Yahaya, 2013). Unless the efficacy of policy coordination and policy implementation are improved, Malaysia will continue to fall short of its food security and nutrition aspirations.

The key limitations that we were not able to include are the following: **Mega projects like hydropower dams and road building in Sarawak** (which will include the construction of Pan Borneo Highway in the coming years) are also driving the loss and degradation of forest. **Rapid urbanization in Peninsular Malaysia** is also encroaching into high conservation value areas. While these play important roles in land-use system, they are yet to be included in the model.

Currently, some important dimensions to describe land use evolution such as geo-spatial information, supply-demand dynamics and price elasticity have not yet been considered in the FABLE Calculator. In the particular case of Malaysia, we will strive to include in future iterations details of oil palm crop operations, which is such a key commodity in the country.

Annex 1. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)

Current Trends Pathway	Sustainable Pathway
The population is expected to reach 40.8 million by 2050. Based on UN DESA (2019). (SSP1 scenario)	Same as Current Trends

LAND Constraints on agricultural expansion

Current Trends Pathway	Sustainable Pathway
Deforestation for agriculture is relatively low in Peninsular Malaysia, but logging persists in some states, and urbanization also used up some forested land. In Malaysian Borneo, the state governments have made clear their policies in limiting logging activities and further oil palm expansion. The problem of enforcement lies in the premise of illegal logging which may cause further forest degradation. We may safely assume that the deforestation rate due to agricultural expansion will gradually decrease to zero by 2030 in this scenario, but probably we will not be able to track forest degradation due to logging, which is a much serious issue. (No deforestation beyond 2030) Based on Borneo Post (2015, 2019)	In the most sustainable scenario, not only conversion to cropland, unsustainable logging (including previously untraceable illegal logging) is also completely banned, forcing the uptake of stricter sustainable forest management (SFM) certification. Wood production may be reduced but maintained at a reasonable rate. In this case, we can safely assume that no deforestation will take place. Urbanization will be compromised, but that may affect housing prices and thus the GDP growth. (No expansion) Based on Borneo Post (2015, 2019)

LAND Afforestation or reforestation target (1000 ha)

Current Trends Pathway	Sustainable Pathway
Some afforestation is going on, as well as natural regeneration. However, without further conversion of forest, those unforested land will remain the only space for agricultural expansion. In such a situation, natural regeneration may not widely take place. Conservatively, we can assume no new forested area. (NoAfforestation scenario selected) No national targets; All assumptions are those of the authors.	Global economic downturn may positively affect natural regeneration as many lands may be abandoned. Under such circumstances, we may see some increase in forested areas in regions far from urbanization. (BonnChallenge scenario selected) No national targets; All assumptions are those of the authors.

BIODIVERSITY Protected areas (1000 ha or % of total land)

Current Trends Pathway	Sustainable Pathway
We used the by-default assumption in the FABLE Calculator which is that in the ecoregions where current level of protection is between 5% and 17%, the natural land area under protection increases up to 17% of the ecoregion total natural land area by 2050.	Same as Current Trends

PRODUCTION Crop productivity for the key crops in the country (in t/ha)

Current Trends Pathway	Sustainable Pathway
By 2050, crop productivity reaches: • 26.49 tons per ha for palm oil • 3.39 tons per ha for rice • 1.22 tons per ha for rubber (Same growth as over 2000 - 2010) All assumptions are those of the authors.	By 2050, crop productivity reaches: • 29.35 tons per ha for palm oil • 4.02 tons per ha for rice • 1.42 tons per ha for rubber Based on statistical evidence and literature for major cash crops such as palm oil, we conclude that large yield increases are unlikely; with the most sustainable pathway being that of increased resilience against yield declines. (Higher productivity than 2000 – 2010) Based on Malaysian Palm Oil Board, (2020).

PRODUCTION Livestock productivity for the key livestock products in the country (in t/head of animal unit)

Current Trends Pathway	Sustainable Pathway
Malaysia's largest source of meat is chickens, followed by pigs, ducks and cattle. Yields for all four groups have been on a general upward trajectory over the last 20 years, albeit with some years of decreasing yields. (BAU Growth) Based on FAO (2020)	With no major modifications to the livestock rearing process, yields for all four livestock groups should remain at roughly the same levels as 2010. This is evident in the FAO dataset's yields for pigs, ducks and cattle only deviating slightly downwards in 2018. An exception to this is chicken which increased its yield by approximately 18% between 2010 and 2018. (No Growth) Based on FAO (2020)

PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)

Current Trends Pathway	Sustainable Pathway
By 2050, the average ruminant livestock stocking density is 0.44 TLU/ha per ha. All assumptions are those of the authors.	By 2050, the average ruminant livestock stocking density is 0.22 TLU/ha per ha. All assumptions are those of the authors.

PRODUCTION Post-harvest losses

Current Trends Pathway	Sustainable Pathway
No data available.	No data available.

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

Current Trends Pathway	Sustainable Pathway
For 16 largest imports consumed in Malaysia in 2010, namely corn, rice, milk, cassava, wheat, beef, coconut, fish, other fruits, onion, orange, potato, soya bean, other vegetables, soy cake, and raw sugar, the share of consumption which is imported in 2050 is calculated to be the average historical share observed in 2000, 2005 and 2010 (FAO, 2013). As the observations of most of the products displayed mean reversion characteristics in the observation period, the average of the observations was used for the basket of 16 products during the forecast period.	The Sustainable Pathway assumes the structural share of imports to be similar to the Current Trends Pathway, allowing domestic policies to improve productivity and reduce food loses, hence describe achievement of environmental targets, without noise from external factors.

TRADE Evolution of exports for key exported products (1000 tons)

For palm oil and palm kernel cake, the 1st and 4th largest exports in Malaysia in 2010, export quantities for 2050 were calculated using a growth rate of 3.1%/yr and 2.8%/yr, respectively, which were linearly regressed from actual annual exports from 1990 to 2010 (FAO, 2013). A linear regression was judged to be suitable to model a linear trend over a 40-year forecast period as seasonal trends are not relevant for such a long forecast period. After trade adjustment, net exports were adjusted to track global net imports within a band of no greater than 10% of net imports. Therefore, annual growth rates drop to 1.8%/yr, and 1.9%/yr, respectively.

Plywood and sawn wood, the 2nd and 3rd largest exports in 2010, are to be included in the next iteration of the Scenathon which will include a forest product module.

In the Sustainable Pathway, we assume that global net imports for palm oil and palm kernel cake have declined vis-à-vis the Current Trends Pathway. As a result, total palm oil exports for the forecast period falls by 8.4% and total palm kernel cake exports fall by 9.7%.

FOOD Average dietary composition (daily kcal per commodity group or % of intake per commodity group)

Current Trends Pathway

By 2030, the average daily calorie consumption per capita is 2805 kcal and is:

- 1,255 kcal for cereals
- 107 kcal for fish
- 143 kcal for fruits and vegetables

Per capita consumption of beef and poultry is increasing while mutton and pork are decreasing (Sheng, Shamsudin, Mohamed, Abdullah, & Radam, 2010). National health and morbidity surveys do not do time series data but suggests that our diet outcomes are very poor (see NHMS 2003 and 2014 conclusions), falling short of the governments' own targets, recommended nutrient intake (RNI).
(SSP2 scenario)

Sustainable Pathway

By 2030, the average daily calorie consumption per capita is 2805 kcal and is:

- 1,255 kcal for cereals
- 107 kcal for fish
- 143 kcal for fruits and vegetables

National Plan of Action for Nutrition of Malaysia III 2016-2025 (Ministry of Health, 2016) in place but no update on progress publicly available. The plan aims to promote healthy eating and active living; address nutritional deficiencies, obesity and other diet-related NCDs; sustain food systems to promote healthy diets, and; ensure food safety and quality.
(SSP1 scenario)

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

Increased share by 10% compared to 2010. No time series data available. Badgie puts the waste generation rate for Kuala Lumpur increasing 3% annually, if this is used as a very rough proxy, it looks like a linear upward trend. KPKT estimates of municipal solid waste in 2005 were 17,000 tons and projects for more than 30,000 tons for 2020 (Kementerian Perumahan Dan Kerajaan Tempatan, 2005). Food waste composition in municipal solid waste among residential households between 30.84% (high income) and 54.04% (low income) in KL (Badgie, Abu Samah, Manaf, & Muda, 2012). Plan in place to handle municipal solid waste situation but not specifically food waste.
(Increased share compared to 2010)

Reduced share by 50% compared to 2010. Public awareness on the scale of food loss is growing. The development of a National Strategic Plan for Food Waste Management in Malaysia was under way, but no progress reported since. It cites "Solid waste in Malaysia consists of 50% of food waste (at source), and 70% (as disposed at the landfill sites)". The 10th Malaysia Plan (2011-2015) had aimed to "household recovery of waste from 15% to 25% by 2015" (Yahaya, 2013), but no progress has been reported since.
(Reduced share compared to 2010)

Malaysia

BIOFUELS Targets on biofuel and/or other bioenergy use

Current Trends Pathway	Sustainable Pathway
By 2050, biofuel production accounts for: • 474 kt of palm oil production. No national targets. For liquid biofuels, due to low prices of palm oil, more subsidies are given to the local biodiesel market, creating a buffer for excessive stock. This policy may maintain for the next couple of years but highly uncertain due to expected economic downturn. We assume it will maintain at the current rate, 10% (B10 blending) for the next 5 years. In 2018, total diesel consumption was about 10 billion liters. (OECD_AGLINK) All assumptions made with informal communications with the National Agency of Innovation Malaysia and based on the National Biomass Strategy 2020 (Agensi Inovasi Malaysia, 2013).	By 2050, biofuel production accounts for: • 474 kt of palm oil production. No national targets. Second-generation bioethanol and biogas from oil palm residues may be realized with substantial financial inputs from the government. It can only happen if the economic status is going extremely well. In the most extreme, best-case scenario, the biomass in Malaysia may supply up to millions of liters of second-generation bioethanol from all residues, but this is highly uncertain. Due to this uncertainty, a similar scenario to the Current Trends pathway is used. (OECD_AGLINK) All assumptions made with informal communications with the National Agency of Innovation Malaysia and based on the National Biomass Strategy 2020 (Agensi Inovasi Malaysia, 2013).

CLIMATE CHANGE Crop model and climate change scenario

Current Trends Pathway	Sustainable 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 GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilization effect.	By 2100, global GHG concentration leads to a radiative forcing level of 2.6 W/m2 (RCP 2.6). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilization effect.

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)

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

g – gram

GHG – greenhouse gas

ha – hectare

kcal – kilocalories

kg – kilogram

km^2 – square kilometer

km^3 – cubic kilometers

m – meter

Mha – million hectares

mm – millimeters

Mm^3 – million cubic meters

Mt – million tonnes

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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