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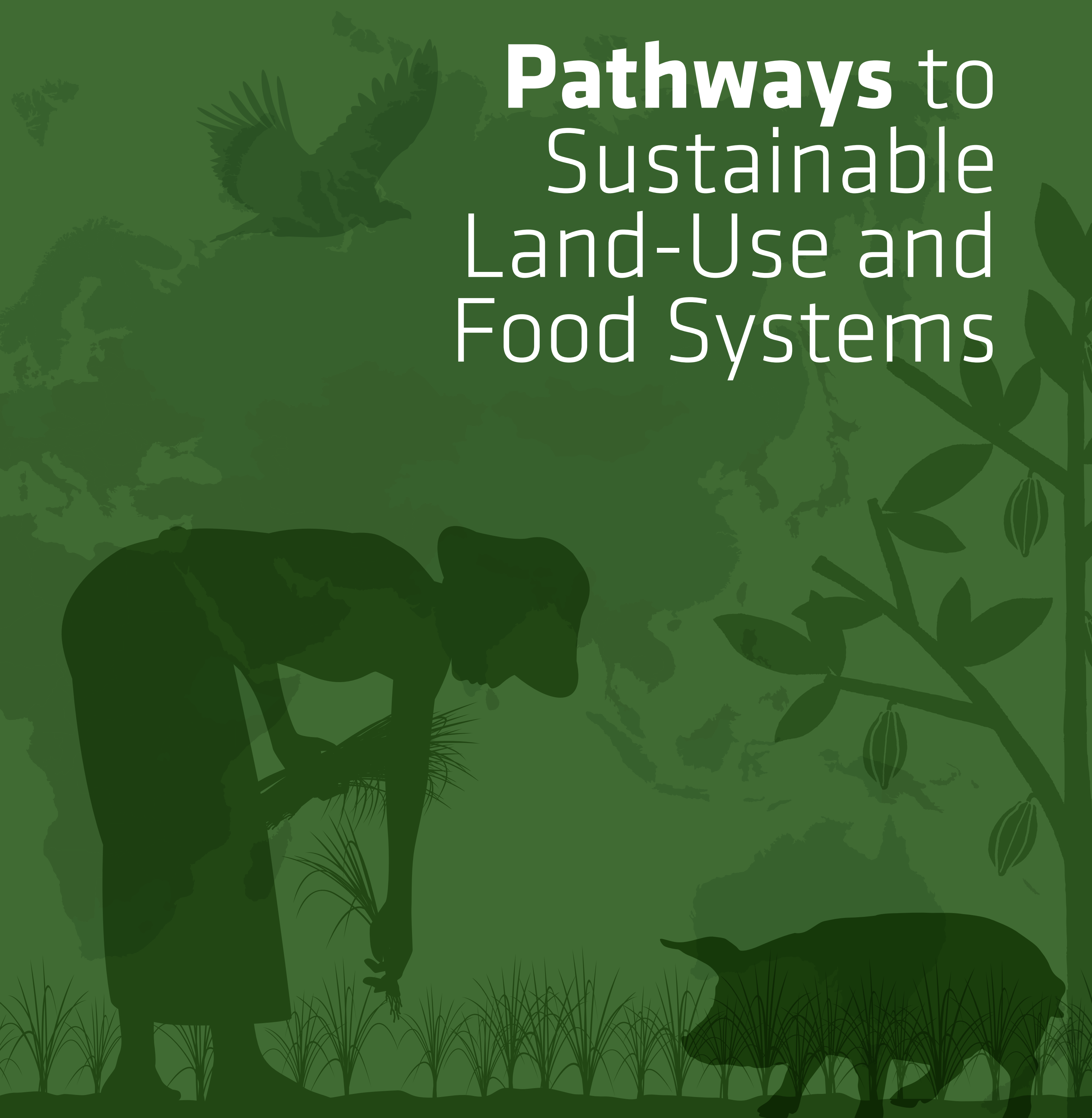
SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

The Food and Land Use Coalition

2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems



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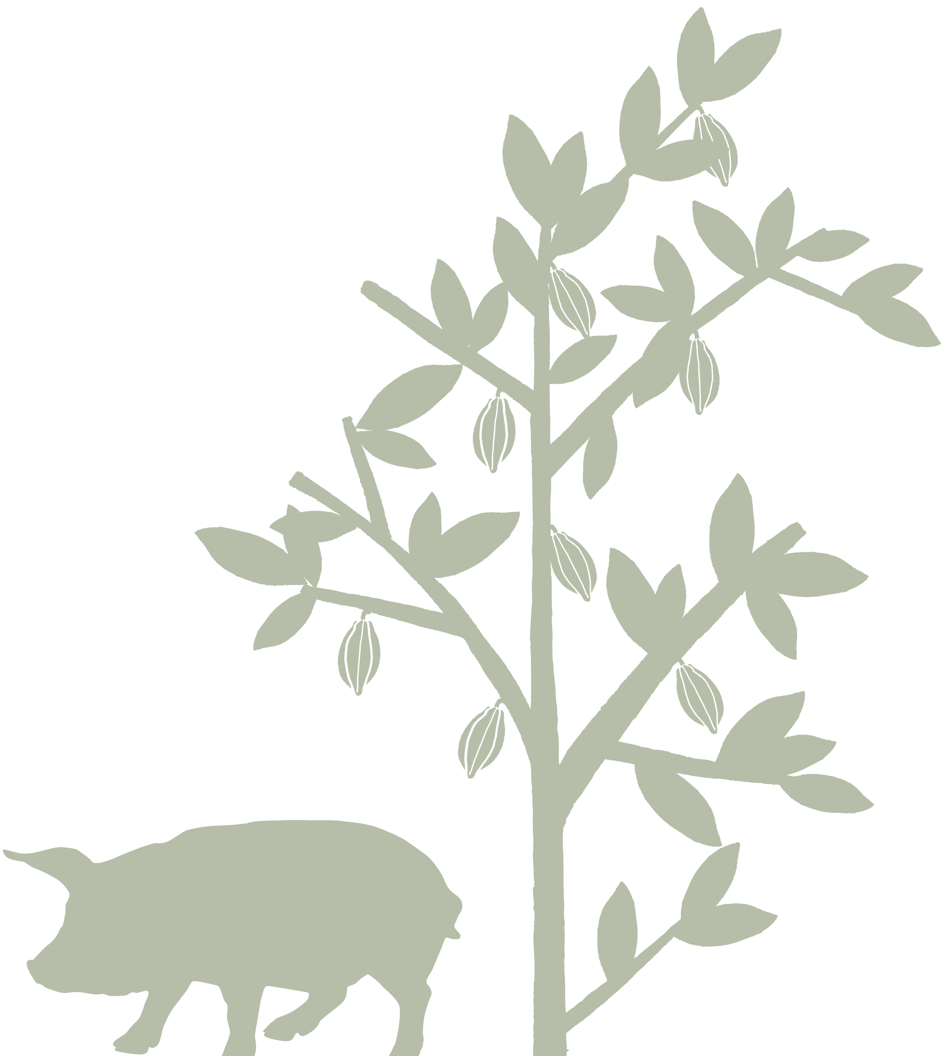
2020 Report of the FABLE Consortium

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



Sweden

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This chapter of the 2020 Report of the FABLE Consortium *Pathways to Sustainable Land-Use and Food Systems* outlines how sustainable food and land-use systems can contribute to raising climate ambition, aligning climate mitigation and biodiversity protection policies, and achieving other sustainable development priorities in Sweden. It presents three pathways for food and land-use systems for the period 2020-2050: Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition (referred to as "Current Trends", "Sustainable", and "Sustainable +" in all figures throughout this chapter). These pathways represent the low, medium and higher bounds of realistic pathways to achieve sustainability in food and land-use systems at the national level. They examine the trade-offs between achieving the FABLE targets under limited land availability and constraints to balance supply and demand at national and global levels. We developed these pathways in consultation with national stakeholders, including representatives from farmers' unions, producers, retailers, government agencies, and environmental organizations, and modeled them with the FABLE Calculator (Mosnier, Penescu, Thomson, and Perez-Guzman, 2019). See Annex 1 for more details on the adaptation of the model to the national context.

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 Sweden's Nationally Determined Contribution (NDC) treat the FABLE domains. According to the NDC, Sweden has committed to reducing its GHG emissions by 40% by 2030 compared to 1990. This includes emission reduction efforts from energy, industrial processes, agriculture, forestry, and other land use. Envisaged mitigation measures from agriculture and land-use change include food productivity improvement and dietary change towards low-carbon foods, adoption of regenerative agricultural practices such as conservation tillage, utilization of low carbon energy sources, afforestation, and expansion of protected forest areas. Under its current commitments to the UNFCCC, Sweden 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

	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					
(EU) NDC (2016)	1990	n/a	2030	At least 40% reduction	Energy, industrial processes, agriculture, land-use change and forestry, and waste	Y	N	N	Forests

Note. "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)
Source: EU (2016)

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 2011, 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 are however less restrictive in quantifying the targets, especially in reducing the deforestation target.

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

NBSAP Target	FABLE Target
The milestone target on environmental consideration in forestry is that by 2015 the expectations of society on environmental considerations in forestry are clarified and known to the forestry industry so that they can be applied in practice.	**DEFORESTATION:** Zero net deforestation from 2030 onwards
The milestone target on varied forestry is that provisions have been clarified so that by 2015 there are good conditions for varied forestry.	**DEFORESTATION:** Zero net deforestation from 2030 onwards
The milestone target on the protection of land areas, freshwater areas and marine areas is that at least 20 per cent of Sweden's land and freshwater areas, and 10 per cent of Sweden's marine areas, by 2020 contribute to achieving national and international biodiversity targets.	**BIODIVERSITY:** At least 30% of the global terrestrial area protected by 2030

Brief Description of National Pathways

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

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by medium population growth from 10.1 million in 2020 to 12.4 million in 2050, limited constraints on agricultural expansion, no afforestation target, no change in the extent of protected areas, low productivity increases in the agricultural sector, no change in diets and a minimum (10%) reduction in food waste and post-harvest losses (see Annex 2). This corresponds to a future based on current policy and historical trends that would also see considerable progress with regards to food self-sufficiency envisioned in the national food policy by improving productivity and competitiveness of the agri-food sector (MoEI, 2017). 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 wheat, barley, oats, potato, sugar beet, peas, beans, apple, tomato, and onion (see Annex 2).

Our Sustainable Medium Ambition Pathway represents a future in which significant efforts are made to adopt sustainable policies and practices and corresponds to an intermediate boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would lead to a higher consumption of plant-based foods such as cereals, pulses and nuts, improvement in agriculture productivity and expansions of forest lands and protected areas, but a lower intake of red meat such as beef, pork and lamb, and reduction of food waste and post-harvest losses (see Annex 2). This corresponds to a future based on the conscious choice of healthy foods and the practice of low carbon agriculture that would also see considerable progress with regards to competitiveness and sustainability of the agricultural sector by adopting innovative technologies and ensuring a high level of environmental and animal welfare standards (OECD, 2018). With the other FABLE country teams, we embed this Sustainable Medium Ambition Pathway in a global GHG concentration trajectory that would lead to a lower radiative forcing level of 2.6 W/m2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

Our Sustainable High Ambition Pathway represents a future in which cropland use declines through the reduction in food waste and post-harvest losses (50%) and improvement in crop productivity. This pathway assumes an expansion of forest lands by 250,000 ha by 2050, even though the country has no commitments in this regard in national and international committees, e.g. the Bonn Challenge. For protecting the space for nature as in Baillie & Zhang (2018), this high ambition pathway explores the possible enlargement of the protected area network to 30% ecoregion coverage by 2030. This pathway thus corresponds to the highest boundary of feasible action. Compared to the Sustainable Medium Ambition Pathway, we assume that this future would lead to a further increase in areas of forest lands and protected areas and even more reduction in food waste and post-harvest losses (see Annex 2). As in the Sustainable Medium Ambition Pathway, we embed this Sustainable High Ambition Pathway in a global GHG concentration trajectory that would lead to a lower radiative forcing level of 2.6 W/m2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

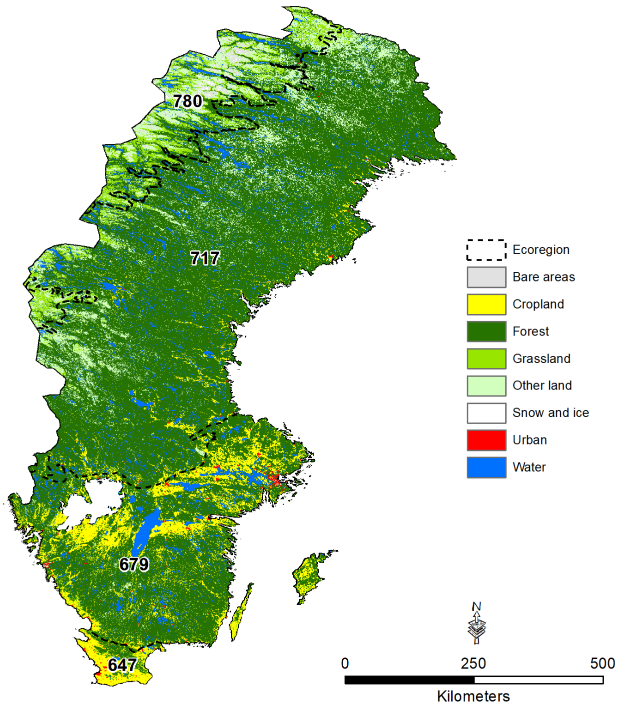
Land and Biodiversity

Current State

In 2010, Sweden was covered by 6.5% cropland, 1.1% grassland, 66.8% forest, 0.5% urban and 25.1% other natural land. Most of the agricultural area is in southern Sweden, while forest and other natural land are mainly concentrated in the northern part of the country (Map 1). In Sweden, abandonment of farmland and pastoral systems, intensified forestry and eutrophication are the major threats to the terrestrial and wetland biodiversity (MoE, 2014). Thus, the Swedish government has prioritized the restoration of forests and wetlands with high nature value to enhance connectivity and integration of protected areas into the landscape (OECD, 2018).

We estimate that land where natural processes predominate[2] accounted for 62% of Sweden's terrestrial land area in 2010 (Map 2). The 780-Scandinavian Montane Birch forest and grassland holds the greatest share of land where natural processes predominate, followed by 717-Scandinavian and Russian taiga and 679-Sarmatic mixed forest (Table 3). Across the country, while 6,3 Mha of land is under formal protection, falling short of the 30% zero-draft CBD post-2020 target, only 19.9% of the land where natural processes predominate is formally protected. This indicates that the 647/679-Baltic and Sarmatic mixed forests are important for establishing the connectivity of protected areas across the country.

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

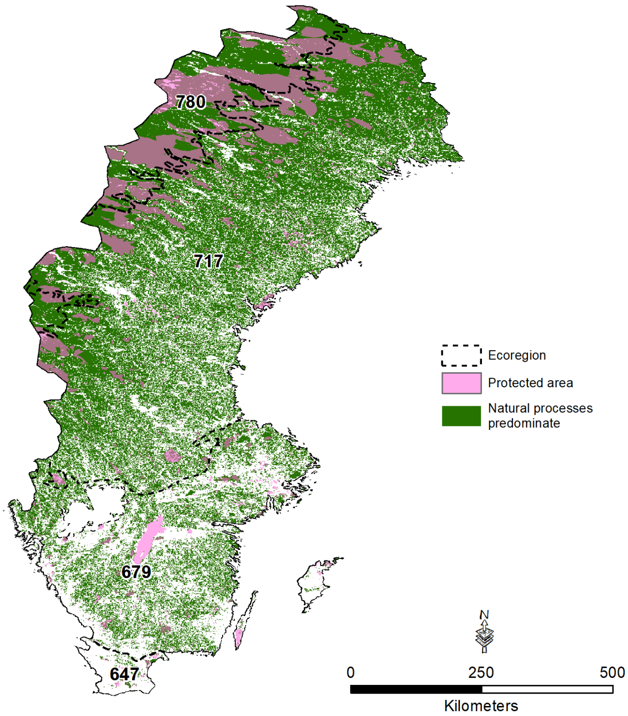


Notes. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3.
Sources. ccountries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)

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".

Approximately 47.2% of Sweden's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively biodiversity-friendly croplands are most widespread in 679-Sarmatic mixed forest, followed by 717-Scandinavian and Russian taiga and 647-Baltic mixed forests. The regional differences in the extent of biodiversity-friendly cropland can be explained by regional production intensity and urban development on farmland (Hallgren, 2015).

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



Notes. 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 (%)
647	Baltic mixed forests	864.5	7.4	11.1	28.6	71.4	489.0	22.0
679	Sarmatic mixed forests	11,984.0	6.3	36.3	7.5	92.5	2,527.9	47.9
717	Scandinavian and Russian taiga	2,5933.3	11.2	70.0	14.3	85.7	556.1	65.5
780	Scandinavian Montane Birch forest and grasslands	5,030.9	50.2	93.1	51.2	48.8	10.4	97.1

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.

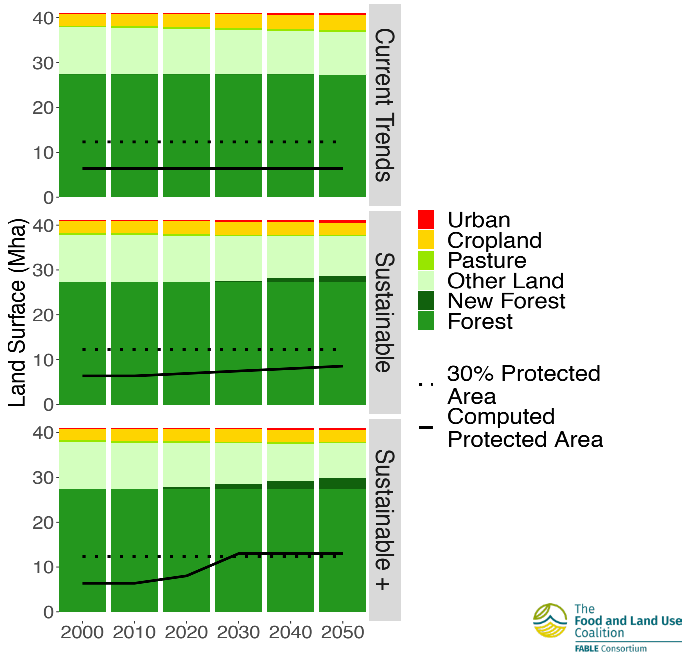
Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions, including no constraints on land conversion beyond protected areas, no planned afforestation or reforestation, and protected areas remain at 6.4 Mha, representing 11% of total land cover (see Annex 2).

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result from an increase of cropland, pasture and urban area and a decrease in other land areas. This trend evolves over the period 2030-2050: cropland, pasture and the urban area further increase and other land areas further decrease (Figure 1). The expansion of the planted area for barley, wheat and oats explains 75% of total cropland expansion between 2010 and 2030. For barley, 32% of the expansion is explained by an increase in exports and demand for animal feed. For wheat, 31% of the expansion is due to an increase in internal demand for food and animal feed. Finally, for oats, 11% results from an increase in demands for feed and exports. Pasture expansion is mainly driven by the increase in internal food consumption of milk and beef while livestock productivity per head and ruminant density per hectare of pasture remain constant over the period 2020-2030. Between 2030-2050, cropland expansion is explained by an increase in demands of cereal grains, particularly barley, oats and wheat in export and domestic feed markets, and an increase in domestic consumption of wheat and sugar beet. This results in a reduction of land where natural processes predominate by 5% by 2030 and by 10% by 2050 compared to 2010, respectively.

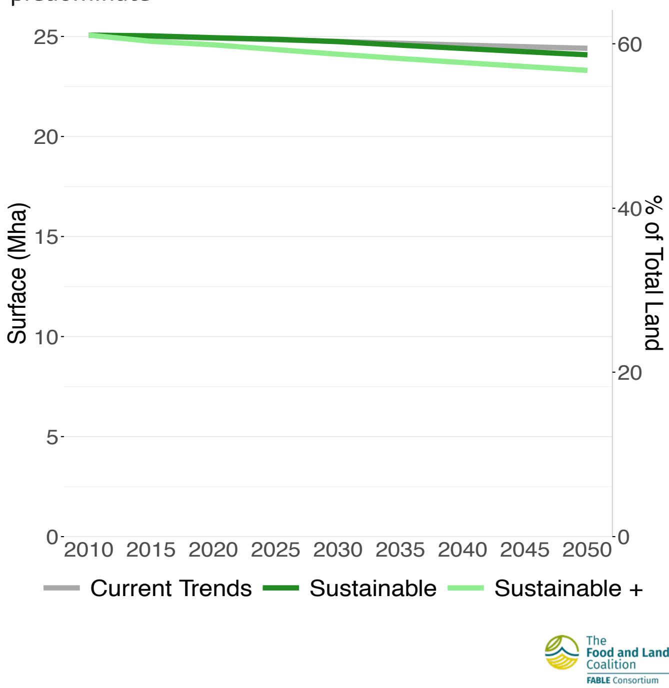
In the Sustainable Medium Ambition and Sustainable High Ambition Pathways, assumptions on protected areas have been changed to reflect a better management of protected areas and the creation of additional

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



Source. Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000, and the World Database on Protected Areas (UNEP-WCMC & IUCN, 2020) for protected areas for years 2000, 2005 and 2010.

Figure 2 | Evolution of the area where natural processes predominate



areas unavailable for agricultural expansion. The main assumptions include protected areas increase from 11% of the total land in 2010 to 30% in 2030 (cf. Annex 2).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Sweden in the Sustainable Medium Ambition and Sustainable High Ambition Pathways: (i) a reduction in cropland, (ii) an increase in the expansion of urban cities, and (iii) an increase in protected areas and forest land. In addition to the changes in assumptions regarding land-use planning, these changes compared to the Current Trends Pathway are explained by a decrease in the production of barley and wheat due to lower demand in the export market and high reduction in demand for animal products internally and globally. In the Sustainable Medium Ambition and Sustainable High Ambition Pathways, the area predominated by natural processes is decreased by 2-4% between 2025 and 2050, due to expansion of protected forest areas in shrubland and intact areas of sparse vegetation and trees (Figure 2).

GHG emissions from AFOLU

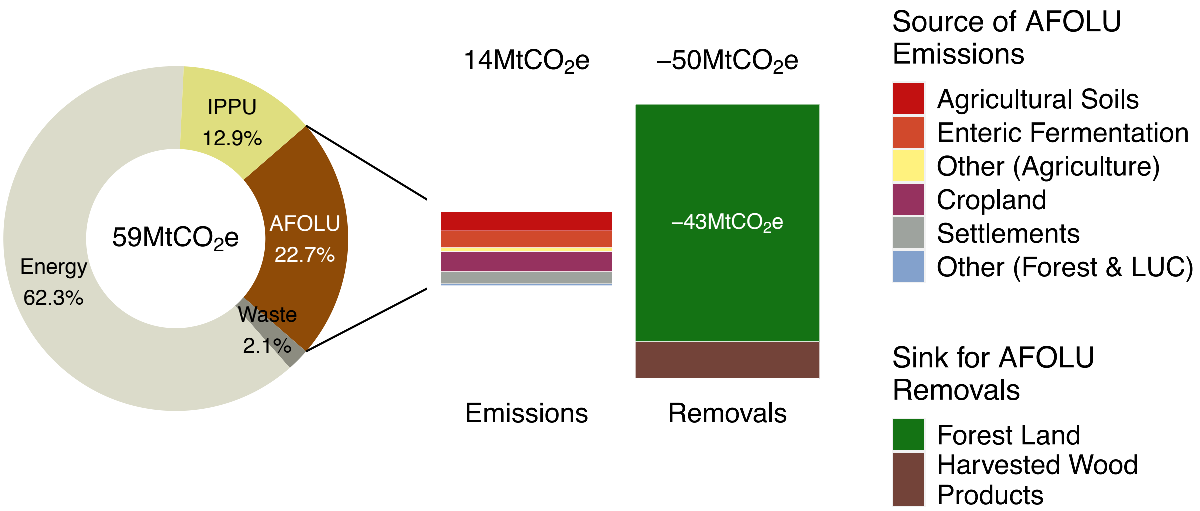
Current State

Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 22.7% of total emissions in 2010 (Figure 3). Cropland is the principal source of AFOLU emissions, followed by agricultural soils, enteric fermentation, and settlements. This can be explained by increasing consumption of red meat and dairy products, expansion of farmland on drained peatlands and urban development on farmlands (Hallgren, 2015; Jordbruksverket, 2014).

Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU rise to 8.3 $MtCO_2e$/yr in 2030, before reaching 9 $MtCO_2e$/yr in 2050 due to an increase in the production of grains and oilseed crops such as barley, wheat, oats, rye and rapeseed (Figure 4). In 2050, the livestock sector is the largest source of emissions (4.5 $MtCO_2e$/yr) while biofuel acts as a sink (-0.5 $MtCO_2e$/yr). Over the period 2020-2050, the strongest relative increase in GHG emissions is computed for the agriculture sector (27%), while a reduction is computed for land-use change in other lands such as shrubland and other vegetation (2.1%).

Figure 3 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2010



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

In comparison, the Sustainable Medium Ambition Pathway leads to a reduction of AFOLU GHG emissions by 71% and the Sustainable High Ambition Pathway to a reduction by 110% by 2050 compared to Current Trends Pathway (Figure 4). The potential emissions reductions under the Sustainable Medium Ambition Pathway is dominated by a reduction in GHG emissions from land-use change and livestock sectors (Figure 5). The most important drivers of this reduction are dietary shifts towards plant-based foods, an increase in livestock productivity, a decrease in exports of agricultural commodities, increased afforestation and, an expansion of protected forest areas. Under the Sustainable High Ambition Pathway, GHG emissions from land-use change are further reduced thanks to higher levels of afforestation and of expansion of protected areas.

Compared to Sweden's commitments under the UNFCCC (Table 1), our results show that AFOLU could contribute by as much as 12% of the country's total GHG emissions reduction objective by 2030. Such reductions could be achieved through dietary changes to low-carbon foods, agricultural productivity improvement, afforestation, and the expansion of protected forest areas. These measures could be particularly important in contributing to full-fill the GHG mitigation target in the NDC (see Table 1), and to achieve the national climate targets of zero net GHG emissions by 2045, and thereafter negative emissions.

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

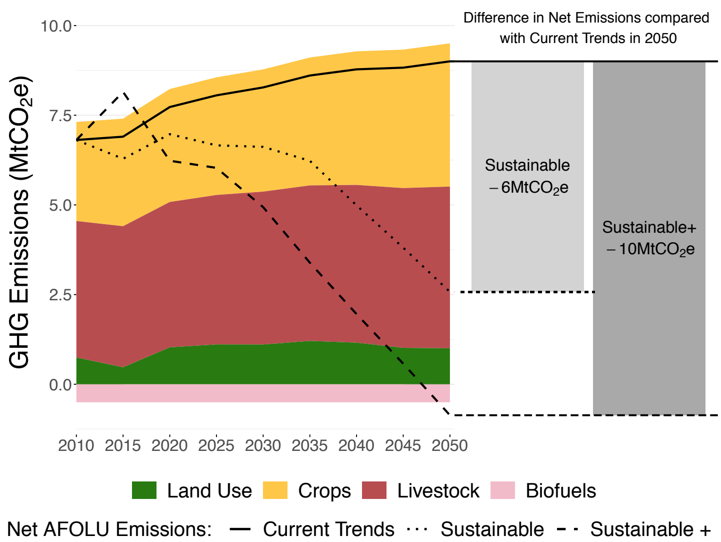
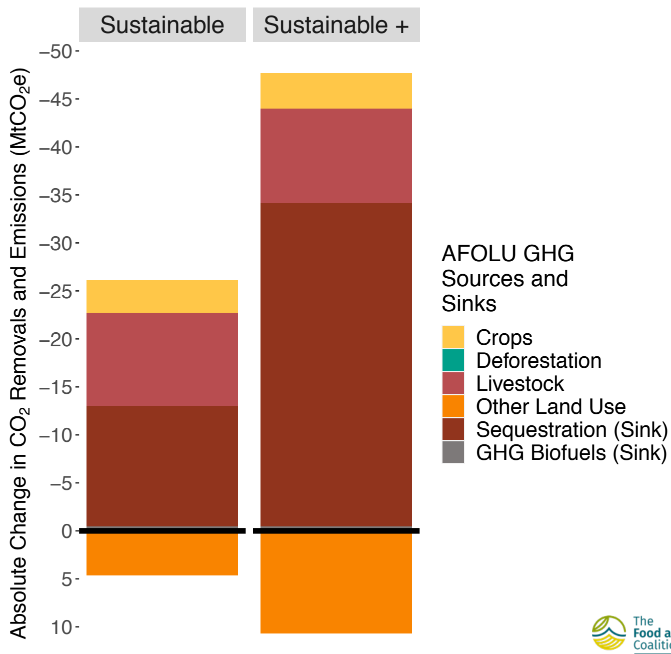


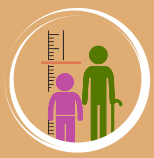
Figure 5 | Cumulated GHG emissions reduction computed over 2020-2050 by AFOLU GHG emissions and sequestration source compared to the Current Trends Pathway



Food Security

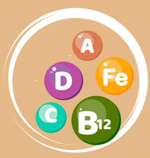
Current State

The "Triple Burden" of Malnutrition



Undernutrition

2.5% of the population were undernourished in 2016. This share has been constant since 2000 (FAO, 2020).



Micronutrient Deficiency

15.4% of women suffered from anemia in 2016, which can lead to maternal death (FAO, 2020).

5.2% of the population is deficient in vitamin A, which can notably lead to blindness and child mortality, and 1.2% were deficient in iodine, which can lead to developmental abnormalities (IHME, 2017).

Overweight/ Obesity

11.4% of the population and 18.3% of adults and 4.4% of children were obese in 2015.

28.7% of the population, and 39.3% of adults and 18.1% of children, were overweight in 2015. These shares have increased since 1990 (IHME, 2017).

Disease Burden due to Dietary Risks

14.9% of deaths were attributable to dietary risks, or 137.3 deaths per year (per 100,000 people) in 2017.

4.2% of the population suffers from diabetes and 18.6% from cardiovascular diseases, which can be attributable to dietary risks (IHME, 2017).

Table 4 | Daily average fats, proteins, and kilocalories intake under the Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition Pathways in 2030 and 2050

	2010	2030			2050		
	Historical Diet (FAO)	Current Trends	Sustainable Medium Ambition	Sustainable High Ambition	Current Trends	Sustainable Medium Ambition	Sustainable High Ambition
Kilocalories (MDER)	2,752 (2,091)	2,734 (2,081)	2,795 (2,081)	2,795 (2,081)	2,734 (2,079)	2,858 (2,079)	2,858 (2,079)
Fats (g) (recommended range)	116 (61-92)	116 (61-91)	112 (62-93)	112 (69-93)	116 (61-91)	109 (64-95)	109 (64-95)
Proteins (g) (recommended range)	96 (69-241)	94 (68-239)	88 (70-245)	88 (70-245)	94 (68-239)	81 (71-250)	81 (71-250)

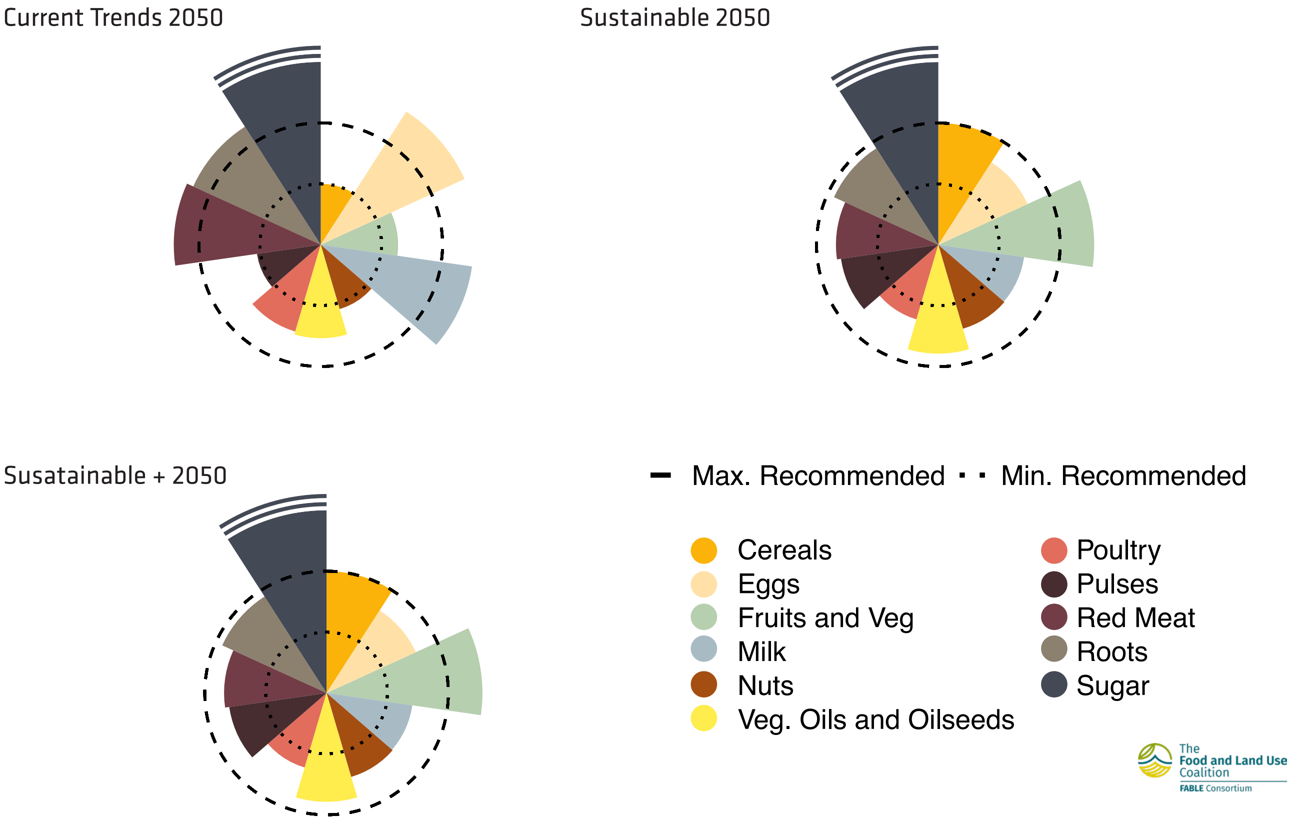
Notes. Minimum Dietary Energy Requirement (MDER) is computed as a weighted average of energy requirement per sex, age class, and activity level (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015) and the popula-tion projections by sex and age class (UN DESA, 2017) 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, the computed average calorie intake is 31% higher in 2030 and 2050 (Table 4). The current average intake is mostly satisfied by cereals, dairy, oilseed products, added sugar and red meat (pork and beef), representing 25%, 16%, 16%, 15% and 11% of the total calorie intake, respectively. The consumption of fruits, vegetables, pulses and nuts on aggregate represents less than 10% of the total calorie intake. Under the Current Trends Pathway, we assume that the consumption of food diets will remain stable between 2010 and 2050. Compared to the EAT-*Lancet* recommendations (Willett et al., 2019), red meat, sugar, eggs, fish and milk are over-consumed while cereals, nuts and pulses are consumed in the lower part of the recommended range in 2050 (Figure 6). Fat intake per capita exceeds the dietary reference intake (DRI) in 2030 and 2050, while protein intake per capita is sufficient to meet the minimum recommendations. This can be explained by excess consumption of animal products such as milk, eggs and red meat, and added sugar, but a lower intake of plant-based foods such as cereal grains, fruits, vegetables, pulses and nuts (Figure 6).

Under the Sustainable Medium Ambition Pathways, we assume that diets will transition towards plant-based foods, with increased consumption of cereals and pulses, but decreases consumption of red meat. Similar assumptions are made under the Sustainable High Ambition Pathway. The ratio of the computed average intake over the MDER increases to 34% in 2030 and 37% in 2050 under the Sustainable Medium and High Ambition Pathways. Compared to the EAT-Lancet recommendations, the consumption of cereals, sugars, fruits and vegetables remains outside of the recommended range with the consumption of red meat, starchy roots, eggs, milk and fish being now within the recommended range (Figure 6). Moreover, the fat intake per capita exceeds the dietary reference intake (DRI) in 2030 and 2050, showing some improvement compared to the Current Trends Pathway. The protein intake per capita hardly meets the lower bound of the recommended range (Table 4). An increase in consumption of pulses, nuts and poultry may improve the protein intake.

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



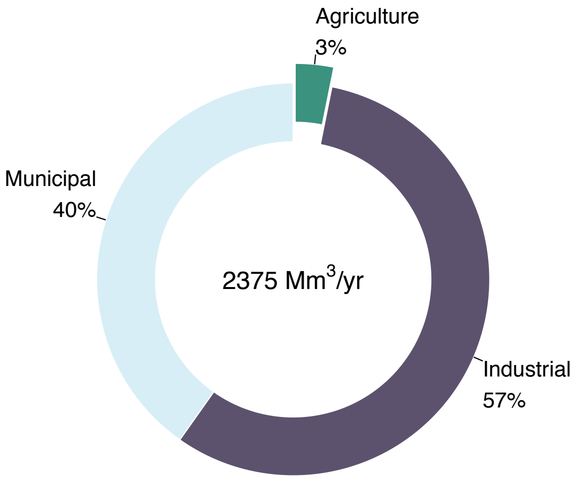
Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings) i.e. different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended 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.

Water

Current State

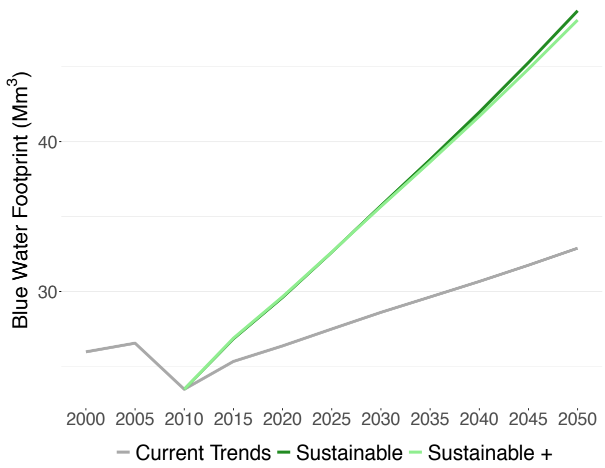
Sweden is characterized by the cool temperate climate with 624 mm average annual precipitation that mostly occurs over the period June - August. The agricultural sector represented 3% of total water withdrawals in 2010 (Figure 7). In 2016, 2% of agricultural land was equipped for irrigation, representing 34% of estimated-irrigation potential (Jordbruksverket, 2018). The three most important irrigated crops - potato, sugar beet and cereals, account for 89% of the total harvested irrigated area. These crops are the most traded crops in Sweden. In 2016, about 30% of cereals, 8% of sugar beet, and 3% of potato were exported (Chatham House, 2018). About 70-80% of their acreages are irrigated in Sweden (Jordbruksverket, 2018).

Figure 7 | Water withdrawals by sector in 2010



Source. Adapted from AQUASTAT Database (FAO, 2017)

Figure 8 | Evolution of blue water footprint in the Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition 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 & 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.

Pathways and Results

Under the Current Trends Pathway, annual blue water use decreases between 2000-2010 (26 and 23.5 Mm^3/yr), before reaching 28.6 Mm^3/yr and 32.9 Mm^3/yr in 2030 and 2050, respectively (Figure 8), with vegetables, sugar beet and potato accounting for 39%, 31% and 29% of computed blue water use for agriculture by 2050[4]. In contrast, under the Sustainable Medium Ambition Pathway, the blue water footprint in agriculture reaches 35.7 Mm^3/yr in 2030 and 48.7 Mm^3/yr in 2050, respectively. Under the Sustainable High Ambition Pathway, the blue water footprint further decreases to 48.1 Mm^3/yr in 2050. This is primarily explained by the impact of climate change over time (Annex 2) that influences the crop productivity and consumption of irrigation water. Under the Sustainable Pathways, the supply of irrigation water increases, due to sustainable intensification scenarios for crop and livestock productions (see Annex 2). This scenario assumes to increase crop yields by closing the yield gaps between the current and potential yields, which may require increased use of irrigation water without significant environmental drawbacks. However, the footprint of greywater would remarkably decrease under the Sustainable Pathways with a reduced production of animal products, mostly milk and pork in Sweden. As the droughts are projected to occur more frequently and severely in Northern Scandinavia (Spinoni, Vogt, Naumann, Barbosa, & Dosio, 2018), we could expect more requirements of irrigation water, particularly in arid and drought-stricken regions to close the potential yield gaps under the Sustainable Pathways.

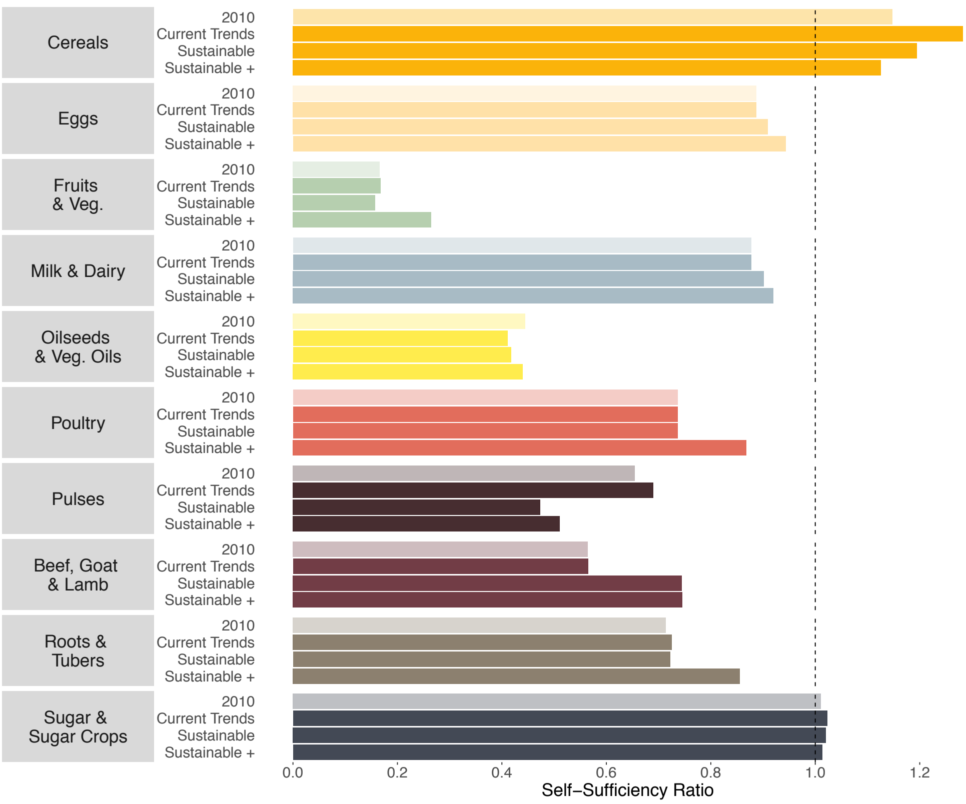
Resilience of the Food and Land-Use System

The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Sweden'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

About half of the Swedish food consumption is domestically produced, by which we can infer the degree of self-sufficiency to about 55-60% (Eriksson et al., 2016). In the national food strategy, the Swedish government has stressed for the improvement in food self-sufficiency through an increase in domestic food production (MoEI, 2017). However, strict environmental indicators and animal welfare can increase the cost of local production. In 2012, Sweden was self-sufficient in the supply of dairy, potatoes, sugar beet and cereal grains, particularly oats, wheat, barley and rye, but heavily reliant on imports of red meat (beef and pork), fish and seafood, and animal feed (Eriksson et al., 2016; McNitt, 1987).

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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FABLE Consortium

Under the Current Trends Pathway, we project that Sweden would be self-sufficient in cereals and sugar crops such as sugar beet in 2050, with self-sufficiency by product group remaining stable for the majority of products from 2010 – 2050 (Figure 9). The product groups which the country depends the most on imports to satisfy internal consumption are fruits and vegetables, oilseeds and vegetable oils, and red meat (beef, goat and lamb) and this dependency will remain stable until 2050. Under the Sustainable Medium Ambition Pathway, the self-sufficiency has been relatively improved for red meat by 2050. Similar results have been found for fruits and vegetables, poultry meat and starchy roots and tubers under the Sustainable High Ambition Pathway, as can be seen in the vertical bars of these food commodities that approach the horizontal dotted line for 2050 (Figure 9). This is explained by changes in crop productivity and food diets.

Diversity

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

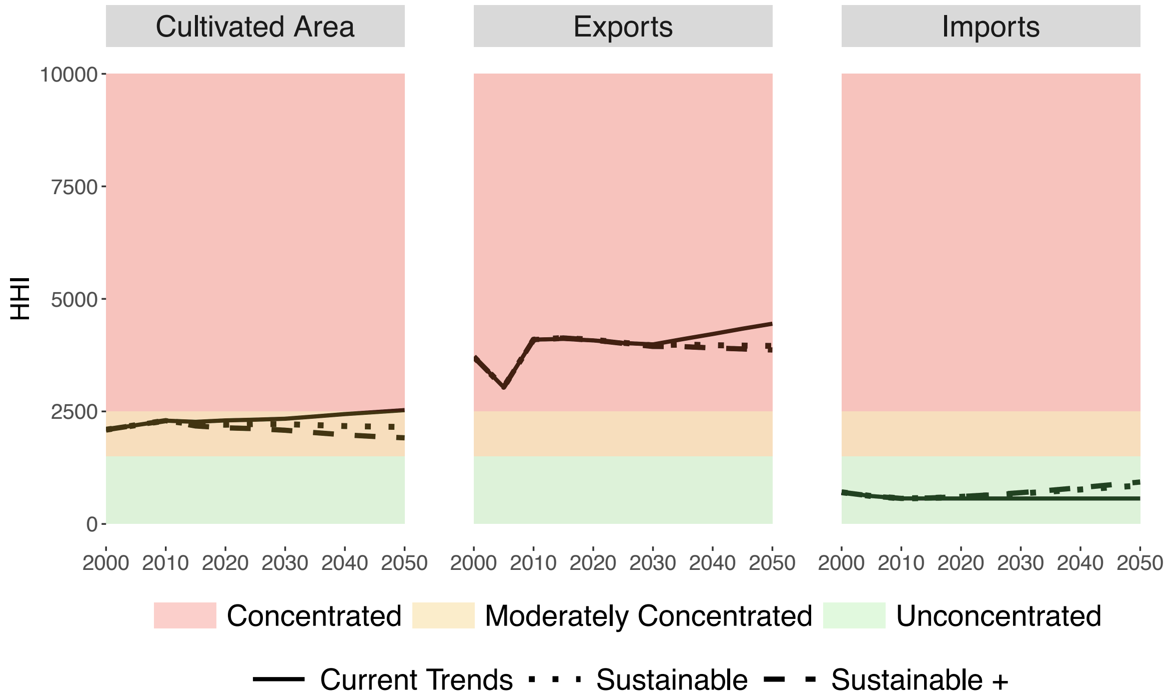
- ❑ **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- ❑ **Exports and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

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

In 2010, the diversification of crop species, as shown by the HHI of planted area in Figure 10, was moderately concentrated on few major crops such as potato, barley, wheat, oats, rye and sugar beet. A similar trend was observed on the exports of crops, which was concentrated on a few crop products. However, the imports of food commodities were unconcentrated in the same year. This indicates that in 2010 a wide range of Swedish food items relied on the import market.

Under the Current Trends Pathway, we project a high concentration of crop exports and planted areas in 2050. The trends have constantly increased over the period 2010 - 2050. This indicates low levels of diversity across the national production system and exports. In contrast, under the Sustainable Medium and High Ambition Pathways, we project relatively low concentration of crop exports, and medium concentration in the range of crops planted in 2050, indicating moderate levels of diversity across the national production system. The crop exports are highly concentrated, but the level of diversity is high for crop imports across three pathways (Figure 10). This is largely explained by the transformation of meat-based to plant-based diets.

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

In Sweden, we find two main drivers of unsustainable food and land-use systems. First, food is generally overconsumed and the dietary mix is moderately unhealthy and dominated by red meat, added sugar and animal fats. There is also a substantial food loss and waste challenge. Additionally, the increasing intensification of agricultural activities is primarily responsible for the ongoing loss of natural vegetation and ecosystems. This has led to an enormous impact on the environment, including biodiversity loss and overuse of natural ecosystem services in many places through eutrophication and land-use change.

To mitigate these environmental and health issues and increase local ecosystem resilience, we investigated the potential of alternative sustainable pathways within various country-specific determining factors, including future estimated economic and population growth, alternative diets with more healthy food, sustainable agricultural productivity to achieve national and international climate and environmental policies, as well as biodiversity conservation. Next to the Current Trends Pathway, two alternative variants of Sustainable Pathways are defined with medium and high levels of ambition in achieving sustainable indicators. These pathways aim at bringing a dietary shift from the current red meat-based diet towards more plant-based foods. Additionally, the sustainable high ambition pathway considers an increase of protected forest areas to 30% of terrestrial land by 2030 and halving of the food waste from the current level by 2050. Moreover, a socio-economic conversion to the high ambition pathway would make it possible to achieve the zero net-emission target by 2050.

The results show that a dietary change under the two Sustainable Pathways reduces the cur-rent trend of unhealthy diets and overconsumption of red meat, pork, milk and animal fats, while increasing the intake amount of grains, nuts, and pulses. The Swedish diet under the Sus-tainable Pathways shows that, compared to the EAT-Lancet recommendations (Willett et al., 2019), the consumption of cereals, fruits and vegetables, and sugars remains outside the recommended range.

Next to the dietary changes for public health, a transformative change in the management of ecosystem services to achieve the proposed Sustainable Pathways also has implications on environmental sustainability. Cropland use and blue water consumption can markedly decrease under these Sustainable Pathways, mainly due to dietary changes, followed by an increase in agricultural productivity and improvement in water-use efficiency. Compared to the Current Trends, the Sustainable Pathways lead to a substantial reduction of GHG emissions by 2050, especially AFOLU emissions. Here, afforestation and expansion of protected areas are the most important drivers of this reduction. Additionally, self-sufficiency of commodities as fruits, vegetables, eggs, poultry meat and starchy roots are relatively improved. However, these pathways still require an increase in local production to close yield gaps. Currently, Swedish consumption relies on high imports of grains, pulses, nuts, fruits and vegetables that would be diminished when implementing the Sustainable Pathways.

We hope that this present study can enable policymakers and stakeholders to understand the current trends and ambitious pathways for the transformative changes in dietary patterns, land-use change, and footprints of natural resources (cropland and blue water). Specifically, it could inform setting new national targets to fulfil signed national goals in international com-mitments such as the Paris Agreement, the CBD's Aichi targets or the national SDGs. On a global scale, the FABLE Scenathon measures various environmental indicators such as GHG emissions and evaluates the contribution of the Sustainable Pathways to the Paris Agreement goal of limiting the rise in global temperature below 2Ð above pre-industrial levels and the CBD's strategic plan for biodiversity.

Even though the FABLE Calculator covers many components of the food and land-use system for developing Sustainable Pathways, it still faces limitations for certain country-specific char-acteristics that cannot be covered adequately. For example, the Swedish Parliament has al-ready set goals to achieve 30% organic farmland and 60% organic food purchases in the public sector by 2030 as part of the national food policy (European Commission, 2019; Pekala, 2020). In this context, the Swedish team may further utilize the FABLE Calculator in analyzing the tri-lemma of organic farming, food security, and environment. Similarly, an alternative inclusion of insect-based feeds could be a more extreme, out-of-the-box scenario for reducing the Swe-dish dependency of chicken and bovine feed market on external imports of conventional soy meal. This alternative animal feed diet scenario cannot be implemented in the current scenario analysis, which could result in an increased food supply.

In the future, the present study could be further expanded to integrate risk due to uncertainty in the food supply chain, a topic of particular relevance with the ongoing outbreak of COVID-19. Such an assessment could help inform policymakers on the resilience of our food and land-use system and their ability to cope with extreme events. Finally, in future Scenathons, we will also aim to incorporate stakeholders' perspectives by working with them to co-develop a stakehold-er-specific pathway for a sustainable food and land-use system in Sweden.

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

Following changes are made in the FABLE Calculator to adapt it to the national context:

- A new food diet scenario is defined for a new plant-based diet. This diet assumes low consumption of red meat, but more intake of grains, pulses, vegetables, and fruits. This diet is defined based on the normative decisions made by stakeholders, including representatives from farmers' unions, producers, retailers, government agencies, and environmental organizations (Karlsson et al., 2017; Wood et al., 2019).
- Animal feed diets are re-calibrated to historical observations, based on the Swedish feed requirement data available at (Cederberg et al., 2009). In this process, new feed ingredients such as palm kernel and sunflower cake, vegetable oil, potato, sugar beet and rye are also added.
- In the "customized import" scenario under the Sustainable Medium Ambition and Sustainable High Ambition Pathways, trends of food imports are customized for each product, based on their demands on study diets (e.g. sufficiency diet). In this process, we assumed a 20% reduction in import quantity if the commodities are consumed 20% less in the selected diet, in otherwise case a 50% reduction is imagined. A stable import is defined for the food items, which largely increase in the diet scenario (e.g. fruits and vegetables).
- A sustainable intensification scenario is defined to increase crop yields equivalent to 75-95% of their potentials, depending upon low-performing to highly productive areas (Clark, Hill, and Tillman, 2018). To execute this, we computed the additional productivity as business-as-usual plus 50% yield gaps of high growth scenario.
- A new scenario for the expansion of protected areas is defined to achieve the Aichi Biodiversity targets. The Sustainable Medium Ambition Pathway is defined for a target of achieving 17% protected areas of terrestrial land by 2030. An ambitious target of 30% protected areas by 2050 is assumed under the Sustainable High Ambition Pathway. These scenarios are implemented in the FABLE Calculator with a reference to Müller et al. (2020).
- The expansion of urban areas is calibrated as a function of GDP growth.

Annex 2. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
No change in current policies to influence demographics. 12.4 million population is projected by 2050. (SSP2 scenario selected)	Incentives to influence demographics in the direction which is supposed to improve the sustainability of the system. 12.8 million population is projected. (SSP1 scenario selected)	Same as Sustainable Medium Ambition Pathway

LAND Constraints on agricultural expansion		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
Free expansion of productive land under the total land boundary. No constraint on the expansion of the agricultural land outside beyond existing protected areas and under the total land boundary.	Free expansion of productive land under the total land boundary. No constraint on the expansion of agricultural land outside beyond existing protected areas and under the total land boundary.	Free expansion of productive land under the total land boundary. No constraint on the expansion of agricultural land outside beyond existing protected areas and under the total land boundary.
LAND Afforestation or reforestation target (1000 ha)		
No active afforestation / reforestation.	Medium level of afforestation to contribute to the Bonn Challenge. 100,000 ha areas will be forested by 2050.	High ambition of afforestation. 250,000 ha areas will be forested by 2050.

BIODIVERSITY Protected areas (1000 ha or % of total land)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
No expansion of protected areas beyond the current. Currently, Sweden has 11% protected areas of total terrestrial areas, including inland waters (Statistics Sweden, 2017).	Better management of protected areas and/or creation of additional protected areas. Protected areas are extended to 17% of terrestrial and inland water by 2030 and remain stable afterward.	Protected areas are extended to achieve an ambitious target of 30% of terrestrial land by 2030. These additional areas are protected to make them unavailable for agricultural expansion (Müller et al., 2020).

Sweden

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

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
Medium pace of technological change in agriculture. Yield growth mainly due to an increase in input use. The current business-as-usual (BAU) trend of productivity growth is assumed. By 2050, productivity of major crops increases as below, while that for other crops remains the same: • 4.2 t/ha for barley. • 31.7 t/ha for potato. • 66.2 t/ha for sugar beet. • 2.2 t/ha for rapeseed. • 4.9 t/ha for wheat. • 26.2 t/ha for vegetables. Source: Authors' calculation based on FAO statistics.	Crop yields improve more moderately, equivalent to 75-95% of their potentials, depending on low-performing to highly productive areas (Clark et al., 2018). By 2050, productivity of major crops increases as below, while that for other crops remains the same: • 4.3 t/ha for Barley. • 32.5 t/ha for potato. • 66.4 t/ha for sugar beet. • 2.8 t/ha for rapeseed. • 5.3 t/ha for wheat. • 31.5 t/ha for vegetables. Source: Authors' calculation based on assumptions of productivity growths.	Same as Sustainable Medium Ambition Pathway
PRODUCTION Livestock productivity for the key livestock products in the country (in t/head of animal unit)		
Animal productivity growth mostly concentrated in pig and poultry sectors driven by structural change towards industrial livestock production. The current trend growth is assumed (BAU growth). By 2050, livestock productivity reaches: • 90 kg/head for beef. • 28 kg/head for chicken. • 60 kg/head for eggs. • 7.3 t/head for milk. • 250 kg/head for pork. Source: Authors' calculation based on FAO statistics.	Animal productivity growth is driven by structural change in industrial livestock production. High productivity growth is favored for the low-GHG production system. By 2050, livestock productivity reaches: • 90 kg/head for beef. • 33 kg/head for chicken. • 73 kg/head for eggs. • 9.6 t/head for milk. • 300 kg/head for pork. Source: Authors' calculation based on productivity growth assumptions by 10-25% for mutton, beef and milk, 50% for egg and 85-100% for chicken and pork by 2050.	Same as Sustainable Medium Ambition Pathway
PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)		
No change in the management of the permanent pasture area. Average ruminant livestock stocking density is 3.49 livestock units/ha pasture land. Based on FAO (2020).	Same as Current Trends Pathway	Same as Current Trends Pathway
PRODUCTION Post-harvest losses		
No change in the current scenario of post-harvest losses. Constant share of supply available lost during storage and transportation after 2010 (up to 8% post-harvest losses for fruits and vegetables). Source: authors' calculation.	Medium reduction of post-harvest losses reduced by 30% based on dry matter production of modeled products in 2010. Based on FOLU (2019)	High reduction of post-harvest losses halved by 2050 compared to BAU. Regulatory frameworks, R&D, and investment for improved storage and processing. Based on FAO (2018)

TRADE Share of consumption which is imported for key imported products (%)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
No policy changes, imports may increase up to 30% of the 2010 levels by 2050 for major food commodities such as cereal grains, fruits, vegetables, red meat (pork and beef) and dairy products. For production feasible commodities, the import shares of total consumption reduce: • Up to 25 % by 2050 for pork, milk, chicken, eggs, potato, and other cereals. • 36% by 2050 for rapeseeds. • 45 % by 2050 for beef. • 60-100% by 2050 for mutton, tropical fruits, vegetables, cereals, sunflower, soybeans. Source: Authors' calculation.	Reduction of trade barriers, reduced imports by up to 50% by 2050 if consumptions decrease in scenario diet. High demand for food commodities in the scenario diet is supplied by increased domestic production. For production feasible commodities, the import shares of total consumption reduce by: • Up to 25 % by 2050 for pork, milk, chicken, eggs, potato, other cereals, and rapeseeds. • 25 % by 2050 for beef and mutton. • 60-100 % by 2050 for tropical fruits, vegetables, cereals, and soybeans. Source: Authors' calculation.	Reduction of trade barriers, reduced imports by 50% by 2050 with increase domestic production. For production feasible commodities, the import shares of total consumption reduce by: • Up to 15 % by 2050 for pork, milk, chicken, eggs, potato, rapeseeds, and other cereals. • 25 % by 2050 for beef and mutton. • 35-45% by 2050 for apple, beans and other fruits and oilseeds. • 60-100 % by 2050 for tropical fruits, vegetables, cereals, and soybeans. Source: Authors' calculation.
TRADE Evolution of exports for key exported products (1000 tons)		
No major changes in trade policy, double exports by 2050 as follows: • 1275 k tons by 2050 for barley. • 283 k tons by 2050 for wheat. • 235 k tons by 2050 for oats. • 99 k tons by 2050 for rye. • 22 k tons by 2050 for peas. Source: Authors' calculation.	No major changes in trade policy, increase exports by 50% by 2050 as follows: • 728 k tons by 2050 for barley. • 173 k tons by 2050 for wheat. • 169 k tons by 2050 for oats. • 74 k tons by 2050 for rye. • 31 k tons by 2050 for peas. Source: Authors' calculation.	No changes in trade policy, stable exports by 2050 as follows: • 481 k tons by 2050 for barley. • 112 k tons by 2050 for wheat. • 115 k tons by 2050 for oats. • 50 k tons by 2050 for rye. • 31 k tons by 2050 for peas. Source: Authors' calculation.

FOOD Average dietary composition (daily kcal per commodity group or % of intake per commodity group)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
High levels of consumption and share of livestock products, sugar, and fat in the diet. Food demand directly linked to population growth unless no intervention is made (SSP2 scenario). The average daily calorie consumption/cap remains stable at 2752 kcal over the study period 2010-2050 and is: • 586 kcal for cereals. • 383 kcal for dairy milk. • 383 kcal for vegetable oils. • 357 kcal for added sugars. • 284 kcal for red meat (pork and beef). • 148 kcal for fruits and vegetables. • 122 kcal for fish and poultry. • 48 kcal for eggs. • 55 kcal for pulses and nuts. • 84 kcal for roots. • 148 kcal for animal fat. Based on FAO (2020)	More sustainable and healthy diets. Livestock products' share decreases with more consumption of plant-based foods such as cereal grains, fruits, vegetables, pulses, and nuts. By 2050, the average daily calorie consumption/cap reaches to 2858 kcal and is: • 711 kcal for cereals. • 108 kcal for dairy milk • 171 kcal for vegetable oils. • 23 kcal for added sugars. • 132 kcal for red meat (pork and beef). • 358 kcal for fruits and vegetables • 55 kcal for fish and poultry. • 19 kcal for eggs. • 432 kcal for pulses and nuts. • 57 kcal for roots. • 1 kcal for animal fat. Based on Karlsson et al. (2017)	Same as Sustainable Medium Ambition Pathway

Sweden

FOOD Share of food consumption which is wasted at household level (%)		
No change in the current scenario of food loss and waste, a business-as-usual (BAU) scenario. A slow reduction in food loss and waste, that is, 10% by 2050.	Regulatory frameworks, R&D and investment for improved storage and processing, and consumer awareness drastically reduce food loss and waste in 2050 by 25% of the share compared to the 2010 level (Searchinger et al., 2018).	Regulatory frameworks, R&D and investment for improved storage and processing, and consumer awareness drastically reduce food loss and waste in 2050 by 50% compared to the share in 2010 (Wood et al., 2019). However, a breakthrough in technology may be required for a 50% reduction in food loss and waste (Searchinger et al., 2018).

BIOFUELS Targets on biofuel and/or other bioenergy use

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
Medium technology development of renewables, first-generation biofuels maintained at current target levels. Assume a No Change (Stable biofuel demand as 2010).	OECD-AGLINK Scenario, moderate growth in the supply of biofuels from agriculture. By 2050, biofuel production accounts for: • 4109 kt of wheat production. • 4107 kt of corn production. • 12187 kt of sugar beet production. • 8854 kt of rapeseed production.	Same as Sustainable Medium Ambition Pathway

CLIMATE CHANGE Crop model and climate change scenario

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition 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.	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

kha – thousand hectares

km^2 – square kilometer

km^3 – cubic kilometers

kt – thousand tonnes

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

References

Baillie, J., & Zhang, Y. P. (2018). Space for nature. Science, 361(6407), 1051. https://doi.org/10.1126/science.aau1397

BirdLife International. (2019). Digital boundaries of Important Bird and Biodiversity Areas from the World Database of Key Biodiversity Areas. Retrieved February 8, 2019, from BirdLife International website: http://datazone.birdlife.org/site/requestgis

Cadena, M., Supples, C., Ervin, J., Marigo, M., Monakhova, M., Raine, P., & Virnig, A. (2019). *Nature is counting on us: Mapping progress to achieve the Aichi Biodiversity Targets.* United Nations Development Programme.

CBD. (2020). Sweden—National Targets. Retrieved May 8, 2020, from Convention on Biological Diversity website: https://www.cbd.int/countries/targets/?country=sw

Cederberg, C., Sonesson, U., Henriksson, M., Sund, V., & Davis, J. (2009). *Greenhouse gas emissions from Swedish production of meat, milk and eggs 1990 and 2005.* The Swedish Institute for Food and Biotechnology, SIK Report No 793, Gothenburg. Retrieved from http://www.diva-portal.org/smash/get/diva2:943352/FULLTEXT01.pdf

Chatham House. (2018). "resourcetrade.earth" [Database]. Retrieved from http://resourcetrade.earth/

Clark, M., Hill, J., & Tilman, D. (2018). The Diet, Health, and Environment Trilemma. *Annual Review of Environment and Resources, 43*(1), 109–134. https://doi.org/10.1146/annurev-environ-102017-025957

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., … Saleem, M. (2017). An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm. *Bioscience, 67*(6), 534–545. https://doi.org/10.1093/biosci/bix014

Eriksson, M., Pano, N., & Ghosh, R. (2016). *Food Chain Sustainability in Sweden* (Report No. 168). Department of Economics, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden. Retrieved from https://pub.epsilon.slu.se/13495/

ESA. (2017). *Land Cover CCI Product User Guide Version 2. Tech. Rep.* Retrieved from maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf

EU. (2016). *Intended Nationally Determined Contribution of the EU and its Member States.* https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Sweden%20First/EU%20First%20NDC.pdf

European Commission. (2019). *2019 SBA Fact Sheet - Sweden.* The Small Business Act for Europe (SBA), The European Commission Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW).

FAO. (2017). *AQUASTAT* [Database]. Retrieved from http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

FAO. (2018). *The future of food and agriculture - Alternative pathways to 2050.* Food and Agriculture Organization of the United Nations (FAO). Retrieved from http://www.fao.org/3/I8429EN/i8429en.pdf

FAO. (2020). *FAOSTAT* [Database]. Retrieved from http://www.fao.org/faostat/en/#home

FOLU. (2019). *Growing Better: Ten Critical Transitions to Transform Food and Land Use.* The Food and Land Use Coalition (FOLU). Retrieved from https://www.foodandlandusecoalition.org/global-report/

GADM. (2020). *Global Administrative Areas. Version 3.6.* Retrieved from https://gadm.org/data.html

Hallgren, J. (2015). *Farmland in municipal physical planning - A production perspective of farmland conversion.* Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden. Retrieved from https://stud.epsilon.slu.se/8471/1/hallgren_j_150909.pdf

Hattori, T. (2019). *IGES NDC Database v7.1.* Retrieved from https://www.iges.or.jp/en/pub/iges-indc-ndc-database/en

IHME. (2017). *GBD Compare.* Institute for Health Metrics and Evaluation (IHME), University of Washington. Retrieved from http://vizhub.healthdata.org/gbd-compare

Jacobson, A. P., Riggio, J., M. Tait, A., & E. M. Baillie, J. (2019). Global areas of low human impact ('Low Impact Areas') and fragmentation of the natural world. *Scientific Reports, 9*(1), 4179. https://doi.org/10.1038/s41598-019-50558-6

Jordbruksverket. (2014). *Utsläpp av växthusgaser från torvmark* [Greenhouse gas emissions from peatland]. Rapport 2014:24, Jordbruksverket. Retrieved from https://www2.jordbruksverket.se/download/18.64f2616c14acd372c5c4391c/1420810674894/ra14_24.pdf

Jordbruksverket. (2018). *Jordbrukets behov av vattenförsörjning* [Agricultural need of water supply]. Rapport 2018:18, Jordbruksverket. Retrieved from https://www2.jordbruksverket.se/download/18.6c309e13163f38127225024/1528806838383/ra18_18v2.pdf

Karlsson, J., Röös, E., Sjunnestrand, T., Pira, K., Larsson, M., Andersen, B. H., … Brubæk, S. (2017). *Future Nordic Diets: Exploring ways for sustainably feeding the Nordics.* Nordic Council of Ministers, Denmark. Retrieved from www.norden.org/nordpub

McNitt, H. A. (1987). Exporting U.S. *Food to Sweden, Norway and Finland.* Washington DC: International Economics Division, Economic Research Service, U.S. Department of Agriculture. Foreign Agricultural Economic Report No. 227.

Mekonnen, M.M. and Hoekstra, A.Y. (2010a). The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands. Retrieved from http://www.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf

Mekonnen, M.M. and Hoekstra, A.Y. (2010b). The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M.M. and Hoekstra, A.Y. (2011) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No. 50, UNESCO-IHE, Delft, the Netherlands.

MoE. (2014). *Fifth National Report to the Convention on biological diversity, Sweden.* Ministry of the Environment (MoE), The Swedish Government, Stockholm. Retrieved from https://doi.org/10.3366/edinburgh/9781845861193.003.0047

MoEI. (2017). *A National Food Strategy for Sweden - more jobs and sustainable growth throughout the country: short version of Government bill 2016/17:104.* Retrieved from https://www.government.se/498282/contentassets/16ef73aaa6f74faab86ade5ef239b659/livsmedelsstrategin_kortversion_eng.pdf

Mosnier, A., Penescu, L., Thomson, M., Perez-Guzman, K. (2019). Documentation of the FABLE Calculator: SDSN/IIASA. Retrieved from https://www.abstract-landscapes.com/fable-calculator

Müller, A., Schneider, U. A., & Jantke, K. (2020). Evaluating and expanding the European Union's protected-area network toward potential post-2020 coverage targets. *Conservation Biology, 34*(3), 654-665. https://doi.org/10.1111/cobi.13479

OECD. (2018). *Innovation, Agricultural Productivity and Sustainability in Sweden.* OECD Food and Agricultural Reviews, OECD Publishing, Paris. https://doi.org/10.1787/9789264085268-en

Pekala, A. (2020). *Market analysis of organic foods in the Nordic and Baltic countries.* The Nordic Council of Ministers. Retrieved from https://norden.diva-portal.org/smash/get/diva2:1386343/FULLTEXT01.pdf

Potapov, P., Hansen, M. C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., … Esipova, E. (2017). The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Science Advances, 3*(1). https://doi.org/10.1126/sciadv.1600821

Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., … Lawrence, D. (2019). Contribution of the land sector to a 1.5 °C world. Nature Climate Change, 9(11), 817–828. https://doi.org/10.1038/s41558-019-0591-9

Searchinger, T., Waite, R., Beringer, T., Forslund, A., Guyomard, H., Le Mouël, C., ... Marajo-Petitzon, E. (2018). *Creating a Sustainable Food Future. The World Resources Institute.* Retrieved from https://wrr-food.wri.org/

Spinoni, J., Vogt, J. V., Naumann, G., Barbosa, P., & Dosio, A. (2018). Will drought events become more frequent and severe in Europe? International Journal of Climatology, 38(4), 1718–1736. https://doi.org/10.1002/joc.5291

Statistics Sweden. (2017). *Protected Nature in Sweden.* Retrieved from www.scb.se

UN DESA. (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables* [Working Paper]. Retrieved from United Nations website: https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf

UNEP-WCMC, & IUCN. (2020). *Protected Planet: The World Database on Protected Areas (WDPA).* Retrieved from UNEP-WCMC and IUCN website: www.protectedplanet.net

UNFCCC. (2020). *Greenhouse Gas Inventory Data—Flexible Queries Annex I Parties* [Database]. Retrieved from https://di.unfccc.int/flex_annex1

U.S. Department of Health and Human Services and U.S. Department of Agriculture. (2015). *2015-2020 Dietary Guidelines for Americans, 8th Edition* (p. 144). Retrieved from U.S. Department of Health and Human Services website: http://health.gov/dietaryguidelines/2015/guidelines/

U. S. Department of Justice, & Federal Trade Commission. (2010). *Horizontal Merger Guidelines.* Retrieved from https://www.justice.gov/atr/horizontal-merger-guidelines-08192010#5c

Wanner, N., Cafiero, C., Troubat, N., & Conforti, P. (2014). Refinements to the FAO Methodology for estimating the Prevalence of Undernourishment Indicator. *ESS Working Paper No. 14-05.* Retrieved from http://www.fao.org/3/a-i4046e.pdf

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., Vries, W. D., Sibanda, L. M., ... Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet, 393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Wood, A., Gordon, L. J., Röös, E., Karlsson, J. O., Häyhä, T., Bignet, V., ... Bruckner, M. (2019). *Nordic food systems for improved health and sustainability: baseline assessment to inform transformation.* Stockholm Resilience Centre, Stockholm University. Retrieved from http://pure.iiasa.ac.at/id/eprint/16122/