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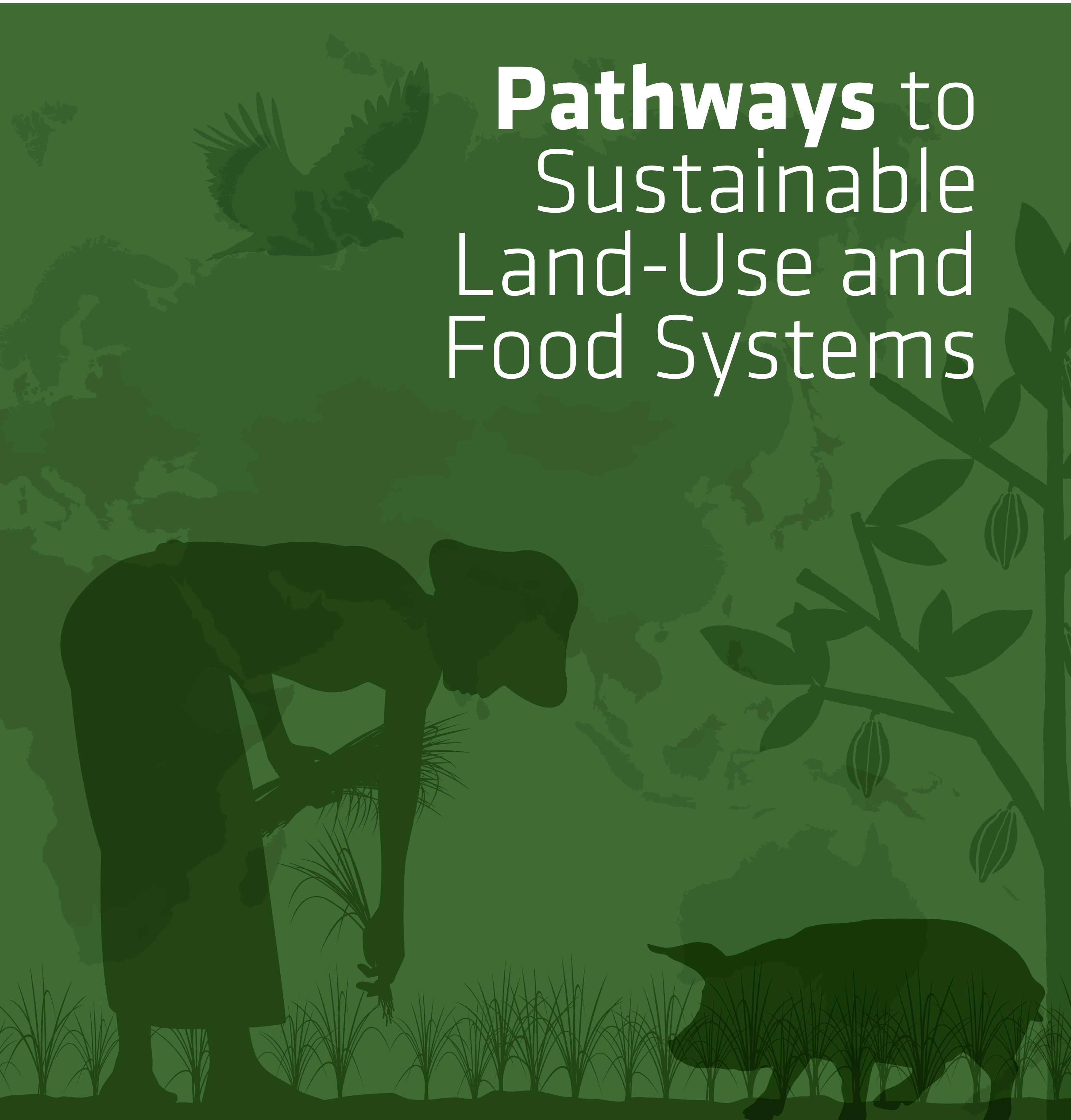
The Food and Land Use Coalition

2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems



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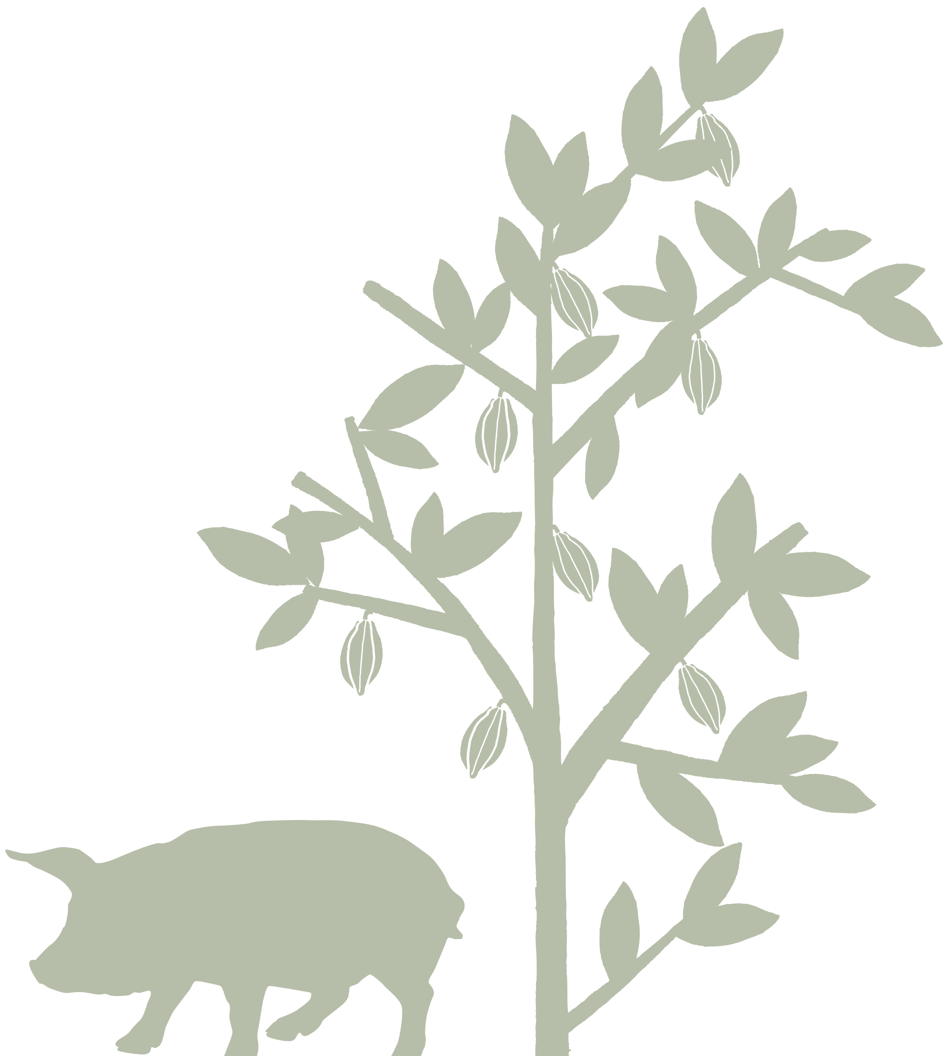
2020 Report of the FABLE Consortium

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



Germany

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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 Germany. 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 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 benefitting from consultations with national stakeholders and experts, including from the Chamber of Agriculture in Lower Saxony (Landwirtschaftskammer Niedersachsen), the Farmers' Association North East Lower Saxony (Bauernverband Nordostniedersachsen), the Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (Nds. Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz), the Lower Saxony Ministry of Food, Agriculture and Consumer Protection (Nds. Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz), the Lower Saxony Ministry for the Environment, Energy, Building, and Climate Protection (Nds. Ministerium für Umwelt, Energie, Bauen und Klimaschutz), Greenpeace Hamburg, and the German Federation for the Environment and Nature Conservation Lower Saxony (BUND Niedersachsen) as well as interviews with farmers in the context of the Integrative modeling lab on agricultural adaptation in North Germany (IMLAND), 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 the European Union's (EU) NDC, which applies to Germany, and Germany's Long Term Low Emissions and Development Strategy (LT-LEDS) address the FABLE domains. According to the LT-LEDS, Germany has committed to reducing its GHG emissions by at least 55% by 2030 and by 80 to 95% by 2050 compared to 1990. This includes emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include substantial reductions in surplus nitrogen and ammonia emissions, increasing the share of organically farmed land to 20% by 2030 (from 6.3% in 2014), and optimizing the next reform of the EU Common Agricultural Policy (CAP) and its elements in light of their effectiveness for climate change mitigation under the principle of "public funds for the public good" (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit [BMUB], 2016). Under its current commitments to the UNFCCC, Germany mentions biodiversity conservation.

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

	Total GHG Mitigation					Mitigation Measures Related to AFOLU (Y/N)	Mention of Biodiversity (Y/N)	Inclusion of Actionable Maps for Land-Use Planning[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	1,249	2030	At least 40% reduction	Energy, industrial processes, agriculture, land-use change and forestry, and waste	Y	N	N	Forests
LT-LEDS (2016)	1990	1,248	2030 / 2050	At least 55% / 80 to 95% GHG emissions reduction	Economy-wide (Energy, buildings, transport, industry, agriculture, other)	Y	Y	N	food security, water, forests

Note. "Total GHG Mitigation" and "Mitigation Measures related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)
Source: EU (2016) for the NDC, UNFCCC (2020) for GHG inventory data, and EU (2020) for the LT-LEDS

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, German NBSAP Targets are on the whole less precise and ambitious.

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

NBSAP Target	FABLE Target
10% of public woodland allowed to develop naturally	**DEFORESTATION:** Zero net deforestation from 2030 onwards
Initiative for more wilderness in Germany	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
Improve the conservation status of species and habitats	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate

Brief Description of National Pathways

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

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by a small population decline (from 81.86 million inhabitants in 2020 to 78.91 million in 2050), significant constraints on agricultural expansion, no afforestation target, no change in the extent of protected areas (37.7% of total land in 2010), medium productivity increases in the agricultural sector, and a slow reduction of the share of food wasted by consumers to 50% compared to 2010 levels by 2050. Furthermore, we assume an evolution towards a slightly more flexitarian diet, expressed through a cultural shift towards 10% vegetarians and 1.5% vegans, as well as a reduction in average overall caloric intake by 10% and by 50% in sugar and fat intake, respectively (see Annex 2). This corresponds to a future based on current policy and historical trends that would also see considerable progress with regard to crop and livestock productivity, as projected from historical data trends, food waste, and dietary changes, as targeted by current policies, and slow popularity growth of plant-based diets, especially among younger generations (Bundesministerium für Ernährung und Landwirtschaft [BMEL], 2018b, 2019a, 2019d, 2020a; Drenckhahn et al., 2020). 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 corn, soybeans, and wheat (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 a high boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would lead to a slight population growth instead of a decline (from 82.2 million inhabitants in 2020 to 82.4 million in 2050) due to SSP1-associated improvements in overall human wellbeing and mortality. Furthermore, we assume a higher extent of protected areas (from 37.7% of total land in 2010 to 42% in 2050), higher productivity increases in the agricultural sector, a quicker pace of the 50% reduction in the share of consumer food waste, and a stronger cultural shift towards a more flexitarian diet, with an increasing number of vegetarians (20%) and vegans (2%) by 2050 as well as a 30% reduction in overall average caloric and a 50% reduction in sugar and fat intake. The restrictions on agricultural expansion and the low national afforestation target are the same for both the Current Trends Pathway and the Sustainable Medium Ambition Pathway (see Annex 2). This corresponds to a future based on policies that favor a shift to plant-based diets, such as carbon prices in the agricultural sector and agro-environmental subsidies, large investments into research and development of technologies improving agricultural productivity, information campaigns about food waste as well as support for food-saving initiatives, and treating biodiversity protection of similar importance as climate change. This future would also see considerable progress with regard to GHG emission mitigation and land-use, due to the reduction in required resources. 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/m^2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

Our Sustainable High Ambition Pathway represents a future in which politicians and society follow the Sustainable Medium Ambition Pathway but put even more effort into changing the dietary culture in Germany. The target diet would rely mostly on plants, increasing especially the share of legumes and nuts, while (often drastically) reducing animal products and reducing overall average caloric intake by about 30% in comparison to 2010, effectively working towards the EAT-*Lancet* diet, as defined by (Willett et al., 2019). The pathway corresponds to the highest boundary of feasible action. Compared to the Sustainable Medium Ambition Pathway, we assume that this future would lead to a greater reduction of consumed animal products. The diet change is the only difference between the Sustainable Medium Ambition and Sustainable High Ambition Pathway, all other scenarios are the same (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/m^2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

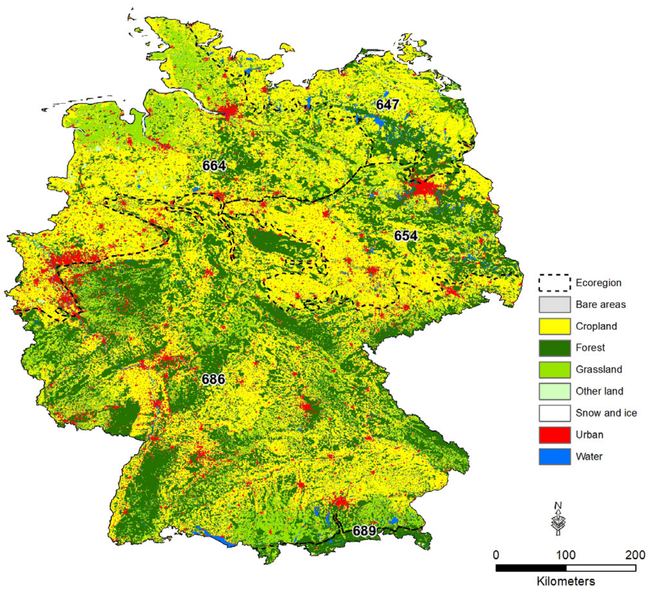
Land and Biodiversity

Current State

In 2010, Germany was covered by 36% cropland, 14% grassland, 32% forest, 7% urban, and 11% other natural land. While agriculture is an important sector in all German regions, agricultural areas are especially prevalent in the north and the east. Similarly, forests and other natural land can be found everywhere in Germany, but they are especially dense in areas not suited for intensive agriculture, such as mountainous regions in the center and south (Map 1). The loss of biodiversity, and especially insects, is a core issue for biodiversity policies in Germany, which has at its disposal a range of measures, such as incentivizing insect-friendly agriculture, investing in research and development of digital agricultural technologies that may increase biodiversity protection, and reducing the expansion of land used for housing and transport to net-zero by 2050 (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit [BMU], 2019a).

We estimate that land where natural processes predominate[2] accounted for 19% of Germany's terrestrial land area in 2010 (Map 2). The 689-Alps conifer and mixed forests hold the greatest share of land where natural processes predominate, followed by 647-Baltic mixed forests and 654-Central European mixed forests (Table 3). Across the country, while 13.1Mha of land is under formal protection, meeting the 30% zero-draft CBD post-2020 target, only 67.9% of land where natural processes predominate is formally protected. This indicates that large parts of German forests will stay important in the future, especially since there is low risk of deforestation in general in Germany, even without formal protection. However, German forests may increasingly face other issues, such as the changing climate resulting in more severe droughts and storms, more frequent and more severe forest fires, and novel and

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



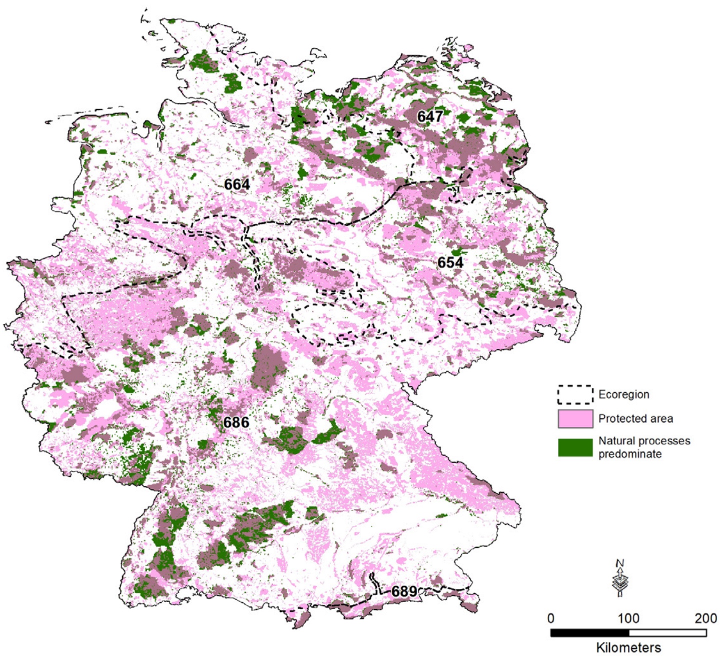
Notes. Correspondence between original ESACCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3.
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)

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".

stronger pests. To counteract these problems, policies increasing forest protection and reforestation have been put into action (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz [BMELV], 2011; BMEL, 2019b).

Approximately 36% of Germany's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively biodiversity-friendly croplands are most widespread in 689-Alps conifer and mixed forests, followed by 686-Western European broadleaf forests and 664-European Atlantic mixed forests. The regional differences in the extent of biodiversity-friendly cropland can be partly explained by less intensive, more traditional agricultural practices, as seen in the Alps.

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)

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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 $1km^2$ (%)
647	Baltic mixed forests	3113.7	43.5	37.3	68.1	31.9	1826.1	29.0
654	Central European mixed forests	4881.2	37.2	18.4	75.2	24.8	2755.7	24.9
664	European Atlantic mixed forests	7750.2	29.0	16.9	62.8	37.2	4142.8	35.4
686	Western European broadleaf forests	19472.0	39.0	18.2	66.9	33.1	7392.5	42.2
689	Alps conifer and mixed forests	345.2	61.9	37.9	95.5	4.5	6.8	90.7

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.

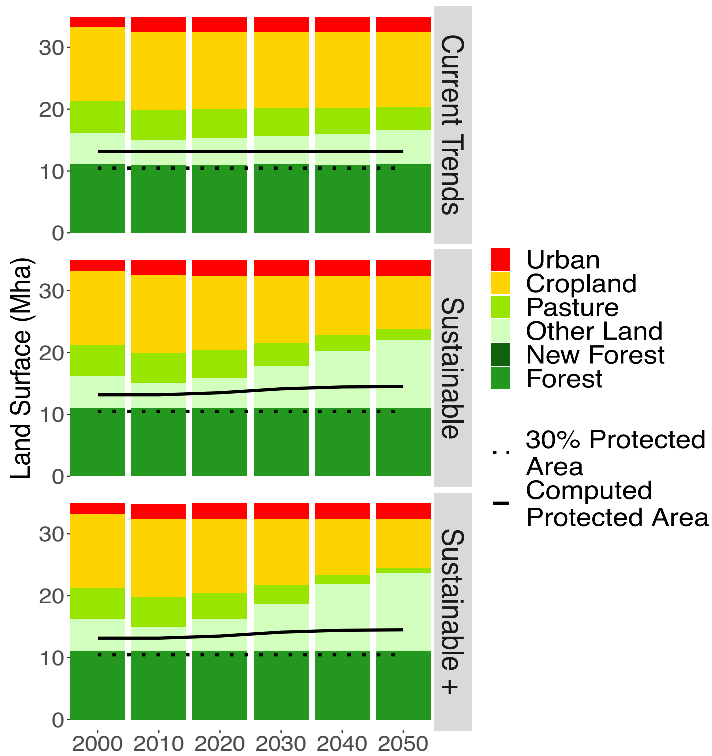
Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions, including constraints on the expansion of agricultural land beyond its current area, no planned afforestation, with reforestation limited to keeping net-zero forest loss, and protected areas remaining at 13.2Mha, representing 37.7% 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 in other natural land area and a decrease in pasture area. This trend remains stable over the period 2030-2050: other natural land area will further increase at the expense of pasture area (Figure 1). Pasture reduction is mainly driven by an increase in milk consumption and a decrease in beef consumption while livestock productivity per head increases and ruminant density per hectare of pasture remains constant over the period 2020-2030. Between 2030-2050, the further decrease of pasture area and the corresponding increase in other natural land area is explained by a continued increase in livestock productivity outweighing the growing demand for milk. This results in an expansion of land where natural processes predominate by 10% by 2030 and by 26% by 2050 compared to 2010, respectively (Figure 2).

In the Sustainable Medium Ambition and Sustainable High Ambition Pathways, assumptions on protected areas have been changed to reflect discussions beyond the Aichi biodiversity targets, EU-wide recognition of the importance of ecosystem services, and highly ambitious targets, such as the "Nature Needs Half" initiative (Drenckhahn et al., 2020; European Commission, 2011; *Germany - Nature Needs Half*, n.d.). The main assumptions include net-zero forest loss, constraints on the expansion of agricultural land beyond its

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

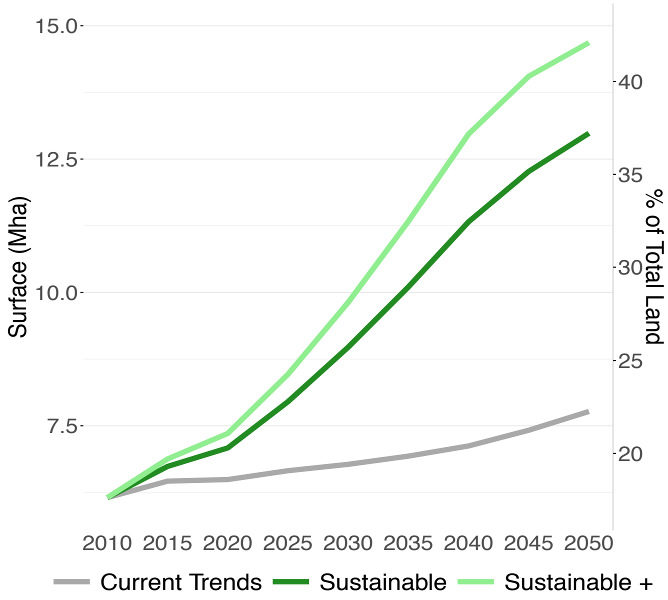


Source. Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000, and the World Database on Protected Area (UNEP-WCMC & IUCN, 2020) for protected areas for years 2000, 2005 and 2010.

current area, and protected areas increase from 37.7% of total land in 2010 to 42% in 2050, including at least 50% protected area in each ecoregion (see Annex 2).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Germany in the Sustainable Medium Ambition and Sustainable High Ambition Pathways: (i) cropland steadily decreases starting in 2025, (ii) pasture area decreases even more, especially between 2020–2050, and (iii) other natural land area increases accordingly to the loss in agricultural area), where all of these effects are stronger in the Sustainable High Ambition Pathway compared to the Sustainable Medium Ambition Pathway. In addition to the changes in assumptions regarding land-use planning, these changes compared to the Current Trends Pathway are explained by dietary shifts that reduce the amount of pasture-intensive animal products consumed, such as milk and beef, while also reducing overall caloric intake, including from crop products, and higher increases in crop and livestock productivity. This leads to an increase in the area where natural processes predominate: the area increases by 111% between 2010 and 2050 in the Sustainable Medium Ambition Pathway and by 139% in the Sustainable High Ambition Pathway, creating 37% and 42% of total land in Germany where natural processes predominate, respectively (Figure 2).

Figure 2 | Evolution of the area where natural processes predominate

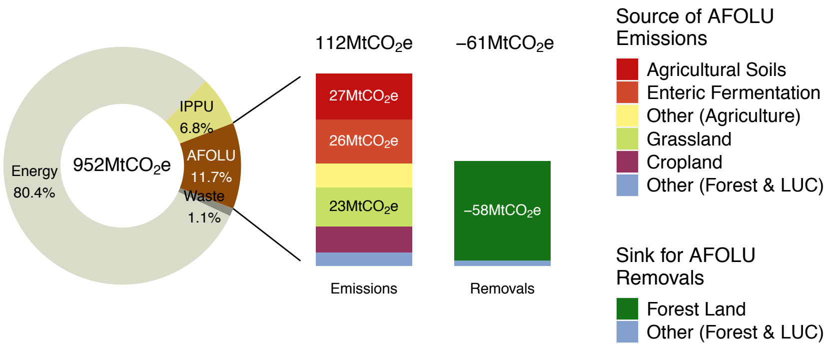


GHG emissions from AFOLU

Current State

Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 11.7% of total emissions in 2017 (Figure 3). Agricultural soils are the principal source of AFOLU emissions, followed by enteric fermentation, grassland, cropland, and manure management. This can be explained by the large number of dairy cattle in Germany as well as both storage and intensive application of manure and other fertilizers. Furthermore, large shares of German agricultural land are drained and degraded peatlands. These lands are often very productive, but also sources of a significant amount of the GHG emissions from the German agricultural sector (Tiemeyer et al., 2020; Umweltbundesamt [UBA], 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 2017

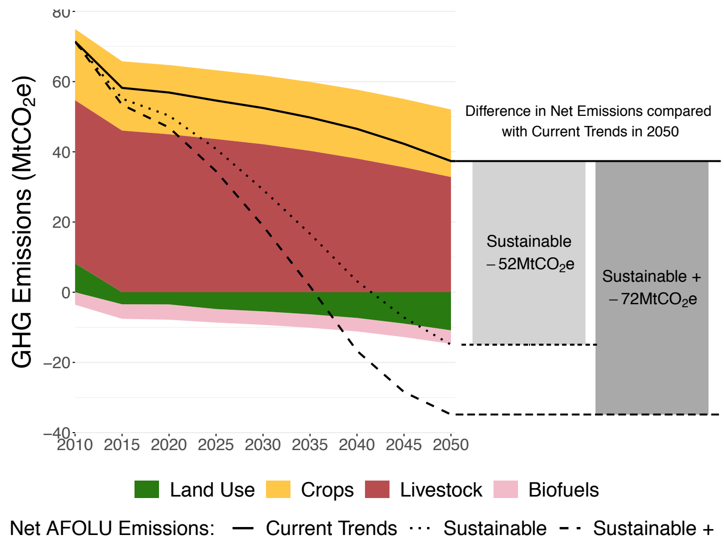


Note. IPPU = Industrial Processes and Product Use
Source. Adapted from GHG National Inventory (UNFCCC, 2020)

Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU decrease to 52.5 Mt CO_2e/yr in 2030, before declining further to 37.4 Mt CO_2e/yr in 2050 (Figure 4). In 2050, livestock is the largest source of emissions (33 Mt CO_2e/yr) while biofuels and sequestration act as sinks (-4 Mt CO_2e/yr and -11 Mt CO_2e/yr, respectively). Over the period 2020-2050, the strongest relative decrease in GHG emissions is computed for livestock (-27%)

Figure 4 | Potential AFOLU emissions reductions by 2050 by trajectory compared to the Current Trends Pathway

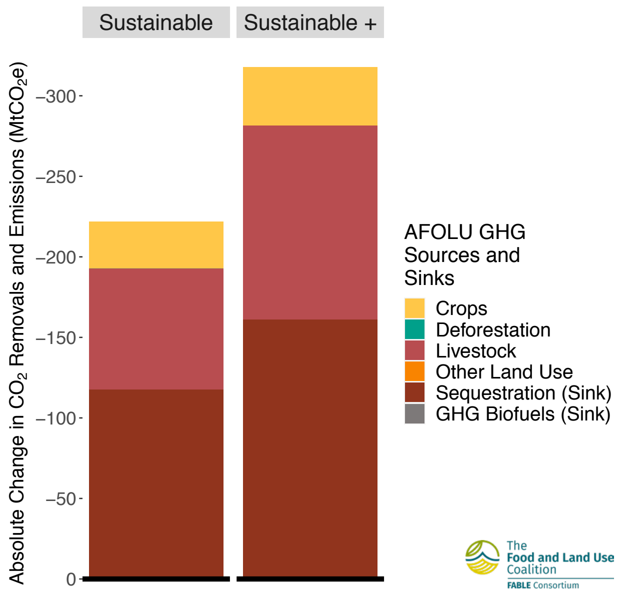


while sequestration sees the strongest relative increases (179%).

In comparison, the Sustainable Medium Ambition Pathway leads to a reduction of AFOLU GHG emissions by an additional 140% and the Sustainable High Ambition Pathway to a reduction by an additional 193% compared to the Current Trends Pathway (Figure 4) emission levels by 2050. The potential emissions reductions under the Sustainable Medium Ambition Pathway is dominated by a reduction in GHG emissions from livestock. The assumed diet change towards a more plant-based lower-calorie diet and the increasing livestock productivity are the most important drivers of this reduction. Under the Sustainable High Ambition Pathway, GHG emissions from livestock are further reduced thanks to further, more ambitious changes in diet assumptions (Figure 5).

Compared to Germany's commitments under UNFCCC (Table 1), our results show that beyond the Current Trends Pathway contributions AFOLU could contribute to as much as 7% of its total GHG emissions reduction objective by 2030 under the Sustainable High Ambition Pathway. Such reductions could be achieved through policy measures, such as incentivization and advertisement of a more plant-based and overall more sustainable diet, e. g. by extending carbon pricing to all sectors and removing subsidies counteracting these price effects, and higher investments into research and development, allowing for sustainable intensification, higher yield efficiency, and higher crop resilience to pests and climate. The positive effects of such policies may be further increased by extending current reforestation policies to afforestation of land freed up due to consumption changes These measures could be particularly important when considering options for NDC enhancement. AFOLU is, by far, the sector with the smallest amount of emissions, but still contributes tens of millions of tonnes CO_2e which these policies may help to reduce even further than currently planned, as far as potentially achieving sectoral net negative emissions by 2050. Considering the shared EU goal of at least 40% domestic GHG emissions reduction by 2030, such a sector emissions pathway would either slightly reduce pressure in other sectors, enabling easier transitions, or allow for even more ambitious reductions overall, such as Germany's national climate action plan 2050, targeting GHG emissions reductions of overall at least 55% and about 30% in the agricultural sector by 2030–which is barely met by the Current Trends Pathway, while the Sustainable Medium Ambition and Sustainable High Ambition Pathways go beyond it.

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

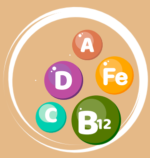
Current State

The "Triple Burden" of Malnutrition

Undernutrition

Less than 2.5% of the population was undernourished in 2017. This share is estimated based on EU shares and has likely been this low for several decades (FAO et al., 2019).

1.7% of children under 5 stunted and 0.3% wasted in 2016 (Schienkiewitz et al., 2018).



Micronutrient Deficiency

16.3% of women of reproductive age (15–49) and 12.4% of children under 5 suffer from anemia in 2016, which can lead to maternal death (WHO, 2017a, 2017b)

27% of school-age children were deficient in iodine in 1999, which can lead to developmental abnormalities (WHO, 2006).

Overweight/ Obesity

54% of adults were overweight in 2014, including 18.1% of adults who were obese. These shares have increased since 1999 (Schienkiewitz et al., 2017).

15% of children between 3 and 17 were overweight in 2016, including 6% of children between 3 and 17 who were obese. These shares have stayed the same since 2005 (Kurth & Schaffrath Rosario, 2007; Schienkiewitz et al., 2018).

Disease Burden due to Dietary Risks

0.2% of adult deaths are attributable to dietary risks (cardiovascular diseases, diabetes mellitus type 2, neoplasms), or 162 deaths per year (per 100,000 people) (Afshin et al., 2019).

8.5% of the population suffered from diabetes (type 2) in 2015, and 10% from cardiovascular diseases in 2010, which can be attributable to dietary risks (Robert Koch-Institut & Destatis, 2015; Tönnies et al., 2019).

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)	3,175 (2,106)	3,012 (2,083)	2,800 (2,083)	2,831 (2,083)	2,812 (2,079)	2,189 (2,079)	2,276 (2,079)
Fats (g) (recommended range)	135 (71-106)	129 (67-100)	122 (62-93)	128 (63-94)	116 (62-94)	96 (49-73)	112 (51-76)
Proteins (g) (recommended range)	94 (79-278)	94 (75-264)	84 (70-245)	87 (71-248)	100 (70-246)	69 (55-192)	77 (57-199)

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

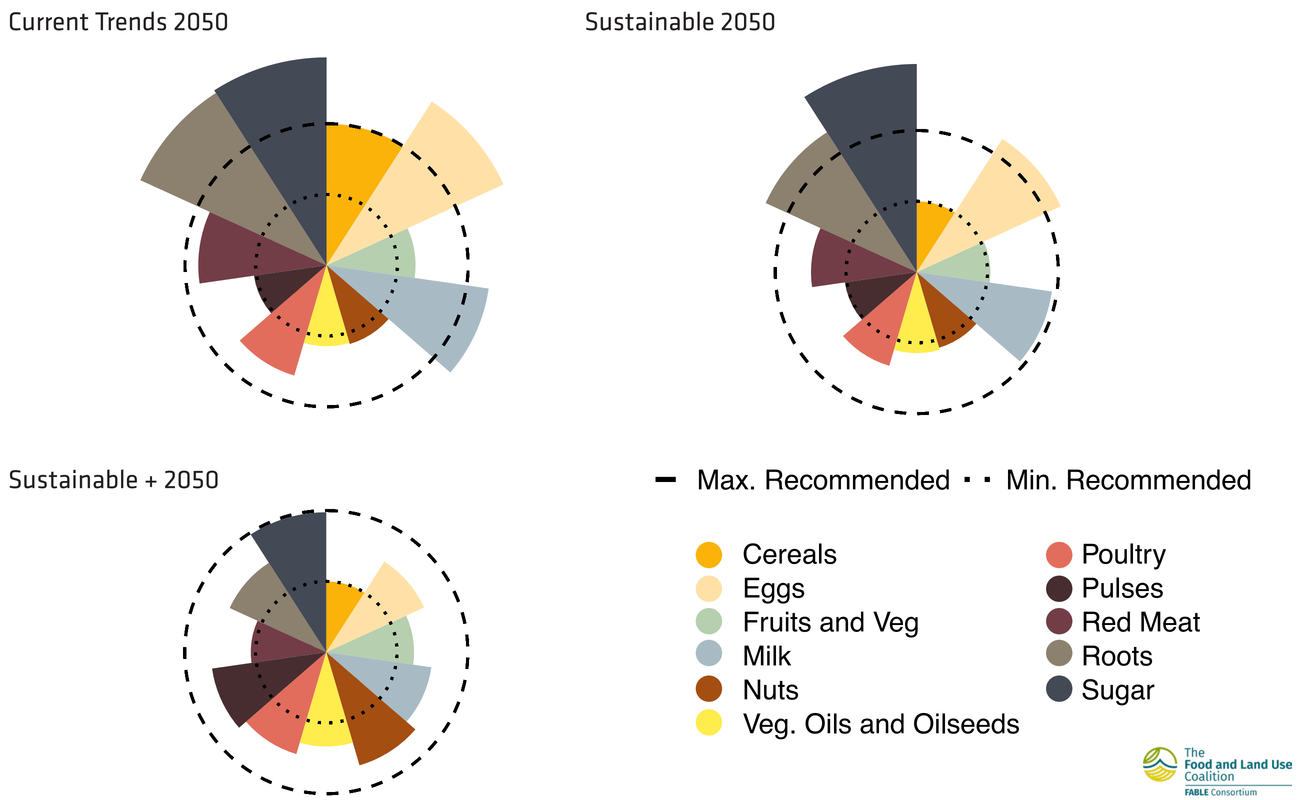
Requirement (MDER) at the national level, our computed average calorie intake is 45% higher in 2030 and 35% higher in 2050 (Table 4). The current average intake is mostly satisfied by cereals, oilseeds and vegetable oils, sugar, milk, pork, and animal fats. Animal products currently represent 28% of the total calorie intake. In general, we assume that the share of consumption of animal products will increase by 11% and, specifically, that the relative share of consumption of milk and eggs will increase by 12% between 2020 and 2050. The consumption of cereals, fruits and vegetables, roots, pulses, and nuts will also increase while the consumption of oilseeds and vegetable oils, sugar, pork, poultry, red meat, and animal fat will decrease. Compared to the EAT-*Lancet* recommendations (Willett et al., 2019), eggs, roots, milk, and sugar are over-consumed in 2050 (Figure 6). Moreover, despite a reduction between 2020-2050, fat intake per capita exceeds the dietary reference intake (DRI) in both 2030 and 2050, while protein stays within the reference range. This can be explained by a decline in the consumption of animal fats, and oilseeds and vegetable oils.

Under the Sustainable Medium Ambition Pathway, we assume that diets will transition towards a more plant-based diet with reduced overall caloric intake. Similar assumptions are made under the Sustainable High Ambition Pathway, where the target diet is even closer to the EAT-Lancet recommendations. The ratio of the computed average intake over the MDER decreases to 34% in 2030 and 5% in 2050 under the Sustainable Medium Ambition Pathway, and 36% in 2030 and 9% in 2050 under the *Sustainable High Ambition Pathway*.

Compared to the EAT-Lancet recommendations, only the consumption of eggs, roots, and sugar remains outside of the recommended range (albeit to a smaller degree compared to the Current Trends Pathway), while the consumption of milk is within the recommended range under the Sustainable Medium Ambition Pathway. Under the Sustainable High Ambition Pathway, all calculated product groups are within the recommended range in 2050 (Figure 6). Moreover, while the fat intake per capita still exceeds the DRI in 2030, it shows some improvement compared to the Current Trends Pathway.

Incentives, such as carbon pricing, restrictions on additives, and information campaigns on both personal and planetary benefits of such diet changes will be particularly important to promote this shift in diet. Regarding other sectors, similar mechanisms are already in place, foremost the EU Emissions Trading System (EU ETS), covering currently about 45% of all EU GHG emissions, as well as a more recent national pricing system covering German emissions from heating and transportation. AFOLU emissions, on the other hand, are currently not covered despite experts pushing for such a policy expansion. The recent political movement towards an animal welfare label, the adoption of the NutriScore food label, and the start of a campaign to reduce sugar and fat in convenience food highlight possible ways of restricting and informing about unhealthy products (BMEL, 2018a, 2018b, 2019c; BMUB, 2016; BMU, 2019b; Drenckhahn et al., 2020).

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



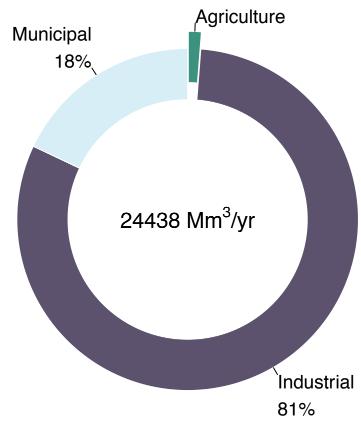
Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings) i.e. different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended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

Germany is characterized by a moderate climate, without any prolonged periods of extreme heat or cold (which tend to occur more in the continental south and east) and more maritime climate in the coastal regions and the northwest with 700mm average annual precipitation that occurs all year long and peaks in the period May–August. The agricultural sector represented 1% of total water withdrawals in 2016 (FAO, 2017; Figure 7). Moreover, in 2015, 100% of agricultural land was equipped for irrigation, representing 100% of estimated-irrigation potential. The three most important irrigated crops, corn, sugar beet, and potatoes, account for 25%, 19%, and 12% of total harvested irrigated area. Germany exported 11% of corn, 17% of potatoes, and 0.4% of sugar beet produced in 2017 (FAO, 2020).

Figure 7 | Water withdrawals by sector in 2016

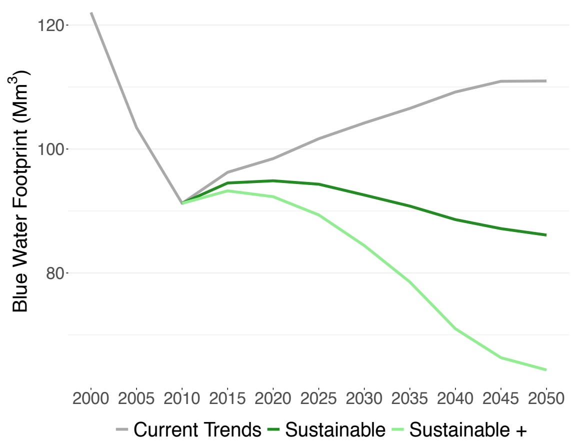


Source. Adapted from AQUASTAT Database (FAO, 2017)

Pathways and Results

Under the Current Trends Pathway, annual blue water use decreases between 2000-2015 (122 and 96.2 Mm^3/yr), before increasing to 104.2 Mm^3/yr and 111 Mm^3/yr in 2030 and 2050, respectively (Figure 8), with potato accounting for 90% 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 92.6 Mm^3/yr in 2030 and 86.1 Mm^3/yr in 2050, respectively. Under the Sustainable High Ambition Pathway, the blue water footprint further decreases to 64.3 Mm^3/yr in 2050. This is explained by changes in the produced amounts of water-intensive crop products, foremost potatoes, due to a decline in internal food demand due to diet changes. This effect is even more pronounced in the Sustainable High Ambition Pathway, where potato production decreases.

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 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.

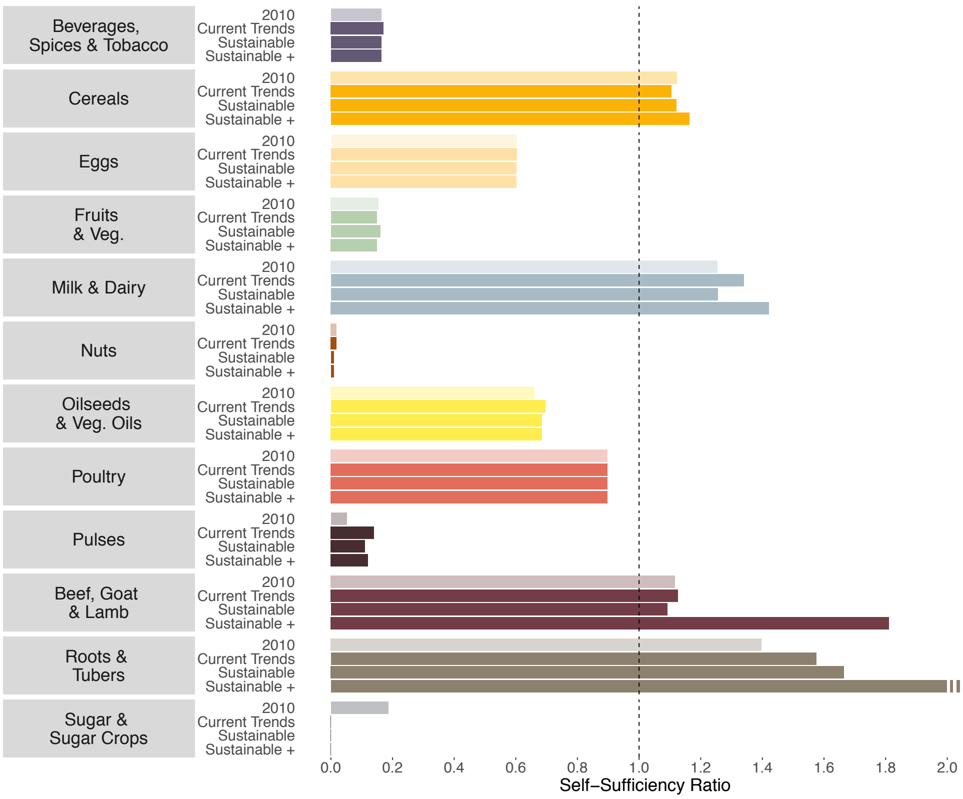
Resilience of the Food and Land-Use System

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 Germany'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

Germany has a strong agricultural sector, taking up roughly half of all its land. Despite this size, it is reliant on imports for a variety of products, especially feed for its livestock. That is both because of its large livestock sector but also because of land-use conflicts between crops for biofuel, food, and feed. On the other hand, many imports are provided by European neighbors and, in most situations, being part of the EU may increase Germany's resilience, even though this would not strictly be considered self-sufficiency.

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. The discontinuous lines on the right of this figure, as seen for roots and tubers, indicate a high level of self-sufficiency for these categories.

Under the Current Trends Pathway, we project that Germany would be self-sufficient in cereals, milk and dairy, beef, goat and lamb, and roots and tubers in 2050, with self-sufficiency by product group increasing for the majority of products from 2010–2050 (Figure 9). The product groups where the country depends the most on imports to satisfy internal consumption are nuts, fruit and vegetables, pulses, sugar and sugar crops, and beverages, spices and tobacco and this dependency will remain stable for most products, increase for pulses, and decrease for sugar and sugar crops until 2050. Despite changes in internal demand, the overall self-sufficiency differs neither in the Sustainable Medium Ambition Pathway nor the Sustainable High Ambition Pathway to a large degree. This is despite notable increases in self-sufficiency in the Sustainable High Ambition Pathway regarding beef, goat and lamb, and roots and tubers since Germany was completely self-sufficient in these two groups even before the increase while product groups below self-sufficiency show little to no change.

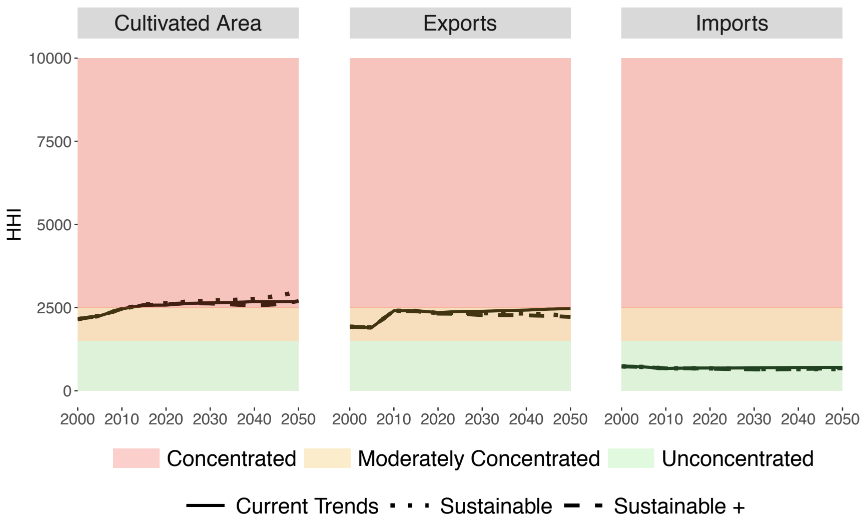
Diversity

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

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

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

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



Germany

According to the HHI, the planted crop area in 2010 is moderately concentrated and follows a trend towards high concentration. Similarly, exports are moderately concentrated bordering on highly concentrated in 2010 after a rapid spike in the previous years. Imports, on the other hand, diversified even further in the years 2000–2010 and were very unconcentrated.

Under the Current Trends Pathway, we project medium concentration of crop exports and crops planted in 2010 and low concentration of imports. Exports concentration rises slowly towards the upper limit of medium concentration between 2020–2050, concentration of crops planted rises slightly to a high concentration and levels off between 2030–2050, and the concentration of imports remains constant at very low concentration levels between 2020–2050. This indicates low levels of diversity across the national production system and exports, while imports seem to be highly diversified. Similarly, under both the Sustainable Medium Ambition Pathway and the Sustainable High Ambition Pathway, we project medium concentration of crop exports, low concentration of imports, and a high concentration in the range of crops planted in 2050, indicating low levels of diversity across the national production system and exports, but high levels of diversity across imports (Figure 10). This is explained by the large focus on a few strong export products, such as wheat and beef, while Germany imports low quantities of a large variety of goods. Similarly, few crops are grown in large amounts for feed, food, or biofuel, leading to highly concentrated cropland, which further concentrates with increasing internal demand towards crops, such as cereals.

Discussion and Recommendations

While many scenarios went into the German FABLE Calculator, the assessment in this chapter and especially the comparison of the Sustainable Medium Ambition and Sustainable High Ambition Pathways show very clearly that some scenarios have far more impact than others on German transformation pathways towards fewer greenhouse gas emissions and improved biodiversity protection in the AFOLU sector. According to these model results, it seems very clear that enhancing policies that move the populace towards a more plant-based diet may have overall very positive impacts. This comes as no surprise since such policies have been assessed thoroughly in the past, for example in the context of the EAT-Lancet recommendations referenced in this model (Willett et al., 2019).

However, advances to encourage a more plant-based diet by, for example, pushing for a "meatless Thursday" (also known as Veggie Day) were met with very vocal opposition in the past, despite the objectively low impact such a policy would have had on any single person's life (BÜNDNIS 90 / DIE GRÜNEN, 2013; „Der Veggie Day teilt das Land", 2013; „Neue Forsa-Umfrage", 2013; Infratest dimap, 2013).

Less controversial approaches may include information campaigns, such as food labels that inform about health and sustainability benefits, or the lack thereof, of certain products. The current move towards implementing the NutriScore system in Germany and the recent implementation of a new animal welfare label may be the first steps in this direction (BMEL, 2018a, 2019c). Furthermore, instead of removing meat options once per week from public canteens, as suggested for the "veggie day", policies encouraging or enforcing a food option in line with the EAT-*Lancet* recommendation in every canteen may be met with less opposition, keeping meat available while also creating more opportunities for people to experience "planetary health" options. Removing incentives, such as subsidies, and extending carbon price mechanisms to include the agricultural sector to internalize environmental damages will also have a nudging effect. Similarly, projected health costs could be internalized. Such pricing mechanisms and labels would need to be applied to all products of course, including imports from outside the European Union to counteract carbon leakage effects (Drenckhahn et al., 2020).

A second important driver of a more sustainable future is technological development. The productivity increases—both in crops and in livestock—assumed in these pathways positively shape the future. Such developments are not guaranteed, but Germany is a rich country well known for its engineers and ingenuity, able to invest in research and development of new technologies, increasing yield, land and water efficiency, and resilience. Using, for example, advanced robotics for precision farming may have positive impacts on farming cost and biodiversity protection due to a focused application of a reduced amount of pesticides, allowing for sustainable intensification. Furthermore, robotic farmhands may be a response to the current COVID-19 crisis and the resulting lack of field workers. To increase adoption rates, such technologies must not only be available but also tailored to farmers' needs (Knierim et al., 2019). Both the EU and Germany are working towards such developments by incentivizing and supporting research (BMEL, 2018c; Standing Committee on Agricultural Research & Directorate-General for Research and Innovation [European Commission], 2013). Vertical farming may reduce the required land for farming and increase yield efficiency (O'Sullivan et al., 2020). In the future, lab-grown meat may be both cheaper and more sustainable than farm-grown options as well—while also solving the ethical dilemma of consuming meat (Bryant & Barnett, 2018).

However, these assumptions are very optimistic in the FABLE Calculator. While Germany has the resources to invest in such developments, its populace has also shown that it is skeptical towards modern agricultural technologies and processes, such as genome editing, potentially holding back important developments

(BMEL, 2019e). The current political target to increase organic farming to 20% of all agricultural land in Germany by 2030 may have a positive effect on local biodiversity but may reduce yield efficiency and thus increase the need for farmland, potentially resulting in overall more pressure on protected areas and a worse footprint per yield tonne (Seufert et al., 2012). However, there are many policies in place and being put in action that will likely have direct positive effects on Germany's biodiversity, e. g. financially incentivizing sustainable farming (BMU, 2019a). Germany also already protects a large share of its land, going beyond the Aichi Target of 17%, albeit still falling short of the very ambitious 50% target formulated by some (*Germany - Nature Needs Half,* n.d.). While there is little political movement towards protection on this level, scientific advisors push in this direction (Drenckhahn et al., 2020).

By design, the model focuses on specific sectors important for sustainable development, while completely or in large parts ignoring others, such as energy, building, and industry, which combined are responsible for over 70% of Germany's greenhouse gas emissions. While there are targets and policies for all sectors, the reduction targets are far steeper for these three (both in absolute and relative numbers). In turn, agricultural emissions as well as reduction targets are lower than in any other sector (up to 34% reduction by 2030 compared to 1990 emissions). This imbalance may be due to the already large investments in the German "Energiewende", keeping the spotlight on the energy and related sectors, while AFOLU policies currently focus on smarter fertilizer application and carbon sequestration. (BMUB, 2016; BMU, 2019b). So, while the modeled and suggested policies' impact might be relatively small in the broader context of German GHG emissions, they may be able to drastically improve the AFOLU sector's footprint beyond current targets and even help to turn it into an overall carbon sink.

As with all models, there are of course caveats. While the model provides insights and trends, more thorough debugging is necessary. Currently, historical data and model calculations do not always align, including extreme outliers in a few cases. Furthermore, important aspects of the German sustainability and climate debate may need to be better reflected in this model, such as the importance of organic soils as carbon storage and emission source. The organic farming target, too, needs to be reflected in yield, land, and emission calculations. Furthermore, due to the way reforestation and afforestation are currently planned, it is only reflected as net-zero forest loss in the model. However, seeing how much land is freed up as "other natural land" due to the changing internal demand, it may make sense to assume active afforestation for Germany. Lastly, biofuel and biogas scenarios need to properly reflect current political targets and alternatives.

Our next steps will be to implement these changes in the FABLE Calculator and to create a second model to confirm our findings and assess the trade-offs and necessary balances between different SDGs in Germany.

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

- Increased the threshold on urban land to prevent the “erasure” of German cities since more than the normally allowed 3.5% of total land are urban land in Germany
- Set up a new way to calculate food waste assumption, aligning reported annual food waste per capita and food waste share assumptions from the original calculator
- Expanded the food loss assumptions to include pork and milk

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
The population is expected to reach 78.9 million by 2050 based on SSP2 (global "middle of the road" sustainability narrative) assumptions regarding rich OECD countries: medium fertility, medium mortality, medium migration, medium education Based on Kc & Lutz (2017).	The population is expected to reach 82.4 million by 2050 based on SSP1 (global "taking the green road" sustainability narrative) assumptions regarding rich OECD countries: medium fertility, low mortality, medium migration, high education Based on Kc & Lutz (2017).	Same as Sustainable Medium Ambition Pathway

LAND Constraints on agricultural expansion

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
We assume no expansion of agricultural land beyond 2010 agricultural area levels. Based on BMEL (2020b).	Same as Current Trends Pathway	Same as Current Trends Pathway
LAND Afforestation or reforestation target (1000 ha)		
We expect net-zero forest loss due to reforestation focus on damaged trees. Based on BMU (2019b).	Same as Current Trends Pathway	Same as Current Trends Pathway

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

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
Protected areas remain stable: by 2050 they represent 37.7% of total land. As German levels are already relatively high, there is little movement towards higher levels.	Protected areas increase: by 2050 they represent 42% of total land, corresponding to at least 50% protection of each ecoregion. Based on Drenckhahn et al. (2020); *Germany - Nature Needs Half* (n.d.)	Same as Sustainable Medium Ambition Pathway

PRODUCTION Crop productivity for the key crops in the country (in t/ha)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
By 2050, crop productivity reaches: • 492.6 tonnes per ha for tomatoes • 75.5 tonnes per ha for sugarbeet • 40.0 tonnes per ha for potatoes Based on own calculations using data from (FAO, 2020).	By 2050, crop productivity reaches: • 696 tonnes per ha for tomatoes • 89.5 tonnes per ha for sugarbeet • 75.7 tonnes per ha for potatoes Based on own calculations using data from (FAO, 2020). Assumptions are more optimistic to reflect both the necessity and the general German capability to improve productivity.	Same as Current Trends Pathway
PRODUCTION Livestock productivity for the key livestock products in the country (in kg/head of animal unit)		
By 2050, livestock productivity reaches: • 9,500 kg per head for cattle • 4,100 kg per head for chickens • 1,500 kg per head for pigs Based on own calculations using data from (FAO, 2020).	By 2050, livestock productivity reaches: • 12,400kg per head for cattle • 6,300kg per head for chickens • 1,900kg per head for pigs Based on own calculations using data from (FAO, 2020). Assumptions are more optimistic to reflect both the necessity and the general German capability to improve productivity.	Same as Sustainable Medium Ambition Pathway
PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)		
By 2050, the average ruminant livestock stocking density is 2.52TLU/ha per ha.	Same as Current Trends Pathway	Same as Current Trends Pathway
PRODUCTION Post-harvest losses		
By 2050, the share of production and imports lost during storage and transportation is the same as in 2010 (NoChange scenario selected)	By 2050, the share of production and imports lost during storage and transportation is reduced by 50%. Analogous to (BMEL, 2019d)	Same as Sustainable Medium Ambition Pathway

TRADE Share of consumption which is imported for key imported products (%)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
Imports are only affected intrinsically, as no specific policy changes are implying otherwise.	By 2050, in response to changing internal demand, the share of total consumption which is imported is: • 71% by 2050 for SoyCake.	Same as Sustainable Medium Ambition Pathway
TRADE Evolution of exports for key exported products (tonnes)		
By 2050, the volume of exports is only affected intrinsically, as no specific policy changes are implying enforced export volumes.	By 2050, in response to changing internal demand, the volume of exports is: • 4,509,000 tonnes by 2050 for milk • 741,000 tonnes by 2050 for pork • 116,000 tonnes by 2050 for beef	Same as Sustainable Medium Ambition Pathway

Germany

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
By 2030, the average daily calorie consumption per capita is 3,064 kcal and is: • 815 kcal for cereals • 308 kcal for milk • 303 kcal for red meat Based on BMEL (2018b, 2019a, 2020a): 10% kcal reduction by 2050 compared to 2010, with 50% kcal reduction from sugar and fat, and a slight decrease in relative meat consumption.	By 2030, the average daily calorie consumption per capita is 2,842 kcal and is: • 725 kcal for cereals • 274 kcal for milk • 262 kcal for red meat Based on BMEL (2018b, 2019a, 2020a): 30% kcal reduction by 2050 compared to 2010, 50% kcal reduction from sugar and fat, and a stronger decrease in relative meat consumption.	By 2030, the average daily calorie consumption per capita is 2,886 kcal and is: • 737 kcal for cereals • 236 kcal for milk • 207 kcal for red meat Based on Willett et al. (2019).

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

By 2030, the share of final household consumption which is wasted at the household level is between 0 and 11%, depending on the product group. Based on BMEL (2019d).	By 2030, the share of final household consumption which is wasted at the household level is between 0 and 7%, depending on the product group. Based on BMEL (2019d).	By 2030, the share of final household consumption which is wasted at the household level is between 0 and 7%, depending on the product group. Based on BMEL (2019d).

BIOFUELS Targets on biofuel and/or other bioenergy use (kt)

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
No expansion of biofuel crop area beyond 2028 OECD projections. By 2050, biofuel production accounts for: • 1,673kt of rape oil production • 781kt of wheat production • 7kt of corn production Based on UBA (2013)	No expansion of biofuel crop area beyond 2028 OECD projections. By 2050, biofuel production accounts for: • 1,673kt of rape oil production • 781kt of wheat production • 7kt of corn production Based on UBA (2013)	No expansion of biofuel crop area beyond 2028 OECD projections. By 2050, biofuel production accounts for: • 1,673kt of rape oil production • 781kt of wheat production • 7kt of corn production Based on UBA (2013)

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

Gt – gigatons

ha – hectare

kcal – kilocalories

kg – kilogram

km^2 – square kilometer

km^3 – cubic kilometers

m – meter

Mha – million hectares

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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