

Global spillover effects of the European Green Deal and plausible mitigation options

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Achieving European Green Deal (EGD) targets for carbon removal and ecological restoration would reduce agricultural and forestry production within the European Union yet simultaneously extend ecosystem impacts elsewhere. Here we quantify such spillover impacts by coupling an extended multi-regional input–output analysis with an agro-ecological zones model. We find that EGD’s agricultural and forestry targets set for 2030 could result in a 23.9 Mha increase in demand for agricultural land outside the European Union, which in turn would lead to an increase in land-use-related carbon emissions by 758.9 MtCO₂-equivalent (244.8% of EGD’s carbon removal target in the land, land-use-change and forestry sectors) and a biodiversity loss of 3.86 million mean species abundance loss. Such spillover impacts far exceed the ecological benefits from EGD conservation-based import policies, such as promoting deforestation-free products and phasing out food-based biofuel. We then propose three options beyond the primary targets of the EGD with the aim to mitigate such spillover impacts. The assessment of these options reveals the critical role of reducing meat and dairy consumption, highlighting the impact of consumer behaviour on environmental outcomes. This raises questions about public awareness, willingness to change diets and the role of policy in influencing consumer behaviours.

To address climate change, sustainable development and biodiversity conservation, the European Green Deal (EGD) was introduced in 2019¹. While EGD targets may benefit the European Union ecologically, they could cause environmental impacts beyond the EU borders, particularly through imports of land-intensive goods². Without understanding these spillover impacts, EGD goals might unintentionally shift environmental degradation to other countries³. This study quantifies the unintentional outsourcing impacts of the EGD on land use, land-related

carbon emissions and biodiversity using the latest available data, enabling a more comprehensive understanding of the EGD’s global environmental implications.

Research on environmental impacts of EU consumption has grown, focusing on trade flow analyses^{4–6} and consumption-based environmental footprints^{7–11}. These studies show that EU consumption patterns lead to larger land footprints than the world average, thus triggering increased biodiversity loss^{12–14} and greenhouse gas (GHG)

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emissions, such as CO₂, CH₄ and N₂O¹⁵. These impacts often stem from land-use changes, such as deforestation, and fertilizer use^{16,17}. The European Union's substantial food imports, due to its limited food self-sufficiency¹⁸, exacerbate these issues. Imports of animal feed, wood-based products and biomass¹⁹ contribute to environmental damages in non-EU countries. Notably, imports of cattle meat, soy, maize and palm oil are linked to deforestation in tropical countries such as Brazil and Indonesia^{20,21}. Multiple studies have demonstrated that the European Union, as a net importer of embodied land-based emissions, indirectly contributes to extraterritorial emissions²².

Part of the EGD's aims were to address the environmental spillover impacts of EU consumption. The European Union's overarching objective is to substantially reduce emissions and become the first climate-neutral continent by 2050. To achieve this, the EGD proposes strategies such as trade policies to limit imports of deforestation-linked meat, feed and soy, as well as policies promoting terrestrial carbon sinks and ecological management practices on 25% of agricultural land within the European Union. However, it is uncertain whether the EGD is sufficient to prevent or reduce ecosystem spillover impacts in other regions.

To address this crucial question, we explore possible scenarios for 2030, including the EGD and plausible options to mitigate its spillover impacts (Table 1). We specify three sets of scenarios: (1) a business-as-usual (BAU) scenario reflecting the current trend of land-use/land-cover changes, (2) scenarios incorporating the EGD policies and their impacts on land use and (3) scenarios aimed at mitigating EGD spillover effects and thus going beyond the primary targets of the EGD. Scenario set (2) includes the EU Deforestation-Free Regulation to stop importing deforestation-linked goods (D1–D4), bioenergy developments (D5–D6), organic agriculture expansion within the European Union (D7) and increasing carbon sinks by converting low-productivity cropland into forest or grassland (D8). Scenario set (3) includes narrowing the crop yield gaps in developing regions (M1), phasing out food-based biofuel in the European Union (M2) and adopting EAT-Lancet Commission-recommended diets²³ (M3).

We assess the impacts of these policies or scenarios on land-use and land-related GHG emissions and biodiversity outside the European Union. Our approach combines environmentally extended multi-regional input–output (EEMRIO) analysis²⁴ with a global agro-ecological zones (GAEZ) model²⁵. EEMRIO analysis quantifies the flows of goods and services and associated virtual flows of resource use by calculating direct and indirect effects along global supply chains. The GAEZ model simulates crop production and suitability at the 10 × 10 km grid-cell level. This combined approach allows us to allocate EU outsourced productions across different regions of the world according to cropping suitability, potential yield and current trade patterns.

Environmental spillover effects

Figure 1 and Extended Data Table 1 present the potential additional required cropland under the proposed eight EGD scenarios (Table 1) from 2020 to 2030, without considering changing circumstances from climate change. Forestland would potentially increase by approximately 2.2 Mha due to EGD deforestation-free import policies on meat (D1), animal feed (D2), soy (D3) and wood-based products (D4). Yet the largest savings to forestland would result from the restriction of palm oil-based biodiesel (D5), which would contribute to 48.8% of the total forestland saving. By contrast, implementing EGD policies could also potentially result in a 23.9 Mha cropland demand increase outside the European Union, which would amount to 73.5% of the outsourced EU cropland footprint (32.5 Mha) in 2020 (Supplementary Table 1 and Supplementary Fig. 1). In addition, EGD policies for bioenergy crops (D6), the introduction of organic agriculture (D7) and the introduction of additional carbon sinks through afforestation (D8) would lead to a decline in domestic food production and trigger a 26.1 Mha cropland

Table 1 | The EGD scenarios and EGD mitigation scenarios

Category	Scenario	Description
BAU	BAU	Business as usual, shared socioeconomic pathways (SSP2)
EGD scenarios	D1	Only deforestation-free meat is imported into the European Union by 2030
	D2	Only deforestation-free feed products are imported into the European Union by 2030
	D3	Only deforestation-free soy is imported into the European Union by 2030
	D4	Only deforestation-free wood-based products are imported into the European Union by 2030
	D5	Phasing out all food-based biofuel import into the European Union by 2030 (currently phasing out palm oil-based biofuel)
	D6	Bioenergy crops expansion by 9Mha in the European Union by 2030 (8.1% of EU cropland in 2020)
	D7	Organic agriculture up to 25% of EU cropland (about 27.7 Mha, year 2020) by 2030
	D8	Carbon sink (310 MtCO ₂ e) in the combined land-use, forestry and agricultural sectors in the European Union by 2030
EGD mitigation scenarios	M1	Narrowing yield gap by improving field management to the intermediate input level of the GAEZ model outside the European Union by 2030
	M2	Complete phasing out of food-based biofuels by 2030 in the European Union
	M3	Adapting diets in the European Union to align with the EAT-Lancet recommendation

increase outside the European Union, which would exceed the total forestland savings caused by D1–D5 by 11.7 times. The expansion of bioenergy crops planting area (D6) within the European Union alone will displace grain production and result in an outsourcing of 17.2 Mha cropland outside the European Union, accounting for 65.8% of the total cropland expansion triggered by D6–D8.

The impact of the EGD on different regions varies substantially due to the European Union's disproportional import structure of agricultural and forestry commodities, as well as variations in crop cultivation suitability and yield under different climates. The majority of cropland expansion is projected to occur in regions with higher crop yield under rainfed conditions, such as the rest of Europe, Russia and Canada (Extended Data Table 1). For example, the rest of Europe is projected to expand cropland, via converting pasture/grassland to cropland, by 10.36 Mha (D1–D8), which is 43.4% of the total projected cropland expansion outside the European Union. By contrast, a slight extent of cropland expansion compared with an obvious forest saving in South Africa and Indonesia (D1–D8) would reduce land demand by 0.36 Mha and 0.60 Mha, respectively.

The impact of EGD on forest protection also varies across regions. The results presented in Extended Data Table 1 indicate that the EU deforestation-free meat (D1) and feed import (D2) policies would benefit the rest of Africa the most, potentially saving 31.7 Kha and 31.8 Kha (35.5% and 33.3% of the total forestland savings from D1 and D2), respectively. This is followed by the rest of America (19.0 Kha from D1 and 19.5 Kha from D2) and Brazil (14.4 Kha from D1 and 20.8 Kha from D2). The EGD's soy import policy (D3) will save 32.3 Kha and 9.8 Kha of forestland in Brazil and the United States (69.5% and 21.0% of the D3 saved area), which are the top two soy exporters of the world.

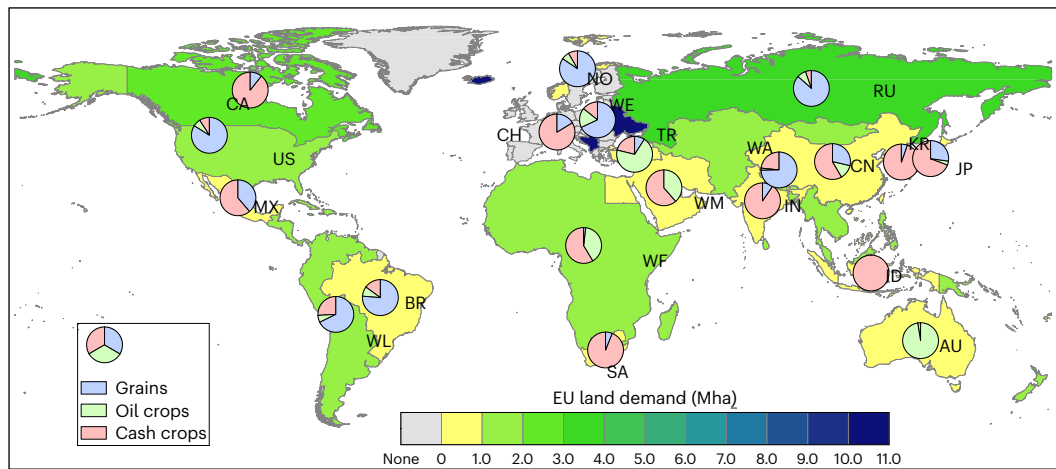


Fig. 1 | Additional cropland requirements under EGD scenarios by 2030 compared with 2020. The background map shows the projected outsourced cropland. The pie charts show the fractions of land requirements associated with grains, oil crops and cash crops. Details of EU outsourced agricultural land are

provided in Supplementary Fig. 1 and Supplementary Tables 1 and 2; the corresponding regional hotspots are shown in Supplementary Fig. 2. Abbreviations of the 20 countries/regions outside the European Union are given in Supplementary Table 4.

In addition, the restriction on wood-product imports from deforested areas (D4) would prevent deforestation mainly in South Africa (458.8 Kha, or 50.5% of the D4 saved forest) and the rest of America (172.5 Kha, or 19.0% of the D4 saved forest). Reducing palm oil demand triggered by the bioenergy policy (D5) would translate into lowering the impacts on major exporters such as Indonesia (572.9 Kha, or 52.7% of the D5 saved forest) and the rest of Asia and Pacific (313.9 Kha, or 28.9% of the D5 saved forest), mainly Malaysia and Papua New Guinea.

The potential land-use change resulting from EGD will trigger a (net) release of about 758.9 MtCO₂-equivalent (CO₂e) of GHGs and a biodiversity loss of 3.86 million mean species abundance loss (MSA-loss) outside the European Union (Extended Data Tables 2 and 3). Although the EGD holds ecosystem and forest protection policies (D1–D5) to stop the imports of deforestation-related products and food-based biofuel, the limited, potential benefits of carbon emissions reduction (–209.0 MtCO₂e) and biodiversity conservation (–0.61 million MSA-loss) would be offset by the much greater ecosystem loss resulting from the D6–D8 induced outsourcing of agricultural land (carbon emissions 967.9 MtCO₂e, biodiversity 4.5 million MSA-loss). Land displacement caused by expansion of bioenergy crops within the European Union (D6) would be the biggest contributor to the increase of GHG emissions (66.9% of the D6–D8, 647.8 MtCO₂e) and the biodiversity loss (65.1% of the D6–D8, 2.91 million MSA-loss) outside the European Union. Meanwhile, among all the EGD land-saving scenarios of D1–D5, phasing out the imports of wood-based products (D4) would contribute 56.5% of the GHG emissions decline (–118.0 MtCO₂e) and 37.8% of the biodiversity gain (–0.23 million MSA-loss).

From a regional perspective, land use and land-use change in biodiversity-rich and high carbon storage forestland is critical to GHG emissions reduction and biodiversity conservation (Fig. 2 and Extended Data Tables 1–3). For example, in the hotspot areas of the rest of America, potential carbon sinks from even a small area of forest saving (396.8 Kha, 17.8% of the D1–D5 global forest saving) would contribute a 44.8 MtCO₂e reduction (21.4% of the D1–D5 global emissions reduction) and 215.1 thousand MSA-loss biodiversity gains (35.1% of the D1–D5 global biodiversity gains). However, as shown in pie charts in Fig. 2, agricultural expansion in the rest of America triggered by the land displacement of D6–D8 accounts for 20.7% of the total biodiversity loss (0.92 million MSA-loss) with only 6.5% of the total land demand (1.7 Mha). Restricting palm oil biodiesel imports (D5) and wood-based products imports (D4) would reduce deforestation in major producers of Indonesia (0.57 Mha, or 52.7% of the D5 saved forest) and South

Africa (0.46 Mha, or 50.5% of the D4 saved forest). By contrast, the considerably larger land demand in the rest of Europe (43.4% of the D1–D8 total land demand) has relatively smaller impacts on local ecosystems (10.9% of the D1–D8 total biodiversity loss) because land conversions are mostly from pastureland.

Given the ongoing Russian invasion in Ukraine and the associated sanctions, and the destruction of agricultural land in Ukraine, it becomes implausible to outsource cropland in the conflict zones (Russia, Ukraine and Belarus). Therefore, we relocated those outsourcing croplands, which were originally assigned to Russia, Ukraine and Belarus, to the rest of the exporters to the European Union. As shown in Supplementary Tables 6–8, because of land productivity difference, an additional cropland expansion of 0.47 Mha is needed to compensate the loss of the EGD's outsourcing cropland in the conflict zones (5.12 + 0.47 Mha). This additional demand for cropland implies additional carbon emissions of 20.0 MtCO₂e and biodiversity loss of 0.46 million MSA-loss.

Possible options to mitigate the spillover effects

To reduce the spillover impacts of the EGD, we propose the following three mitigation strategies (Table 1), which are not (as of this writing) targeted in the EGD: M1, substantially enhancing crop yield outside the European Union; M2, phasing out all food-based biofuel within the European Union; and M3, adapting diets in the European Union to align with the EAT-Lancet recommendation. To assess the environmental impacts of M1–M3, we assume that all the saved cropland compared with 2020 would become fallow first before being turned into grassland. Figure 3a and Extended Data Table 4 report that cropland savings from M1–M3 amount to 11.7 Mha, which is much smaller than the additional outsourcing under the EGD scenarios (23.9 Mha). However, dietary change will benefit more within the European Union, resulting in a decreased demand for cropland of 15.7 Mha (Extended Data Table 5). This leads to a mitigation effect of cropland savings by 3.5 Mha, which can potentially contribute to a noticeable reduction in agricultural-related GHG emissions and substantial restoration in biodiversity, compared with the baseline year. More specifically, shifting towards a diet with less meat and dairy products (Extended Data Table 4, M3) will contribute the largest cropland savings, amounting to 9.9 Mha, or 84.5% of cropland savings from M1–M3 outside the European Union. Reducing pig-meat consumption alone (Extended Data Table 6) can lead to a savings of cropland outside the European Union of 4.50 Mha (45.7% of the cropland savings from M3).

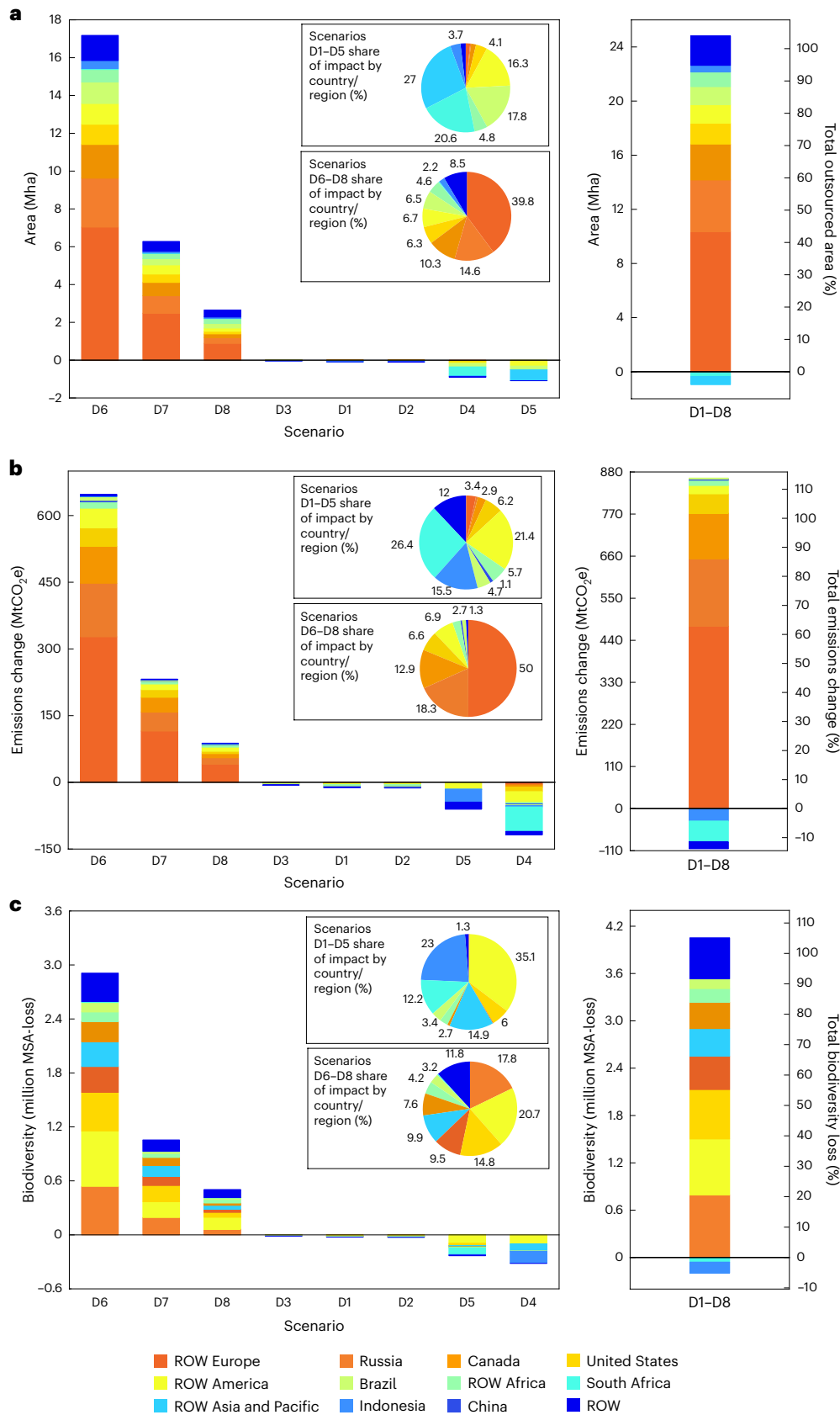


Fig. 2 | Outsourced cropland, GHG emissions and biodiversity loss under different EGD scenarios. a, Outsourced cropland. **b**, Outsourced GHG emissions. **c**, Outsourced biodiversity loss. The bar charts show the total impacts

of land, GHG emissions and biodiversity under different EGD scenarios, and the pie charts show the shares of those impacts in each country/region. ROW, rest of the world.

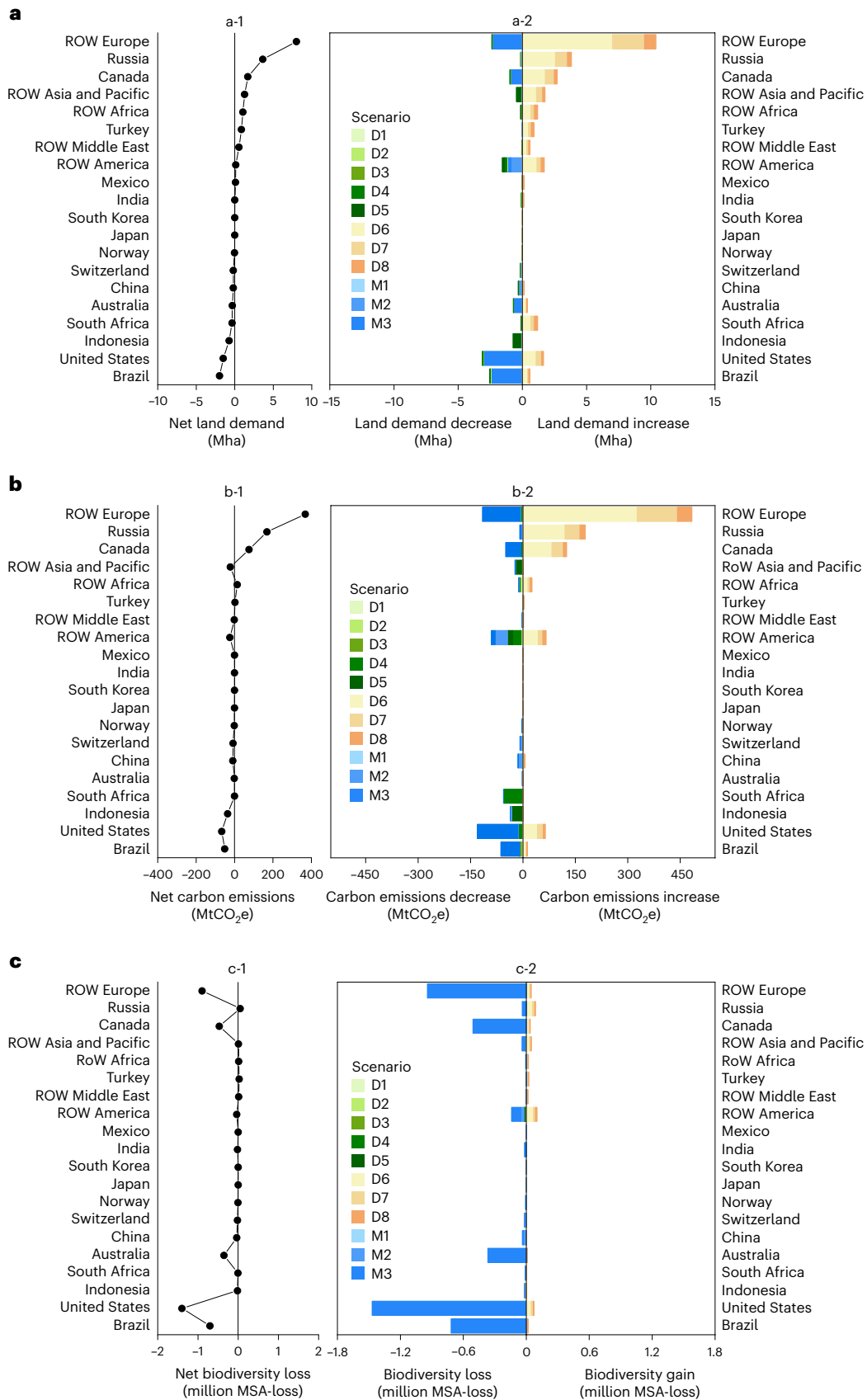


Fig. 3 | Outsourced land, GHG emissions and biodiversity loss under different EGD and EGD mitigation scenarios. a–c. The net impacts on land, GHG emissions and biodiversity loss of all EGD and EGD mitigation scenarios (a-1, b-1, c-1) and the impacts by individual scenarios and by country/region (a-2, b-2, c-2).

Among the EGD's sourcing regions, the United States and Brazil will benefit most (Extended Data Table 4, M3), saving 3.0 Mha (26.0% of M1–M3 cropland) and 2.5 Mha (21.0% of M1–M3 cropland), respectively. Phasing out food-based biofuel within the European Union (M2) can potentially reduce cropping areas for growing bioenergy crops (1.75 Mha), mainly in the ecological hotspots of the rest of America (0.90 Mha, 51.2% of cropland savings from M2). Effects from M1 are very limited (0.06 Mha), however, because current crop yields in most countries have already reached the best attainable levels under the condition of intermediate level of inputs and management as defined by the GAEZ model. In addition, dietary changes will lead to cropland following, mainly in Spain (2.9 Mha), France (2.8 Mha) and Germany (2.0 Mha) (Extended Data Table 5). Among all the potential benefits from reducing animal-based product consumption, Spain will be the biggest contributor in pig meat (24.9%, 1.7 Mha), poultry (19.4%, 0.37 Mha), eggs (20.8%, 0.12 Mha) and lamb (27.8%, 0.03 Mha). France will dominate in dairy (19.4%, 0.73 Mha) and beef (23.6%, 0.57 Mha).

Figure 3b together with Extended Data Table 7 show that the pattern of GHG emissions from agricultural land-use changes outside the European Union is similar to that of the cropland demand changes discussed in the preceding (Fig. 2). Compared with the net emissions increase (758.9 MtCO₂e) caused by the EGD scenarios, the three mitigation strategies in combination are able to reduce GHG emissions by about 404.8 MtCO₂e, including 338.8 MtCO₂e from changes in diet (M3) (83.7% of the total GHG emissions reduction under M1–M3), 65.3 MtCO₂e from phasing out food-based biofuel (M2) and 0.7 MtCO₂e from crop yield promotion (M1), respectively. Dietary change (M3) will also lead to a GHG emissions reduction of 330.2 MtCO₂e within the European Union (Extended Data Table 8).

From a regional perspective, the most substantial reduction in GHG emissions, resulting from the combination of M1–M3 (Extended Data Table 7), is expected from the United States (117.6 MtCO₂e), the rest of Europe (108.8 MtCO₂e) and Brazil (53.2 MtCO₂e). These regions account for 29.1%, 26.9% and 13.2%, respectively, of the total reduction in GHG emissions resulting from M1–M3. In more detail, the United States is able to achieve the biggest emissions reduction under dietary change scenario M3 (116.2 MtCO₂e, representing 34.3% of the reduction under M3). The rest of America leads in emissions reduction from the biofuels scenario (M2) with 34.8 MtCO₂e and is the fifth biggest contributor in GHG reductions resulting from the diet change scenario (M3) with a reduction of 10.8 MtCO₂e, which accounts for 53.3% and 3.2% of the emissions reduction under the M2 and M3 scenarios, respectively. In Russia, promoting crop yields (M1) is expected to result in a slight decrease of 0.5 MtCO₂e, which constitutes 74.2% of the total decrease under M1. As for the EU countries (Extended Data Table 8), Germany will benefit the most, with a GHG emissions reduction of 89.2 MtCO₂e, followed by Denmark (–56.4 MtCO₂e) and Finland (–26.9 MtCO₂e), which account for 27.0%, 17.1% and 8.1% of the total GHG emissions within the European Union.

Figure 3c and Extended Data Table 9 indicate that implementing these mitigation measures could result in vast cropland areas being left fallow and then converted to grassland, pastureland or rangeland, thus potentially reducing global biodiversity loss by about 4.3 million MSA-loss. This reduction is about 1.1 times of the biodiversity loss outsourced by the EGD (3.86 million MSA-loss), and all the countries and regions will experience a net biodiversity increase with these mitigation measures. However, the potential gains vary greatly across countries and regions. The United States (–1.5 million MSA-loss), the rest of Europe (–0.9 million MSA-loss) and Brazil (–0.7 million MSA-loss) stand to benefit the most. Among mitigation scenarios, changes in diet (M3) plays the dominant role and contributes 97.9% (–4.2 million MSA-loss) of the total benefits. Such changes include reducing consumption of animal-based food, which would help protect ecosystems outside the European Union, especially in the United States (–1.5 million MSA-loss), the rest of Europe (–0.9 million MSA-loss) and Brazil (–0.7 million

MSA-loss), as all these areas have experienced agricultural expansion for animal feeds and deforestation, thus severely impacting local ecosystems. Biodiversity gains from M1 (–0.001 million MSA-loss, 0.03% of the total biodiversity gains from M1–M3) and M2 (–0.09 million MSA-loss, 2.0% of biodiversity gains from M1–M3) are relatively limited. China and the rest of America, as major importers of EU food-based biofuels, will see the most notable benefits from M2, at 0.028 million MSA-loss (32.9% of biodiversity gains from M2) and 0.027 million MSA-loss (32.4% of biodiversity gains from M2), respectively. While organic agriculture could increase farmland biodiversity, estimating such impacts on a global scale is challenging and beyond the scope of our study. The European Union will also benefit from the dietary change (Extended Data Table 10), with a total biodiversity gain of 4.7 million MSA-loss. This gain is attributed mostly to the improvements in Spain (1.3 million MSA-loss), France (1.1 million MSA-loss) and Germany (0.7 million MSA-loss), which account for 26.9%, 24.1% and 15.9% of the total biodiversity gains within the European Union, respectively.

Discussion

In this study, we provide a quantitative assessment of the global spillover effects of the EGD. We compare agricultural expansion outside the European Union with land savings from importing deforestation-free products and phasing out bioenergy. We also evaluate the impacts of various EGD scenarios on land-related carbon emissions and biodiversity under the current import structure of food and forestry products. We propose three options to mitigate EGD spillover effects, estimate their impacts and evaluate their effectiveness. Our wall-to-wall comparison approach offers a more detailed and accurate assessment of land-use changes and their implications than previous studies. By showcasing the spatial distribution of potential land-use changes, our findings offer valuable insights for policymakers, enabling them to design targeted interventions that more effectively address environmental and socioeconomic challenges.

The spillover assessment shows that the EGD's agricultural and forestry objectives for 2030 would increase the demand for agricultural land outside the European Union by 23.9 Mha. This could lead to a substantial rise in land-use-related CO₂ emissions, estimated at 758.9 MtCO₂e, which is 244.8% of the EGD's carbon mitigation goal (310 MtCO₂e) in the land, land-use change and forestry sectors. In addition, this expansion could result in a biodiversity loss of approximately 3.86 million MSA-loss, surpassing the environmental gains anticipated from EGD's conservation-focused import policies. To achieve the EGD's bioenergy plan, about 9 Mha of EU cropland would need to be converted to bioenergy plantations, accounting for roughly 8.1% of the European Union's total cropland (year 2020). This conversion alone would drive about 65.8% of the EGD-induced total agricultural land outsourcing (D6–D8), leading to ecosystem damage and potential carbon release outside the European Union.

By contrast, simulations of the three mitigation options, especially the diet changes, provide more encouraging insights. Shifting dietary patterns towards reduced consumption of animal-based products emerges as the most effective way to lessen land-use stress and the land-related GHG emissions and biodiversity loss associated with animal feed production. This shift could fully mitigate the EGD's spillover effect on cropland outside the European Union, the GHG emissions resulting from agricultural land use and biodiversity degradation^{26,27}, if considering benefits within the European Union as well. This finding has twofold implications. First, it highlights the considerable effect of consumer choices on land-use and environmental impacts, underscoring the importance of informing the public on how altering dietary preferences can have a global impact. Second, policies could be developed to encourage dietary shifts, emphasizing the environmental benefits of reducing meat and dairy consumption.

Adopting a dietary change strategy within the European Union also enhances resilience against disruptions in international supply

chains caused by geopolitical conflicts or global health crises. Such disruptions threaten the successful implementation of EGD policies and compromise food security in countries reliant on food imports. For example, the COVID-19 pandemic put immense pressure on global food markets²⁸, with supply shortfalls from major food-exporting countries such as Russia and Ukraine causing food price surges and concerns over global food-supply stability²⁹. The European Union, heavily reliant on imports from these countries for staples such as wheat, maize, and sunflower oil, is particularly vulnerable to shortages. Recently, to address export shortfalls from Ukraine and Russia, the European Union relaxed its green agricultural policies, allowing the cultivation of fallow land for animal feed production³⁰. Aligning the EU diet with the EAT-Lancet recommendations could substantially reduce reliance on imports and animal-based products, lessening the need for emergency agricultural measures and enabling more consistent implementation of sustainable agricultural practices within the European Union.

While a drastic dietary shift is the most effective way to reduce the European Union's outsourced environmental impact, it faces several great challenges³. These include entrenched practices in food production, existing trade agreements, resistance to measures such as a 'meat tax,' difficulties in substituting dietary proteins, and the need for increased public awareness and willingness among policymakers and society. The delay in policy implementation and land management decisions further impedes food system transformation. Despite these challenges, promoting sustainable diets remains essential. Educational programmes are crucial to raise awareness and foster behavioural changes. These programmes should focus on the benefits of sustainable diets for health and the environment, while also addressing cultural and economic barriers. By doing so, they can help create a more informed and motivated populace, which is essential for driving the policy changes needed to achieve the EGD goals. Engaging various stakeholders, including governments, industries and communities, in a coordinated effort will be key to overcoming these obstacles and ensuring a successful transition to more sustainable food systems.

The results also show that phasing out food-based biofuel within the European Union could drastically reduce cropping areas for bioenergy crops in ecological hotspots, suggesting a need to reevaluate biofuel policies. Compared with land-intensive bioenergy, alternative renewable energy sources such as solar and wind power demand less land³¹. Replacing food-based biofuel with agricultural and forestry biomass residues and biomass waste within the European Union would reduce the spillover effects of the EGD and benefit ecosystems globally.

The EGD, while ambitious, risks being perceived as a superficial effort to assert global green leadership if it fails to achieve tangible net benefits for the planet. Without a radical shift in dietary habits, the EGD could result in a net loss for the global environment. Many EGD targets focus primarily on agricultural production, land use and biodiversity rather than dietary change and food consumption within the European Union. In addition, the EGD's implementation may lead to higher food prices and threaten food security in poorer countries, particularly in Africa and Asia. Internal conflicts between the targets of different EU Directorate-Generals (EU-DG) further complicate the EGD's implementation. For example, the EGD promotes a transition to renewable energy, which can potentially conflict in the short term with maintaining industrial competitiveness and economic stability (EU-DG GROW); the EGD's environmental standards can conflict with EU trade agreements (EU-DG TRADE); and subsidies for intensive farming (EU-DG AGRI) can lead to increased GHG emissions, soil degradation and water pollution, undermining the EGD's environmental goals. These conflicts highlight the need for a more integrated and holistic approach to policymaking to ensure that the EGD's goals are met without exacerbating global environmental and food security challenges.

It is worth noting that the European Commission and many EU countries have recognized the importance of bioeconomy strategies

as a major component for implementing the EGD. These strategies involve the sustainable use of biological resources and the enhancement of local ecosystems. They aim to meet targets set by regulations such as Land Use, Land-Use Change, and Forestry and promote deforestation-free products, both of which are key scenarios developed in this study. To mitigate spillover impacts, bioeconomy policies that encourage sustainable consumption, a circular economy and adherence to the waste hierarchy are critical. For example, replacing food-based biofuels (EGD mitigation M2 scenario) or bioenergy crop-based biofuels (EGD D1 scenario) with biofuels derived from recycled waste oil and animal fat within the European Union can substantially reduce land demand and associated spillover effects. Promoting sustainable agricultural intensification and yield improvement with financial and technological support, both within and outside the European Union, is also an effective solution. This is particularly important for EU trade partners that rely heavily on virtual cropland imports (for example, the rest of America) and regions with relatively low crop yields (for example, the rest of Africa). By implementing these strategies, the European Union can enhance its bioeconomy, support global sustainability efforts and achieve the EGD's ambitious goals while mitigating negative externalities and promoting a more sustainable global agricultural system.

Methods

Future scenarios

Table 1 presents the specifications of eight EGD scenarios and three EGD mitigation scenarios. The eight EGD scenarios are developed from the EGD with the aim to identify and quantify the policy impacts outside the European Union³². They include importing deforestation-free products from outside the European Union (D1–D4), phasing out imports of palm oil biodiesel (D5), bioenergy crops expansion up to 8.1% of the European Union's current cropland (D6), putting 25% of current EU cropland under organic agriculture (D7), and achieving a carbon sink capacity of 310 Mt from afforestation by converting cropland with low productivity to forestland within the European Union (D8). The EGD mitigation scenarios include sustainably promoting crop yield outside the European Union (M1), phasing out all food-based biofuel (M2) and shifting EU residents' diet according to EAT-Lancet recommendation (M3).

With regard to the BAU scenario, we use the land-use change projection from the Land-Use Harmonization (LUH2) dataset³³ under the SSP2 scenario (middle of the road), in which socioeconomic development trends typical of recent decades will continue, with some progress and some setbacks. This will provide a global baseline to identify the land-use change caused by EU consumption, including cropland expansion and deforestation. With regard to cropping and rotation distribution across the globe, we consider the 26 crop types of the GAEZ (Supplementary Table 1).

EEMRIO analysis

The EEMRIO is a popular top-down approach for environmental impact assessment based on monetary flows between sectors and regions. It has been widely used to establish consumption-based accounts for analysing complex interactions across the global supply chains and to connect distal (teleconnected or telecoupled) natural and human systems^{2,4,6}. The EEMRIO approach considers the entire (global) economy as its system boundary and is thus able to model the entire global production network. It distinguishes intermediate and final products and includes inter-sectoral flows in monetary values as well as in environmental terms (referred to as virtual, embodied or embedded flows) within and between countries. Therefore, environmental impacts throughout global supply chains can be captured and allocated to a wide range of final products. In this research, we quantify various environmental pressures and impacts associated with EU household consumption. One drawback of the EEMRIO approach is the high

level of sector aggregation and lack of detail at the intra-sector or product level. Existing EEMRIO tables usually aggregate agricultural products into a few larger categories depending on the purpose of the analysis. However, sectoral aggregation becomes less of an issue with recent developments and updates of EEMRIO databases such as EXIOBASE (v.3.8.1)³⁴, which is used in this study. EXIOBASE contains more than 30 sectors for agricultural and forestry products. In more detail, EXIOBASE provides annual MRIO tables over 1995–2022 for 44 countries (28 EU member countries plus 16 other major economies) and 5 rest-of-the-world regions (Supplementary Table 4), including 200 products from 163 economic sectors. Researchers had further improved the environmental footprints assessment by disaggregating the EXIOBASE regions (rest of Africa, rest of America) and the agricultural sectors^{35,36}. Although our estimation at coarser country and sector resolution could not identify the country-specific impacts for smaller countries, the forest-saving allocation at larger scale will maximize the environmental benefits by selecting the grid cells with the biggest environmental gains across the region and identify the environmental hotspots. This will further improve the effects of deforestation-free EGD scenarios by focusing on the countries with the greatest environmental potentials and adjusting their deforestation-related trade with the European Union.

GAEZ model

Conventional EEMRIO captures land appropriation and other environmental indicators only at the national level as trade flows are modelled only between countries. To augment the EEMRIO approach for further investigating geographical differences across grid cells, we couple the EEMRIO with the GAEZ model (GAEZ v.4). The GAEZ model is developed by the International Institute for Applied Systems Analysis and the Food and Agriculture Organization (FAO) of the United Nations²⁵. The GAEZ allows us to model up to 49 crops dependent on land and water resources, soil types, slope and terrain, land cover, alternative input and management levels and to explicitly consider protected areas and changes in agro-climatic resources. The GAEZ includes a global optimization module to spatially allocate the required crop production to the most suitable areas. This enables us to produce global land-use maps of, for example, biofuel crops distribution on the basis of their reallocation and further aggregated by country. Results can then be linked to the MRIO analysis to identify the major driving factors of land demand changes. The GAEZ approach in combination with the global MRIO enables us to explore scenarios such as the land implications of increases in biofuel production or of organic agriculture at fine spatial resolution. The GAEZ approach also considers water availability, temperature and rainfall conditions in simulating crop growth dynamics. With its built-in suitability analysis module, this model is able to automatically match the best crop cultivars with the optimal planting date under the given projected climate, land, soil conditions and different field management levels³⁷. On the basis of simulated potential yields of individual crops, crop suitability analysis and food import demand from different EGD scenarios and EGD mitigation scenarios, we are able to allocate the required crops to the best locations across different regions of the world.

Global emissions analysis

The land-based carbon emission is estimated using the EX-Ante Carbon Balance Tool (EX-ACT v.9.2)³⁸. This tool follows the IPCC (Intergovernmental Panel on Climate Change) methodology for GHG emissions inventories, which is based on the land-use and management practices. It accounts for the GHG emissions and biodiversity impact from agriculture, forestry and other land-use sectors, including specific project inputs of field management, energy, infrastructure, soil and so on³⁹. Therefore, it is a suitable tool to estimate the land-use change caused by GHG emissions in this study. The agricultural land expansion map from the GAEZ model is used to locate the land-cover transition grids

and determine the specific input for the EX-ACT tool, such as the IPCC climate zone, soil type, ecological zone and water-table depth.

The EX-ACT is a small-scale, project-level tool; we need to upscale it for the regional land-based carbon emissions estimation. A few assumptions are made for its upscaling: Under all future scenarios, cropland expansion would be more likely to occur in mixed grids first (grids mixed with agricultural land and other land cover), then the surrounding pasture/grassland. But the expansion would not happen onto existing forestland.

Please note that we assumed all the saved cropland from EGD would fallow first and then turn into grassland; we estimated their land carbon emissions difference using the FAO EX-Ante Carbon Balance Tool.

Physical trade model

To estimate changes in demand for barley, rapeseed, maize, soybean and wheat induced by dietary change in general and reducing animal-based food consumption (beef, pork, poultry, lamb, eggs and dairy) in particular, we applied a physical trade model⁴⁰ to track animal-based food trade flows. The physical trade model uses national production and bilateral trade data to trace the consumption of agricultural products throughout global supply chains.

To account for processed products in global trade, such as soy cake made from soybeans, processed foods are converted into primary product equivalents. In the first step, the physical trade model is applied for individual agricultural products and years. This step provides us with the yearly amount and origin of these products consumed in the European Union. In the second step, we multiply the amount of each product by yearly national yield to compute the extent of crop or pastureland needed for the required production. This results in annual land-use footprints of the EU consumption for individual agricultural products and by country/region.

We use data from FAOSTAT⁴¹ as inputs in the model. National production values, as well as total national import and export values, are taken from the commodity balances until 2013 and from the food balance sheets from 2014 to 2018. If there are no data available in the commodity balances and food balance sheets, we use national production data directly from the national production accounts. Bilateral trade data are sourced from the detailed trade matrix. Furthermore, FAOSTAT provides national pastureland and cropland data.

Land-use data

The LUH2⁴² is employed to obtain the land-use maps from 2020 to 2030. The LUH2 aims at preparing a harmonized set of land-use scenarios that connect the historical reconstructions of land use with the future projections. It estimates the fraction of each land-use type and land-use transition in each grid cell at the spatial resolution of 0.25°. The major land-use types include forest, pasture, rangeland, annual crops (C3 and C4 crops), perennial crops (C3 and C4 crops), nitrogen-fixing crops and urban. The forest and non-forestland uses are subdivided into primary and secondary. The primary land refers to natural vegetation that has never been impacted by human activities such as agriculture or wood harvesting since the beginning of our simulation. In this study, we use the LUH2 annual data from 2020 to 2030 to obtain the land-use transition between different land-use types, and the agricultural expansion under the SSP2 scenario during the study period defines the BAU baseline.

Crop harvest area data

The global gridded crop dataset⁴³ (GAEZ+ 2015) is employed to obtain the annual crop harvest area. The GAEZ+ 2015 provides global irrigated and rainfed cropping areas of 26 different crops/crop categories (Supplementary Table 3) in 2015 with a spatial resolution of 5 arcmin. This dataset is based on national statistics of 160 crops from FAOSTAT and developed from the GAEZ model simulations, providing more recent

data on production, yield and harvest area. In this study, we use the gridded harvest area data to obtain the country-level cropping system, including share of harvest area and multiple cropping index. The multiple cropping index is estimated by dividing all the crops' harvest area with the cropland area in each country. We also assume agricultural expansion follows the same cropping system in potential grid cells within a country.

Sector allocation onto grid cells

We need to allocate the EU outsourced deforestation footprint onto grid cells. This is done by the following four steps (Supplementary Fig. 4a). (1) We use the LUH2 data to obtain the map of the deforested area caused by cropland expansion under BAU (2020–2030), including primary forest and secondary forest converted to annual crops (C3 and C4 crops), N-fixing crops and perennial crops (C3 and C4 crops). (2) We compute the share of each sector's land footprint that is required for EU consumption using the MRIO analysis and the EXIOBASE dataset for 2020. We also assume that the trade structure across countries/regions will remain the same during the study period; thus, the sectoral shares of the European Union's land footprint will be unchanged. (3) We regroup the EXIOBASE sectors to match the LUH2 land-use types, especially the crop types between the EXIOBASE and LUH2 and calculate the EU share under the regrouped sectors. (4) Finally, the deforested area from step (1) and sectoral land footprint shares from steps (2) and (3) are used to obtain the deforested area driven by EU consumption on each deforestation grid cell. In the case of allocating forest saving (under D1–D5), we prioritize grid cells within the EXIOBASE country/region that have the biggest potential for environmental gains in the projected deforestation area. This approach maximizes the benefits from the deforestation-free EGD scenarios.

For allocating the EGD outsourced agricultural expansion, we adopt the following rule of priority (Supplementary Fig. 4b). (1) We compute the crop production loss from the EGD scenarios of bioenergy expansion, organic agriculture and carbon sink and then calculate the additional food import from EU trade partners using the Physical Trade Model. (2) In each EU importer, the mixed grid cells of cropland and potential land-use types (except for primary and secondary natural forest) will be converted into cropland first. (3) If the food production from all the mixed grid cells in a country/region still could not meet the European Union's additional demand, then current managed pasture or rangeland grid cells near the existing cropland will be taken for agricultural expansion, starting from the grid cell with the highest yield. (4) No expansion will occur on other land-use types than the ones listed in steps (1)–(3).

The specific crop selection and land expansion order of the grid cells in each EXIOBASE country/region follows the GAEZ suitability classification maps and best attainable yield levels, and only those above the level of 'suitable' are considered. The potential land is used for main crops first (cereal crops, oil crops, sugar crops), followed by vegetables and other perennial plants (for example, fruit and nut trees). The rule of priority is to allocate each crop to the best available suitability class on the potential land until meeting the European Union's additional demand. However, if the European Union's additional demand cannot be met in the country by the preceding allocation procedure, the remaining food import quantity will be redistributed to other countries/regions according to European Union's current food import structure.

For allocating the cropland's fallowing and conversion into grassland, rangeland or pastureland, the following rules are adopted (Supplementary Fig. 5). (1) If existing cropland is converted to potential land options of grassland, rangeland and pastureland, we use the average biodiversity of each potential land option within a country to represent the biodiversity after land conversion. On each existing cropland grid cell, the potential land conversion with the biggest biodiversity gains is selected. (2) The extent of land savings is equal to the reduction in the

quantity of export to the European Union divided by the sustainably promoting crop yield. The food demand change is estimated under the EGD mitigation scenarios of phasing out all food-based biofuels (M2) and EU residents' dietary change (M3) and is redistributed to EU agricultural trade partners. (3) A new index of 'biodiversity gains per unit of crop yield' on each cropland grid cell is developed to identify the cropland retirement priority, where the cells with relatively low yield but high biodiversity gains will be taken first.

Compared with similar studies that combine the economic trade model with a physical crop model⁴⁴, our model includes cropping adaptation to guide the cropland expansion on more suitable grid cells with higher attainable crop yield, thus minimizing the land demand and the corresponding GHG emissions as well as the biodiversity loss. Similarly, the selection of forest-saving grids on the lower yield ones will optimize the potential benefits of biodiversity preservation.

MSA

The MSA is applied to determine the impacts of land use on biodiversity loss induced by changes in European imports under the EGD scenarios and the mitigation scenarios. The MSA measures local impacts of pressures, such as land use in this study, on biodiversity⁴⁵. For each species present in the local environment, its abundance after applying the pressure is divided by its abundance in an undisturbed, pristine situation to receive its relative abundance, as a value between 0 and 1. Subsequently, the mean abundance, or MSA, of all present species in the local environment is computed. If an applied pressure results in an increase of an opportunistic species, the value is fixed at 1 to avoid misleading effects on the MSA⁴⁶. Hence, an MSA value of 1 describes an undisturbed environment, while high pressure from land use will result in lower MSA values. Biodiversity loss/gain in a larger area is measured as MSA-loss by multiplying the specific land-cover change area between non-cropland and cropland with the corresponding MSA loss per hectare (between 0 and 1) in each grid cell, then aggregating all the grid cells' MSA losses within the study region. The biodiversity change coefficients (MSA-loss ha⁻¹), which translate land use into biodiversity impacts, are applied to the results of the GAEZ model. The agricultural land expansion maps under different EGD scenarios are used to overlap with the MSA-loss map and extract the biodiversity loss in each EXIOBASE region/country. However, because the ecosystem restoration is a gradual but complex process, when assessing the biodiversity impact of the EGD mitigation scenarios, we assume that the cropland would become fallow first and then converted into the nearby grassland, rangeland or pastureland with the biggest biodiversity gains within each country.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Global MRIO table, final demand data and environmental extensions, including the EU member countries, are from the EXIOBASE v.3.8.1 database (<https://zenodo.org/record/4588235>) (ref. 47). The agricultural statistics, including the national crop production, food import and export, are from the commodity balance sheets from FAOSTAT (<https://www.fao.org/faostat/en/>). The bilateral trade data are from the detailed trade matrix from FAOSTAT. The spatial dataset of the mean species abundance (MSA) in year 2015 and the land-use data in year 2020 are from the GLOBIO4 scenario data (<https://www.globio.info/globio-data-downloads>). The global gridded crop dataset, including the annual rainfed and irrigated crops harvest area, was collected from the GAEZ+₂₀₁₅ dataset (https://dataverse.harvard.edu/dataverse/GAEZ_plus_2015). The global land-use projections for specific crops between 2020 and 2030 under SSP2 were obtained from the Land-Use Harmonization (LUH2; <https://luh.umd.edu/>). For creating maps,

shapefiles from National Geomatics Center of China (<https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/>) and the ArcGIS (v. 10.5) software were used. The GAEZ v.4 model and its inputs under intermediate input level and high input level are available from the GAEZ portal (<https://www.gaez.iiasa.ac.at/>, <https://gaez.fao.org/>). The main results are available in the Extended Data tables and Supplementary Information.

Code availability

Code was developed in MATLAB to process and analyse the primary data, which will be available from the corresponding authors on reasonable request. The sequential quantitative analyses were conducted using ArcGIS (v.10.5) and Microsoft Excel (v.2021) software.

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Author contributions

K.H., K.F., L.S. and H.Z. designed the study. H.Z., Y.L., J.D. and B.B. performed the analysis and prepared the manuscript. K.F., L.S. and K.H. coordinated and supervised the project. All authors (H.Z., Y.L., J.D., B.B., K.F., L.S., C.P., Y.S. and K.H.) participated in writing the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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Extended Data Table 1 | Cropland expansion and forest saving area (thousand ha) and share (%) outside the EU under the EGD

Cropland expansion area (thousand ha)												
EGD	WE	RU	CA	US	WA	WL	WF	ZA	ID	BR	ROW	Total
D6	7036.02	2587.04	1784.44	1067.31	1097.85	1136.22	661.97	58.98	2.65	415.34	1330.98	17178.81
D7	2477.98	925.31	706.47	443.80	484.93	326.87	276.60	25.61	1.20	86.77	521.49	6277.02
D8	882.91	305.74	199.47	134.00	173.66	242.80	251.81	18.43	0.88	68.84	371.57	2650.11
Total	10396.91	3818.09	2690.38	1645.11	1756.43	1705.89	1190.38	103.03	4.73	570.96	2224.04	26105.94
Forest saving area (thousand ha)												
EGD	WE	RU	CA	US	WA	WL	WF	ZA	ID	BR	ROW	Total
D5	0.00	0.00	0.00	0.00	-313.86	-184.32	-14.30	0.00	-572.91	-1.81	-0.02	-1087.22
D4	-29.00	0.00	-36.92	-67.16	-38.11	-172.49	-27.94	-458.81	-25.72	-13.26	-38.46	-907.86
D2	-3.29	-3.76	-0.26	-7.53	-5.55	-19.45	-31.78	0.00	-1.13	-20.81	-1.83	-95.38
D1	-3.42	-3.81	-1.50	-7.17	-5.35	-19.00	-31.72	0.00	-1.16	-14.42	-1.79	-89.34
D3	-0.14	-0.14	-1.65	-9.78	-0.23	-1.50	-0.16	0.00	-0.24	-32.32	-0.34	-46.50
Total	-35.85	-7.71	-40.35	-91.64	-363.10	-396.75	-105.90	-458.81	-601.15	-82.62	-42.43	-2226.31
Total (D1-D8)	10361.06	3810.38	2650.04	1553.47	1393.33	1309.14	1084.48	-355.78	-596.42	488.34	2181.61	23879.63
Cropland expansion area (%)												
EGD	WE	RU	CA	US	WA	WL	WF	ZA	ID	BR	ROW	Total
D6	40.96%	15.06%	10.39%	6.21%	6.39%	6.61%	3.85%	0.34%	0.02%	2.42%	7.75%	65.80%
D7	39.48%	14.74%	11.25%	7.07%	7.73%	5.21%	4.41%	0.41%	0.02%	1.38%	8.31%	24.04%
D8	33.32%	11.54%	7.53%	5.06%	6.55%	9.16%	9.50%	0.70%	0.03%	2.60%	14.02%	10.15%
Total	39.83%	14.63%	10.31%	6.30%	6.73%	6.53%	4.56%	0.39%	0.02%	2.19%	8.52%	100.00%
Forest saving area (%)												
EGD	WE	RU	CA	US	WA	WL	WF	ZA	ID	BR	ROW	Total
D5	0.00%	0.00%	0.00%	0.00%	28.87%	16.95%	1.32%	0.00%	52.69%	0.17%	0.00%	48.84%
D4	3.19%	0.00%	4.07%	7.40%	4.20%	19.00%	3.08%	50.54%	2.83%	1.46%	4.24%	40.78%
D2	3.44%	3.94%	0.27%	7.89%	5.82%	20.39%	33.32%	0.00%	1.18%	21.82%	1.92%	4.28%
D1	3.82%	4.26%	1.68%	8.03%	5.99%	21.27%	35.50%	0.00%	1.30%	16.14%	2.00%	4.01%
D3	0.31%	0.30%	3.56%	21.03%	0.49%	3.22%	0.35%	0.00%	0.51%	69.52%	0.73%	2.09%
Total	1.61%	0.35%	1.81%	4.12%	16.31%	17.82%	4.76%	20.61%	27.00%	3.71%	1.91%	100.00%
Total (D1-D8)	43.39%	15.96%	11.10%	6.51%	5.83%	5.48%	4.54%	-1.49%	-2.50%	2.05%	9.14%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4. ROW refers to Rest of the World.

Extended Data Table 2 | Land-related GHG emissions change amount (thousand-ton CO₂-e) and share (%) outside the EU under the EGD

GHG emissions changes from cropland expansion (thousand ton CO ₂ -e)												
EGD	WE	RU	CA	US	WL	WF	CN	BR	ID	ZA	ROW	Total
D6	327245.38	120323.24	82994.42	41560.89	44244.24	14424.37	3282.12	9050.36	72.71	166.93	4404.25	647768.90
D7	115250.68	43036.03	32857.92	17281.55	12728.35	6027.16	1147.45	1890.79	32.81	72.48	1774.45	232099.68
D8	41064.10	14220.09	9277.27	5218.10	9454.72	5486.85	651.31	1499.99	24.15	52.17	1113.09	88061.83
Total	483560.16	177579.36	125129.61	64060.54	66427.31	25938.38	5080.88	12441.14	129.67	291.57	7291.80	967930.41
GHG emissions changes from forest saving (thousand-ton CO ₂ -e)												
EGD	WE	RU	CA	US	WL	WF	CN	BR	ID	ZA	ROW	Total
D4	-5691.19	0.00	-5491.41	-9493.30	-24383.05	-3410.48	-1816.22	-1588.69	-3280.99	-55212.95	-7662.18	-118030.46
D5	0.00	0.00	0.00	0.00	-14727.15	-726.74	-1.32	-87.85	-28886.08	0.00	-16025.97	-60455.12
D2	-644.63	-738.29	-38.96	-1064.39	-2748.95	-3879.29	-205.56	-2493.92	-143.76	0.00	-697.26	-12654.99
D1	-670.44	-747.25	-223.73	-1014.21	-2685.93	-3871.52	-199.20	-1728.31	-148.43	0.00	-674.89	-11963.90
D3	-28.20	-27.20	-246.02	-1382.37	-211.46	-19.71	-47.99	-3874.07	-30.06	0.00	-26.25	-5893.32
Total	-7034.46	-1512.74	-6000.12	-12954.27	-44756.53	-11907.74	-2270.29	-9772.83	-32489.32	-55212.95	-25086.55	-208997.80
Total (D1-D8)	476525.70	176066.62	119129.49	51106.27	21670.78	14030.64	2810.60	2668.30	-32359.66	-54921.37	-17794.75	758932.62
GHG emissions changes from cropland expansion (%)												
EGD	WE	RU	CA	US	WL	WF	CN	BR	ID	ZA	ROW	Total
D6	50.52%	18.58%	12.81%	6.42%	6.83%	2.23%	0.51%	1.40%	0.01%	0.03%	0.68%	66.92%
D7	49.66%	18.54%	14.16%	7.45%	5.48%	2.60%	0.49%	0.81%	0.01%	0.03%	0.76%	23.98%
D8	46.63%	16.15%	10.53%	5.93%	10.74%	6.23%	0.74%	1.70%	0.03%	0.06%	1.26%	9.10%
Total	49.96%	18.35%	12.93%	6.62%	6.86%	2.68%	0.52%	1.29%	0.01%	0.03%	0.75%	100.00%
GHG emissions changes from forest saving (%)												
EGD	WE	RU	CA	US	WL	WF	CN	BR	ID	ZA	ROW	Total
D4	4.82%	0.00%	4.65%	8.04%	20.66%	2.89%	1.54%	1.35%	2.78%	46.78%	6.49%	56.47%
D5	0.00%	0.00%	0.00%	0.00%	24.36%	1.20%	0.00%	0.15%	47.78%	0.00%	26.51%	28.93%
D2	5.09%	5.83%	0.31%	8.41%	21.72%	30.65%	1.62%	19.71%	1.14%	0.00%	5.51%	6.06%
D1	5.60%	6.25%	1.87%	8.48%	22.45%	32.36%	1.66%	14.45%	1.24%	0.00%	5.64%	5.72%
D3	0.48%	0.46%	4.17%	23.46%	3.59%	0.33%	0.81%	65.74%	0.51%	0.00%	0.45%	2.82%
Total	3.37%	0.72%	2.87%	6.20%	21.41%	5.70%	1.09%	4.68%	15.55%	26.42%	12.00%	100.00%
Total (D1-D8)	62.79%	23.20%	15.70%	6.73%	2.86%	1.85%	0.37%	0.35%	-4.26%	-7.24%	-2.34%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4. ROW refers to Rest of the World.

Extended Data Table 3 | Land-related biodiversity change amount (thousand MSA-loss) and the share (%) outside the EU under the EGD

Biodiversity changes from cropland expansion (thousand MSA-loss)												
EGD	RU	WL	US	WE	WA	CA	WF	BR	ZA	ID	ROW	Total
D6	538.90	616.06	429.84	286.41	276.36	224.79	105.29	105.58	9.58	0.62	315.60	2909.04
D7	192.75	177.23	178.73	100.87	122.07	89.00	44.00	22.06	4.16	0.28	123.82	1054.97
D8	63.69	131.65	53.97	35.94	43.72	25.13	40.05	17.50	2.99	0.21	89.12	503.96
Total	795.34	924.94	662.54	423.22	442.15	338.92	189.34	145.14	16.73	1.11	528.55	4467.97
Biodiversity changes from forest saving (thousand MSA-loss)												
EGD	RU	WL	US	WE	WA	CA	WF	BR	ZA	ID	ROW	Total
D5	0.00	-99.94	0.00	0.00	-79.01	0.00	-2.27	-0.46	0.00	-134.51	0.00	-316.20
D4	0.00	-93.52	-27.05	-1.18	-9.59	-4.65	-4.44	-3.37	-74.51	-6.04	-7.30	-231.66
D2	-0.78	-10.54	-3.03	-0.13	-1.40	-0.03	-5.06	-5.29	0.00	-0.26	-0.22	-26.76
D1	-0.79	-10.30	-2.89	-0.14	-1.35	-0.19	-5.04	-3.67	0.00	-0.27	-0.22	-24.86
D3	-0.03	-0.81	-3.94	-0.01	-0.06	-0.21	-0.03	-8.22	0.00	-0.06	-0.04	-13.38
Total	-1.61	-215.12	-36.91	-1.46	-91.40	-5.08	-16.84	-21.00	-74.51	-141.14	-7.77	-612.86
Total (D1-D8)	793.74	709.82	625.63	421.76	350.75	333.84	172.49	124.14	-57.78	-140.03	520.77	3855.11
Biodiversity changes from cropland expansion (%)												
EGD	RU	WL	US	WE	WA	CA	WF	BR	ZA	ID	ROW	Total
D6	18.53%	21.18%	14.78%	9.85%	9.50%	7.73%	3.62%	3.63%	0.33%	0.02%	10.85%	65.11%
D7	18.27%	16.80%	16.94%	9.56%	11.57%	8.44%	4.17%	2.09%	0.39%	0.03%	11.74%	23.61%
D8	12.64%	26.12%	10.71%	7.13%	8.67%	4.99%	7.95%	3.47%	0.59%	0.04%	17.68%	11.28%
Total	17.80%	20.70%	14.83%	9.47%	9.90%	7.59%	4.24%	3.25%	0.37%	0.02%	11.83%	100.00%
Biodiversity changes from forest saving (%)												
EGD	RU	WL	US	WE	WA	CA	WF	BR	ZA	ID	ROW	Total
D5	0.00%	31.61%	0.00%	0.00%	24.99%	0.00%	0.72%	0.15%	0.00%	42.54%	0.00%	51.59%
D4	0.00%	40.37%	11.68%	0.51%	4.14%	2.01%	1.92%	1.45%	32.17%	2.61%	3.15%	37.80%
D2	2.93%	39.41%	11.33%	0.50%	5.22%	0.12%	18.89%	19.77%	0.00%	0.99%	0.83%	4.37%
D1	3.19%	41.44%	11.62%	0.56%	5.42%	0.76%	20.29%	14.74%	0.00%	1.10%	0.88%	4.06%
D3	0.22%	6.06%	29.43%	0.04%	0.43%	1.56%	0.19%	61.39%	0.00%	0.41%	0.27%	2.18%
Total	0.26%	35.10%	6.02%	0.24%	14.91%	0.83%	2.75%	3.43%	12.16%	23.03%	1.27%	100.00%
Total (D1-D8)	20.59%	18.41%	16.23%	10.94%	9.10%	8.66%	4.47%	3.22%	-1.50%	-3.63%	13.51%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4. ROW refers to Rest of the World.

Extended Data Table 4 | Cropland saving area (thousand ha) and share (%) outside the EU under EGD mitigation scenarios

Cropland saving area (thousand ha)												
EGD mitigation	US	BR	WE	WL	CA	AU	CN	RU	ID	WA	ROW	Total
M3	-2996.45	-2448.92	-2327.00	-278.50	-938.87	-690.60	-13.56	-72.42	-0.06	-48.96	-50.27	-9865.62
M2	-37.67	-1.09	-20.96	-897.04	0.00	-2.28	-284.34	-74.00	-129.68	-54.61	-251.56	-1753.22
M1	0.00	-0.03	-2.28	-0.79	0.00	-0.01	0.00	-11.49	0.00	-3.76	-40.72	-59.09
Total	-3034.12	-2450.05	-2350.24	-1176.34	-938.87	-692.89	-297.91	-157.91	-129.75	-107.33	-342.54	-11677.93
Cropland saving area (%)												
EGD mitigation	US	BR	WE	WL	CA	AU	CN	RU	ID	WA	ROW	Total
M3	30.37%	24.82%	23.59%	2.82%	9.52%	7.00%	0.14%	0.73%	0.00%	0.50%	0.51%	84.48%
M2	2.15%	0.06%	1.20%	51.17%	0.00%	0.13%	16.22%	4.22%	7.40%	3.11%	14.35%	15.01%
M1	0.00%	0.05%	3.86%	1.34%	0.00%	0.02%	0.00%	19.44%	0.01%	6.37%	68.91%	0.51%
Total	25.98%	20.98%	20.13%	10.07%	8.04%	5.93%	2.55%	1.35%	1.11%	0.92%	2.93%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4. ROW refers to Rest of the World.

Extended Data Table 5 | Cropland saving area (thousand ha) and share (%) within the EU under EAT-Lancet diet scenario (M3)

Cropland saving area (thousand ha)												
EAT-Lancet diet scenario	ES	FR	DE	PL	DK	RO	HU	FI	CZ	SE	Rest of EU countries	Total
Pig meat	-1727.08	-1024.87	-951.86	-537.09	-670.57	-342.66	-303.93	-156.92	-153.50	-116.85	-950.49	-6935.83
Dairy	-281.84	-728.86	-576.94	-314.78	-282.62	-156.49	-158.49	-224.62	-125.85	-111.48	-790.05	-3752.03
Beef	-366.23	-566.55	-286.16	-182.18	-128.09	-96.77	-82.12	-107.24	-59.18	-72.46	-455.31	-2402.29
Poultry	-373.68	-318.19	-152.37	-290.36	-107.18	-98.73	-121.96	-67.50	-51.86	-28.20	-312.48	-1922.51
Egg	-118.64	-104.02	-60.58	-43.07	-26.64	-31.22	-28.78	-23.12	-14.32	-20.05	-99.45	-569.88
Lamb	-34.23	-24.27	-7.53	-3.61	-3.85	-10.18	-3.51	-1.10	-2.12	-1.66	-31.30	-123.37
Total	-2901.70	-2766.76	-2035.45	-1371.09	-1218.95	-736.05	-698.80	-580.51	-406.83	-350.71	-2639.07	-15705.91
Cropland saving area (%)												
EAT-Lancet diet scenario	ES	FR	DE	PL	DK	RO	HU	FI	CZ	SE	Rest of EU countries	Total
Pig meat	24.90%	14.78%	13.72%	7.74%	9.67%	4.94%	4.38%	2.26%	2.21%	1.68%	13.70%	44.16%
Dairy	7.51%	19.43%	15.38%	8.39%	7.53%	4.17%	4.22%	5.99%	3.35%	2.97%	21.06%	23.89%
Beef	15.24%	23.58%	11.91%	7.58%	5.33%	4.03%	3.42%	4.46%	2.46%	3.02%	18.95%	15.30%
Poultry	19.44%	16.55%	7.93%	15.10%	5.58%	5.14%	6.34%	3.51%	2.70%	1.47%	16.25%	12.24%
Egg	20.82%	18.25%	10.63%	7.56%	4.67%	5.48%	5.05%	4.06%	2.51%	3.52%	17.45%	3.63%
Lamb	27.75%	19.68%	6.11%	2.93%	3.12%	8.25%	2.85%	0.89%	1.72%	1.35%	25.37%	0.79%
Total	18.48%	17.62%	12.96%	8.73%	7.76%	4.69%	4.45%	3.70%	2.59%	2.23%	16.80%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4.

Extended Data Table 6 | Cropland saving area (thousand ha) and share (%) outside EU under EAT-Lancet diet scenario (M3)

Cropland saving area (thousand ha)												
Animal-based products	US	BR	WE	CA	AU	WL	RU	WA	IN	CN	Rest of the World	Total
Pig meat	-1383.24	-1187.46	-1044.23	-398.94	-305.63	-118.41	-26.18	-15.57	-13.91	-5.32	-5.31	-4504.21
Dairy	-705.45	-480.98	-523.05	-226.49	-159.84	-74.37	-22.15	-15.36	-7.95	-4.00	-6.84	-2226.49
Beef	-451.20	-374.03	-342.27	-162.26	-117.41	-41.87	-12.00	-9.25	-5.30	-2.39	-2.71	-1520.70
Poultry	-330.40	-290.08	-308.40	-108.28	-74.00	-31.09	-8.41	-5.10	-4.06	-1.25	-2.06	-1163.14
Egg	-101.73	-89.29	-82.55	-32.64	-24.04	-9.39	-2.64	-1.95	-1.11	-0.45	-0.55	-346.34
Lamb	-24.43	-27.08	-26.50	-10.25	-9.67	-3.37	-1.04	-1.73	-0.30	-0.16	-0.23	-104.75
Total	-2996.45	-2448.92	-2327.00	-938.87	-690.60	-278.50	-72.42	-48.96	-32.62	-13.56	-17.71	-9865.62
Cropland saving area (%)												
Animal-based products	US	BR	WE	CA	AU	WL	RU	WA	IN	CN	Rest of the World	Total
Dairy	30.71%	26.36%	23.18%	8.86%	6.79%	2.63%	0.58%	0.35%	0.31%	0.12%	0.12%	45.66%
Beef	31.68%	21.60%	23.49%	10.17%	7.18%	3.34%	1.00%	0.69%	0.36%	0.18%	0.31%	22.57%
Poultry	29.67%	24.60%	22.51%	10.67%	7.72%	2.75%	0.79%	0.61%	0.35%	0.16%	0.18%	15.41%
Pig meat	28.41%	24.94%	26.51%	9.31%	6.36%	2.67%	0.72%	0.44%	0.35%	0.11%	0.18%	11.79%
Lamb	29.37%	25.78%	23.84%	9.42%	6.94%	2.71%	0.76%	0.56%	0.32%	0.13%	0.16%	3.51%
Eggs	23.32%	25.85%	25.30%	9.79%	9.23%	3.22%	0.99%	1.65%	0.29%	0.15%	0.22%	1.06%
Total	30.37%	24.82%	23.59%	9.52%	7.00%	2.82%	0.73%	0.50%	0.33%	0.14%	0.18%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4.

Extended Data Table 7 | Greenhouse gases emission amount (thousand ton CO₂-e) and share (%) caused by cropland saving outside the EU under EGD mitigation scenarios

GHGs emissions change (thousand ton CO ₂ -e)												
EGD mitigation	US	WE	BR	WL	CA	CN	RU	ID	AU	WA	Rest of the World	Total
M3	-116172.42	-107740.27	-53215.13	-10797.62	-43469.50	-525.88	-3352.95	-1.70	-1919.86	-1063.95	-528.67	-338787.94
M2	-1460.33	-970.32	-23.69	-34778.33	0.00	-11023.98	-3426.20	-3545.41	-6.33	-28.94	-10003.62	-65267.14
M1	0.00	-105.61	-0.68	-30.73	-0.08	0.00	-531.87	-0.12	-0.03	-1.99	-46.04	-717.16
Total	-117632.75	-108816.20	-53239.50	-45606.67	-43469.58	-11549.86	-7311.02	-3547.23	-1926.22	-1094.88	-10578.32	-404772.24
GHGs emissions change (%)												
EGD mitigation	US	WE	BR	WL	CA	CN	RU	ID	AU	WA	Rest of the World	Total
M3	34.29%	31.80%	15.71%	3.19%	12.83%	0.16%	0.99%	0.00%	0.57%	0.31%	0.16%	83.70%
M2	2.24%	1.49%	0.04%	53.29%	0.00%	16.89%	5.25%	5.43%	0.01%	0.04%	15.33%	16.12%
M1	0.00%	14.73%	0.10%	4.28%	0.01%	0.00%	74.16%	0.02%	0.00%	0.28%	6.42%	0.18%
Total	29.06%	26.88%	13.15%	11.27%	10.74%	2.85%	1.81%	0.88%	0.48%	0.27%	2.61%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4.

Extended Data Table 8 | Greenhouse gases emission amount (thousand ton CO₂-e) and share (%) caused by cropland saving within EU under EAT-Lancet diet scenario (M3)

EAT-Lancet diet scenario	DE	DK	FI	CZ	SE	LT	PL	AT	IE	NL	Rest of EU countries	Total
Amount	-89193.30	-56437.28	-26877.42	-18836.33	-16237.77	-14548.49	-14108.48	-13348.63	-9619.20	-9321.99	-61690.06	-330218.95
Share	27.01%	17.09%	8.14%	5.70%	4.92%	4.41%	4.27%	4.04%	2.91%	2.82%	18.68%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4.

Extended Data Table 9 | Biodiversity change (thousand MSA-loss) and share (%) caused by cropland conversion outside the EU under EGD mitigation scenarios

Biodiversity change (thousand MSA-loss)												
EGD mitigation	US	WE	BR	CA	AU	WL	RU	CN	WA	IN	Rest of the World	Total
M3	-1462.84	-941.15	-713.10	-506.82	-366.00	-87.75	-35.79	-8.34	-28.33	-15.55	-5.33	-4171.00
M2	-1.71	-0.55	-0.02	0.00	-0.04	-27.98	-1.44	-28.37	-1.55	-0.37	-24.36	-86.38
M1	0.00	-0.06	0.00	0.00	0.00	-0.02	-0.22	0.00	-0.11	-0.90	-0.06	-1.38
Total	-1464.55	-941.76	-713.12	-506.82	-366.04	-115.75	-37.45	-36.71	-29.98	-16.83	-29.74	-4258.76
Biodiversity change (%)												
EGD mitigation	US	WE	BR	CA	AU	WL	RU	CN	WA	IN	Rest of the World	Total
M3	35.07%	22.56%	17.10%	12.15%	8.77%	2.10%	0.86%	0.20%	0.68%	0.37%	0.13%	97.94%
M2	1.98%	0.63%	0.02%	0.00%	0.04%	32.39%	1.66%	32.85%	1.79%	0.43%	28.20%	2.03%
M1	0.00%	4.33%	0.04%	0.00%	0.01%	1.80%	16.22%	0.00%	7.74%	65.62%	4.23%	0.03%
Total	34.39%	22.11%	16.74%	11.90%	8.60%	2.72%	0.88%	0.86%	0.70%	0.40%	0.70%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4.

Extended Data Table 10 | Biodiversity change (thousand MSA-loss) and share (%) caused by cropland saving within EU under EAT-Lancet diet scenario (M3)

EAT-Lancet diet scenario	ES	FR	DE	PL	RO	SE	DK	LT	IE	EE	Rest of EU countries	Total
Amount	1270.44	1136.76	747.71	307.18	163.06	138.03	117.40	95.56	85.03	84.10	571.49	4716.76
Share	26.93%	24.10%	15.85%	6.51%	3.46%	2.93%	2.49%	2.03%	1.80%	1.78%	12.12%	100.00%

Note. The abbreviations of country and region names are presented in Supplementary Table 4.

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

- | | |
|-------------------------------------|--|
| n/a | Confirmed |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> A description of all covariates tested |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

- | | |
|-----------------|---|
| Data collection | No software was used for data collection |
| Data analysis | Code was developed in MATLAB to process and analyze the primary data, which will be available upon reasonable request. The sequential quantitative analyses were conducted using ArcGIS (v. 10.5) and Microsoft Excel (v. 2021) software. |

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

Global MRIO table, final demand data and environmental extensions, including the EU member countries, were from the EXIOBASE v.3.8.1 database (<https://zenodo.org/record/4588235>). The agricultural statistics, including the national crop production, food import and export, are from the Commodity Balance Sheets from FAOSTAT (<https://www.fao.org/faostat/en/>). The bilateral trade data is also from the Detailed Trade Matrix from FAOSTAT. The spatial dataset of the Mean

Species Abundance (MSA) in year 2015 and the land use data in year 2020 were from the GLOBIO4 scenario data (<https://www.globio.info/globio-data-downloads>). The global gridded crop dataset, including the annual rainfed and irrigated crops harvest area, was collected from the GAEZ+ _2015 dataset (https://dataverse.harvard.edu/dataverse/GAEZ_plus_2015). The global land use projection for specific crop between 2020 and 2030 under SSP2 were obtained from the Land Use Harmonization (<https://luh.umd.edu/>). For creating maps, shapefiles from National Geomatics Center of China (<https://ngcc.cn/ngcc/>) and the ArcMap software were used. The GAEZ model and its inputs under intermediate input level and high input level are available from GAEZ portal (<https://www.gaez.iiasa.ac.at/>, <https://gaez.fao.org/>). The main results are available in the Extended Data and Supplementary Information.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender	N/A
Reporting on race, ethnicity, or other socially relevant groupings	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

Life sciences Behavioural & social sciences Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see [nature.com/documents/nr-reporting-summary-flat.pdf](https://www.nature.com/documents/nr-reporting-summary-flat.pdf)

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Achieving European Green Deal targets may benefit the EU ecologically but increase global environmental impacts. This study quantifies such external impacts and suggests ways to minimize them. We examine three scenarios: (1) a 'business-as-usual' scenario continuing current land-use trends; (2) scenarios incorporating EGD policies, assessing their impact on land use; and (3) scenarios aimed at offsetting the EGD's spillover effects. Scenario set (2) includes measures like anti-deforestation trade policies, bioenergy advancements, ecological agriculture expansion in the EU, and converting low-productivity farmland into carbon sinks. Scenario set (3) proposes optimizing crop yields in developing regions, phasing out food-based biofuels in the EU, and advocating EAT-Lancet Committee-recommended diets. Our analysis employs an environmentally extended multi-regional input-output (EMRIO) analysis and a global agro-ecological zones (GAEZ) model. This dual approach tracks global supply chain effects, simulates crop production, and evaluates crop suitability, enabling a detailed assessment of the EGD's external impacts on land use, emissions, and biodiversity.
Research sample	44 countries (28 EU member countries plus 16 other major economies) and five rest of the world regions; 200 products from 163 economic sectors.
Sampling strategy	We use the full population of data.
Data collection	EXIOBASE v.3.8.1 database at https://zenodo.org/record/4588235 . The Commodity Balance Sheets from FAOSTAT at https://www.fao.org/faostat/en/ . The Detailed Trade Matrix from FAOSTAT. The spatial dataset of the Mean Species Abundance (MSA) in year 2015 and the land use data in year 2020 were from the GLOBIO4 scenario data (https://www.globio.info/globio-datadownloads). The GAEZ+ _2015 dataset at https://dataverse.harvard.edu/dataverse/GAEZ_plus_2015 . The Land Use Harmonization database at https://luh.umd.edu/ . The GAEZ data portal at https://www.gaez.iiasa.ac.at/ , https://gaez.fao.org/ .
Timing and spatial scale	2020-2030, global coverage.
Data exclusions	The datasets we employed have a global coverage.
Reproducibility	Results can be reproduced using these publicly available data and our modeling approach.
Randomization	N/A
Blinding	N/A

Did the study involve field work? Yes No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

- | n/a | Involvement in the study |
|-------------------------------------|--|
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Antibodies |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Eukaryotic cell lines |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Palaeontology and archaeology |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Animals and other organisms |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Clinical data |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Dual use research of concern |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Plants |

Methods

- | n/a | Involvement in the study |
|-------------------------------------|---|
| <input checked="" type="checkbox"/> | <input type="checkbox"/> ChIP-seq |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Flow cytometry |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> MRI-based neuroimaging |

Plants

Seed stocks

N/A

Novel plant genotypes

N/A

Authentication

N/A