EAT-Lancet diet reduces encroachment on high conservation priority sites

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Abstract

The global biodiversity crisis demands urgent action, with global food production being one of the major drivers of biodiversity loss. Transitioning to less animal-intensive diets is a potential solution to decrease impacts. While it is established that diet change can lead to a decrease in agricultural land use, it remains unclear whether these reductions occur in areas at risk of biodiversity loss. This study uses a spatially-explicit land use indicator, based on co-existence of species richness and agriculture, to analyze the impact on four land use types, ranging from land use with low conservation priority to land use with very high conservation priority. We analyze the impact of a diet change scenario where fifty-four high-income countries adopt the EAT-Lancet diet. Our findings indicate a major decrease of about one third of conservation priority land use across all four land use types considered. This means that the diet change is indeed effective in lowering land use in high conservation priority sites. We recognize that even with the adoption of the EAT-Lancet diet there is a need for additional strategies to further decrease high conservation priority land use, with priority sourcing strategies being the most obvious next step.

Keywords: *land use change, biodiversity loss, input-output analysis, EAT-Lancet diet, spatially explicit*

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1 Introduction

Biodiversity provides numerous ecosystem services essential for sustaining life, including food production, waste processing, nutrient cycling, and air purification (Cardoso et al., 2020). However, human activities are putting the biosphere integrity at risk (Richardson et al., 2023). Between 1900 and 2006, 9% of mammalian and avian species have become extinct, with an additional 20% currently at risk of extinction (FAO, 2007). Land use changes significantly contribute to habitat reduction and subsequent biodiversity loss (Newbold et al., 2015). For instance, between 2005 and 2013, the tropics lost an annual average of 5.5 million hectares of forest due to agricultural expansion (Pendrill et al., 2019). With the projected growth of the human population over the next decade, the challenge of feeding more people intensifies the pressure on systems already threatening biodiversity integrity (Calvin et al., 2023).

Ranking the threats to biodiversity can be challenging (Bellard et al., 2022), but it is evident that food production plays a major role (Pendrill et al., 2019; Wilting et al., 2017). The food production industry utilizes 45% of the earth's habitable land (P. Alexander et al., 2016). This extensive land use, coupled with deforestation and the overuse of pesticides and fertilizers (German et al., 2017; Pendrill et al., 2019) leads to habitat destruction, fragmentation, overexploitation, pollution, climate change, and the spread of invasive species (Brook et al., 2008). However beneficial to biodiversity this would be, we can obviously not stop producing food. Therefore, other strategies are needed to tackle the food production's associated impact on biodiversity loss.

One major driver of land use is the consumption of animal-based food (Behrens et al., 2017). Since a healthy diet can be maintained with plant-based foods (Willett et al., 2019), dietary shifts could be part of the solution. Additionally, a diet change can address meat consumption-related health issues, which are a wide-spread societal problem (Godfray et al., 2018). The EAT-Lancet diet aims to enhance health while reducing environmental impacts (Willett et al., 2019) and is modelled in this study. Evaluating viable options to decrease the impact of food production demands a good measuring system of these environmental impacts. Previous studies have estimated the impact of a wide-spread diet shift, including a reduction of meat consumption, in terms of land use, water use, greenhouse gas emissions, and eutrophication impact (Belgacem et al., 2021; Sun et al., 2022; Tuninetti et al., 2022; Willett et al., 2019; Wilting et al., 2017), a shift that gave positive results on global scale. A key question remains: how would widespread adoption of the EAT-Lancet diet affect biodiversity loss?

There are two main strategies to reduce food production's biodiversity footprint: land sparing and land sharing. The former is associated with technology improvements which can lead to higher environmental burdens per production area (Phalan et al., 2011), whereas land sharing is associated with lowering environmental impacts per area. Land can also be spared by changing diets. Diet changes could lead to land-sparing (Behrens et al., 2017) without necessarily compromising the land sharing strategy, which aims to reduce the environmental burden per production area. The discussion on land sharing and sparing could be considered too simplistic since it depends a lot per area to what extent it can be related to biodiversity loss, and therefore the strategy for agricultural production should not be just land sparing nor land sharing (Grass et al., 2021). Also in the case of a wide-spread reduction in meat consumption that would lead to a decrease in land use, the question remains where this land use reduction occurs: in areas that are more or less connected to biodiversity loss.

We lack a comprehensive understanding of the effects of dietary change on biodiversity. The study by Henry et al. (2019) addresses this by measuring natural land use instead of just land use as an indicator, thus trying to just measure land use that could be linked to biodiversity loss. Despite this improvement, differences remain within natural land so it is not possible to distinguish difference degrees of importance of natural land on this basis. Wilting et al. (2017) also made an improvement by analyzing food production on Mean Species Abundance, a measure for biodiversity loss. However, in this study characterization of production and consumption data have a low sectoral resolution. Other research has explored the relationship between biodiversity loss and food system developments on a regional scale or with limited sectoral scope and thereby using spatially-explicit data (Godar et al., 2012; Green et al., 2019; Zu Ermgassen et al., 2020).

Hoang et al. (2023) advances this by linking biodiversity risk maps with global agricultural production data in order to identify potential conflicts between food production and conservation. This allows for the identification of conservation priority associated with land use, addressing the issue of land use otherwise being too general. Thus, a spatially explicit framework for characterizing land use has been established that provides the opportunity to explore scenarios and characterize associated impact on a global scale and with a high sectorial resolution.

This study aims to determine the extent to which adopting the EAT-Lancet diet in 54 high-income countries would reduce land use in areas with high conservation priority. The affordability of the EAT-Lancet diet is questionable for a large part of the world, with the cost of the EAT-Lancet diet exceeding the per capita income for 1.58 billion people in the world (Hirvonen et al., 2020), therefore only high-income nations were modelled. We will use a spatially explicit land use framework to model the adoption of the EAT-Lancet diet in these countries, examining where trade influences food production associated with high conservation priority land use. This could lead to recommendations for additional strategies to decrease land use in areas of high conservation priority.

Connecting industrial production systems with their impact, and analyzing solutions that include societal change is typically a problem linked to industrial ecology. Furthermore, with this research we expand on the field of industrial ecology by employing a spatially-explicit input-output analysis with a scenario analysis. In the next chapter, our methodology is described, followed by the chapter with the obtained results. These are set in context in the discussion and then this report is finished with some final conclusions.

2 Methodology

In this study, we create a scenario where the EAT-Lancet diet is adopted by 54 high-income nations. To derive the consumption levels for this scenario, we combine the quantifications of the EAT-Lancet diet by Sun et al. (2022) with final demand data from FABIO (Bruckner & Kuschnig, 2020) for the year 2019. We then evaluate the impact of this diet change using a demand-pull model with a spatially explicit land use indicator using data from the study by Hoang et al. (2023). Thus, we assess the effectiveness of the diet change in reducing the land use that is most connected with biodiversity loss. The steps are summarized in Figure 1.

2.1 Identifying land use impact for the EAT-Lancet diet

As discussed, the EAT-Lancet diet provides the basis of the dietary scenario. Sun et al. (2022) quantified the diet change for the adoption of the EAT-Lancet diet for 54 high-income nations based on FABIO data in the year 2010. Since in this study the baseline year is 2019, we recalculate the change between consumption-levels and the EAT-Lancet diet as follows: We use the absolute values from Sun et al. (2022) to adjust the final demand of baseline year 2019 within the FABIO model. Because the quantifications are given in per capita units, we multiply them by national population numbers from 2019 (Bank, 2024) before applying them to the final demand figures.

A trade model serves to connect the change in consumption levels to a change in production. We utilized a multi-regional input-output (MRIO) database with a Leontief demand-pull model. Note that Weinzettel & Wood (2018) question the use of MRIO data for agricultural analyses due to aggregation errors when combining sectors. They argue that primary data in a hybrid model would im-

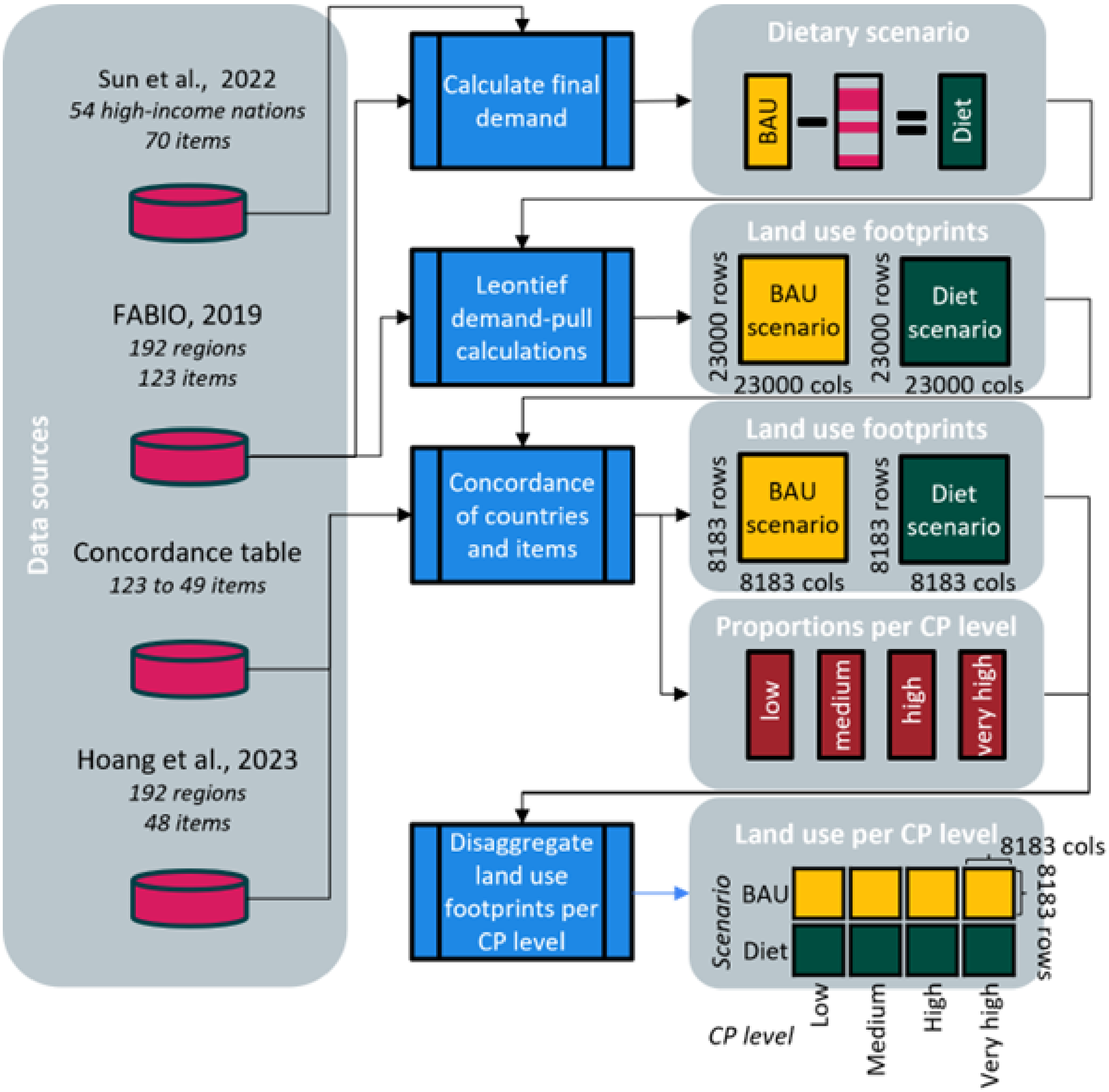

Figure 1: Methodological framework . BAU = Business-as-Usual (year 2019), CP = conservation priority.

	Low	High	Σ
A	$f_{A,low}$	$f_{A,high}$	100%
B	$f_{B,low}$	$f_{B,high}$	100%

1. Proportions of land use per CP level

	A	B	Σ
A	aa	ab	PBA_A
B	ba	bb	PBA_B
Σ	CBA_A	CBA_B	

2. Land use impacts

	A	B	Σ
A	$f_{A,low}$*aa	$f_{A,low}$*ab	$PBA_{A,low}$
B	$f_{B,low}$*ba	$f_{B,low}$*bb	$PBA_{B,low}$
Σ	$CBA_{A,low}$	$CBA_{B,low}$	

3A. Land use impacts in low CP level

	A	B	Σ
A	$f_{A,high}$*aa	$f_{A,high}$*ab	$PBA_{A,high}$
B	$f_{B,high}$*ba	$f_{B,high}$*bb	$PBA_{B,high}$
Σ	$CBA_{A,high}$	$CBA_{B,high}$	

3B. Land use impacts in high CP level

Figure 2: Land use disaggregation example for a case with only two regions (instead of 166) consisting of only one sector (instead of 49) and disaggregated in two CP levels, low and high (instead of four levels: low, medium, high, and very high). CP: conservation priority, CBA: consumption-based accounting, PBA: production-based accounting.

prove accuracy for these studies. Therefore, we use the Food and Agriculture Biomass Input-Output (FABIO) database (Bruckner & Kuschnig, 2020), which is based on physical rather than monetary units, thereby increasing robustness and accuracy, and avoiding putting sectors together with vastly different characteristics. The underlying data comes from FAOSTAT (2023), but has been adjusted for re-export. Since FABIO is built to analyze the food system, it aligns with the aim of this research. FABIO contains data up to 2021, but in order to avoid disturbances due to Covid-19 the year 2019 is more representative. Employing the Leontief demand-pull model with this data, we calculate the footprints in both the business-as-usual (BAU) scenario and the diet scenario with adapted final demand.

2.2 Linking land use to conservation priority levels

Following Hoang et al. (2023) we identify production regions with a higher risk of conflict between agriculture and conservation. This research links sectors to these regions, allowing us to quantify the connection between preservation risks and the production of specific quantities of sectors in certain countries. We can thus disaggregate land use related to the production of sector A in region X to land use in conservation priority level low, medium, high, and very high, with specified proportions per level. Applying this to the land use impacts calculated for both scenarios gives us, for the consumption in region Y of product A produced in region X, the size of the land use related to this production that took place in each conservation priority level. Figure 2 provides further clarification of the disaggregation process.

The land use impact calculated previously does not have the same regions and sectors from the study by Hoang et al. (2023). This makes it impossible to disaggregate the land use. The data with conservation priority ratings from Hoang et al. (2023) has 48 sectors originating from the MapSPAM database (Institute, 2019), while the FABIO data consists of 123 sectors (Bruckner & Kuschnig, 2020). Therefore, a sector concordance is required to disaggregate the land use. Both databases can be converted into FAO codes, but since they refer to completely different FAO codes (except for one) this does not lead to any progress. Disaggregating sectors requires additional data on how to spread the impact over the disaggregated sectors, making it more difficult than aggregation. Therefore, we aggregate land use impact of the FABIO sectors to fit the MapSPAM sectors using a concordance table

(Appendix, Table 2). The concordance table is based on common sense, and where possible, information provided by the linked FAO codes.

Out of the 123 FABIO sectors, 27 sectors d o not have concordance as they are not closely related to any MapSPAM sectors. This would mean that 67.1% of the total land use (BAU scenario, 54 diet countries, production-related) could not be allocated to the MapSPAM database. This is mostly due to the sectors "Grazing" and "Fodder crops" that make up a large proportion of the production-related land use, but that do not exist in the MapSPAM database. In MapSPAM, and Hoang et al. (2023) followed this, all animal feed is assigned to the animal production sector itself (e.g., grazing goes to cattle). Therefore, in this study the "Grazing" and "Fodder crops" sectors in FABIO were also reallocated to the animals' consumption sector. For other sectors (like maize, and soybean) that are partially used as fodder, no reallocation was done so there remain more details on the production side, instead of already allocating all animal feed to the animals and then losing the composition of the feed. After this reallocation step, the 27 sectors make up 12.1% of total land use (BAU scenario, 54 diet countries, production-related) (Table 1) with the largest three being "Meat - Other" (6.0% of total land use), "Hides and skins" (5.1% of total land use), and "Alcohol, Non-Food" (2.4% of total land use), for more information go to Figure 9 in the Appendix. Finally, we map the 96 remaining sectors onto the MapSPAM sectors.

In addition to sector concordance, regional concordance is also needed as the regions used in FABIO do not correspond to the regions from the land use proportions (Hoang et al., 2023). Table 1 shows how land use impact of regions without overlap, and land use impact of sectors without MapSPAM equivalent are related to the total land use impact. The difference in land use is caused by the fact that the production output of sectors with concordance can lead to consumption in sectors without concordance: e.g., when the sector Maize (with concordance) is used as fodder and consumed in the sector "Meat – Other" (without concordance).

We aggregate the conservation levels from numerical intervals into four levels, following the schema in Hoang et al. (2023). The low CP level contains intervals from 0.0 – 0.5, the medium level ranges from 0.5 – 0.7, the high level from 0.7 – 0.9 and the very high level consists of the interval 0.9 – 1.0. In this study, the results from the higher two levels (high and very high) are sometimes aggregated as these generally represent the land use with conservation priority.

After matching the products and countries between the data from FABIO (Bruckner & Kuschnig, 2020) and Hoang et al. (2023), we disaggregate the overall land use per conservation priority level. This provides us with data on territorial land use when employing production-based accounting (PBA) (see Figure 2), and land use footprints when employing consumption-based accounting (CBA), per conservation priority level and for both scenarios. Note that the total land use per conservation priority is constant regardless of the accounting approach, and that aggregating back from land use per conservation priority levels to the overall land use should yield the same number if the land use that could not be disaggregated is included.

3 Results

This study aims to quantify the effects of implementing the EAT-Lancet diet on land use in higher conservation priority areas. The result section presents these effects and explores pathways to further decrease land use in priority areas through trade. First we show the results of disaggregating land use in the various conservation priority levels. We compare this for the various sectors and regions. Then we identify which parts of the world would experience the largest decrease in high and very high conservation priority land use. Lastly, we show the remaining trade flows of high conservation priority land use in the diet scenario for the 54 high-income nations.

Table 1: The proportion and absolute value of land use that could not be disaggregated in conservation priority land use types. Land use is related to the consumption-levels of the 54 high-income countries. Due to small overlaps the sum of the composition is more than 100%.

		BAU		Diet	
		Proportio n	Absolute	Proportion	Absolute
Unidentified land use		12.10%	7.88E+07	11.50%	7.54E+07
Composition	Sectors without concordance	90.80%	7.16E+07	94.90%	7.16E+07
	Regions without overlap	7.50%	5.93E+06	5.10%	3.83E+06
	Missing conservation priority identification	3.50%	2.79E+06	1.90%	1.46E+06

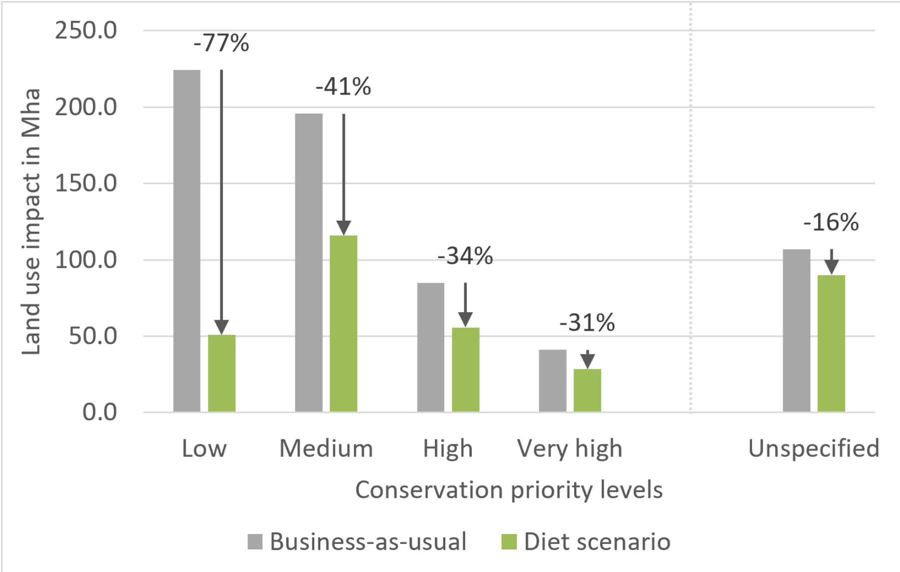

Figure 3: The land use impact per conservation priority (CP) level in both scenarios related to the final demand of the 54 countries that are part of the diet scenario. Note that the land use that could not be disaggregated in the various conservation priority levels is not part of the plot.

3.1 Change under the diet scenario

In order to improve measurements on biodiversity loss this study improves upon the concept of land use as an indicator. Therefore, the land use impact is divided into four conservation priority levels, as shown in Figure 3. Part of the land use impact could not be disaggregated mainly due to inconvertibility of sectors between data sources (more information in Table 1 in the Methods section). In total, 12.1% and 16.0% of the land use change in respectively the BAU and diet scenario could not be disaggregated.

The low and medium conservation priority levels account for a much larger share of land use than associated land use in high and very high conservation priority levels, especially in BAU (Figure 3). This difference is due to a non-homogeneous distribution of the data and the uneven translation from numerical intervals to aggregated levels. For instance, the low conservation priority consists of five numerical intervals, whereas the very high conservation priority level consists of only one. This is slightly different from the study in Hoang et al. (2023) who calculated most more land use to have medium conservation priority level instead of low.

Land use with medium, high and very high conservation priority decreases much less compared

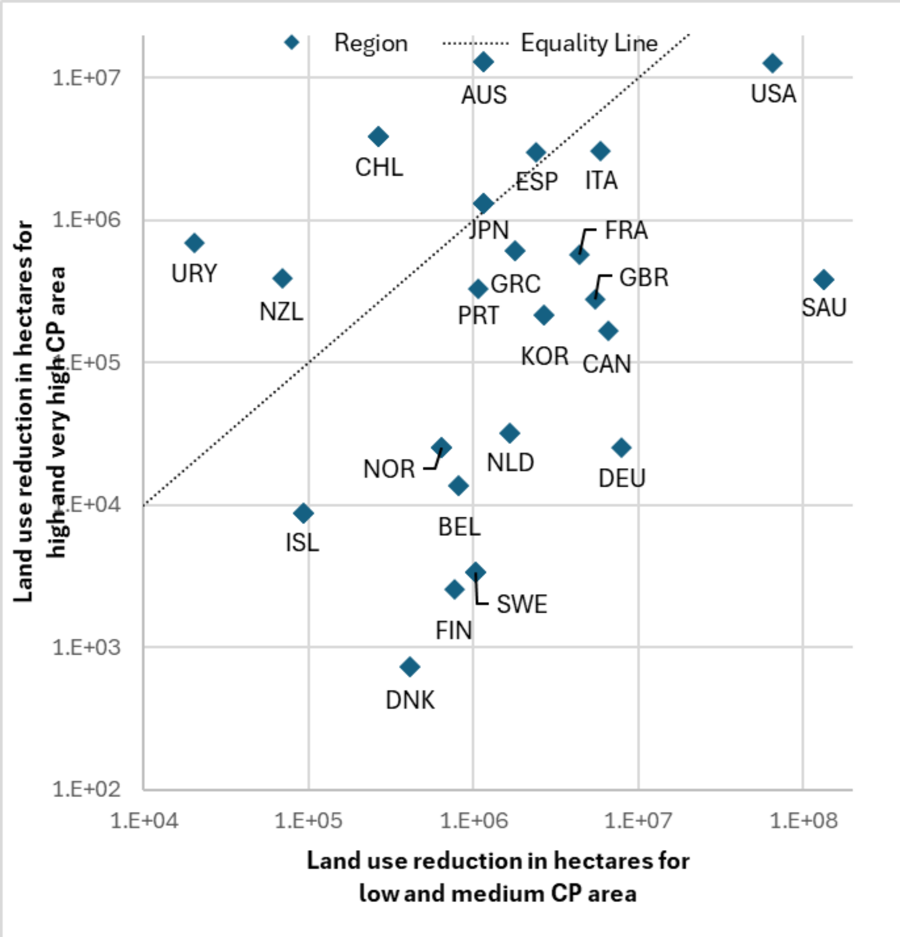

Figure 4: Comparison of land use reductions (consumption-based accounting) per region in low and medium conservation priority (CP) areas versus high and very high CP areas due to the diet adoption. The datapoints are annotated with ISO3 country codes. Regions with only consumption in low conservation priority areas are not part of the plot.

to land use with low conservation priority (Figure 3). This indicates that the diet change is especially effective in lowering land use that is considered to have a lower impact on biodiversity loss. However, also for the other land use types there is a major decrease with the adoption of the EAT-Lancet diet.

Figure **??** shows, among others, the absolute decrease in land use. Surprisingly, Saudi Arabia has a very large overall reduction compared to other countries. This is partially due to the fact that grazing per hectare in Saudi Arabia has little yield compared to other products resulting in high land use. The same results have been obtained by Erb et al. (2016) who explain that this is an overestimation due to definitions in the FAO data (FAOSTAT, 2023). In the FAO data permanent pasture land is defined as pasture land that has been in use for the past five years. However, in climates like the Saudi Arabian climate it is not possible to have permanent grazing over the years so the impact on the land considered could be much lower compared to other regions where this is possible (Erb et al., 2016).

In Figure **??** you can see how it is different for each country to what extent the diet adoption is effective in reducing its consumption-related higher priority land use. There is one country that has increase land use in CP area: Saint-Knitts and Nevis. But here the size of the population (about 50 thousand) could play a role in rounding errors. Also there are some countries whose land use in higher conservation priority land use remains stable and thus only have a decrease in lower conservation priority land use. These countries include Switzerland, United Arab Emirates, Slovakia, Slovenia,

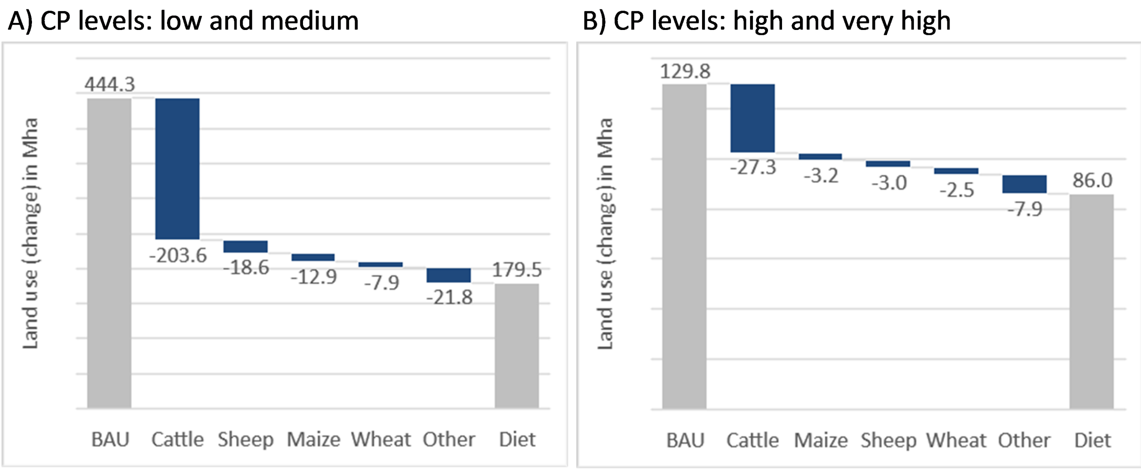

Figure 5: Waterfall plots for the top 4 (in absolute numbers) products contributing most to the land use change under implementation of the diet scenario, aggregated in low and medium (su bplot A), and high and very high (subplot B) conservation priority land use

Austria, Estonia, Ireland, Israel, Kuwait, Latvia and Lithuania.

Apart from differences in effectiveness of the diet change in lowering priority land use between countries, there are also differences between sectors. Sectorial change under the diet scenario can be analyzed using Figure 5 and Figure 6. These figures show how the diet change leads to reductions in high and very high priority land use. As expected, mostly cattle and sheep and some of the main feed crops are responsible for some of the largest reductions in both lower and higher conservation priority areas. This further confirms the effectiveness of switching to a (mainly) plant-based diet in reducing conservation priority land use.

In addition to establishing the effectiveness of adopting the EAT-Lancet diet for a decrease of land use in higher conservation priority levels, it is key to identify where this decrease occurs and which countries regions are involved. Figure 7 provides insights into these questions.

As expected, the dietary scenario leads to a decrease of land use in most countries. However, some countries, like Japan and Panama, experience an increase in land use in high conservation priority areas. This increase is due to higher fruit and soy consumption. An increase in fruit and soy consumption can easily be traced back to the adoption of a healthy and sustainable diet, for instance with soy as protein substitute. One would expect Japan to be associated with a massive decrease of land use when adopting the EAT-Lancet diet. It is quite surprising that this leads to a net negative result as Japan is one of the countries with the highest meat intake per capita in the world. Most of this reduction however happens in areas with lower conservation priority . The cause for the increase in higher CP land use is caused mainly by an increase in soybean for human consumption. While in many countries (like the U.S.) soybean production is decreased as it is used for fodder, this is not the case in Japan, where soybean is too a much lesser extent used for fodder.

3.2 Trade in diet scenario

To further decrease the land use footprint in higher conservation priority areas, it is crucial to know where and by which products priority land use decreases, as depicted in Figures 4 and 5. Furthermore, exploring strategies to decrease the remaining priority land use is essential. One such strategy is outsourcing production to areas with lower conservation priority levels. This raises the question on how much land use is already linked to international trade. About 12% of total land use is traded between regions, for both scenarios and based on the consumption of the 54 high-income countries. This is rel-

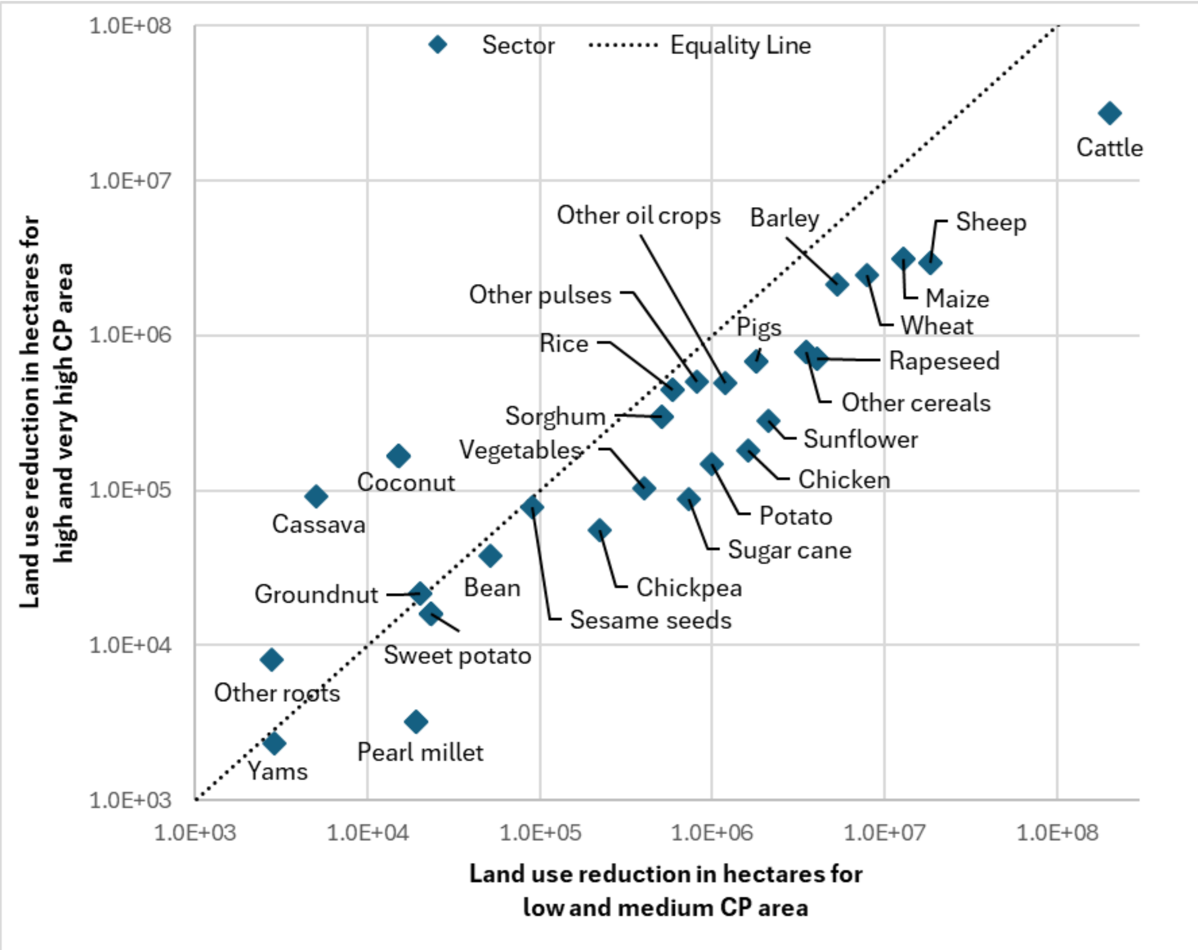

Figure 6: Comparison of land use reductions (consumption-based accounting) per sector in low and medium conservation priority (CP) areas versus high and very high CP areas due to the diet adoption. Products with zero change or change of magnitude close to one hectare are not part of the plot.

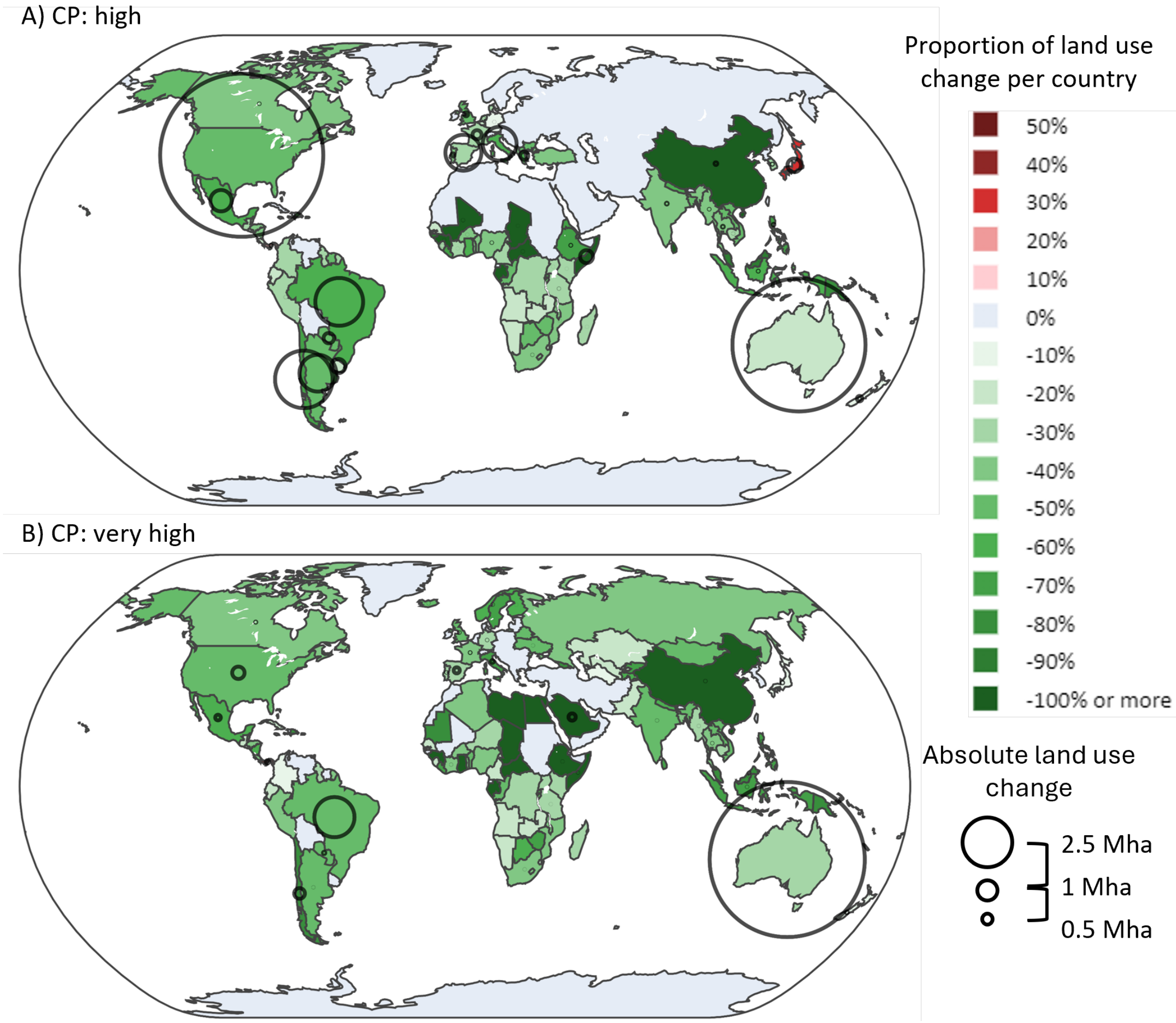

Figure 7: Proportion and magnitude of land use change in A) high and B) very high conservation priority areas under the diet scenario (Production-Based Accounting) related to the consumption of the 54 high-income countries. The color of the countries represents the proportion of land use change per country, with darker colors indicating higher proportions. Hereby, green indicates a reduction of land use, while red indicates an increase. The size of the circles indicates the magnitude of the land use change, for those countries where the change is large enough to be visible on this scale.

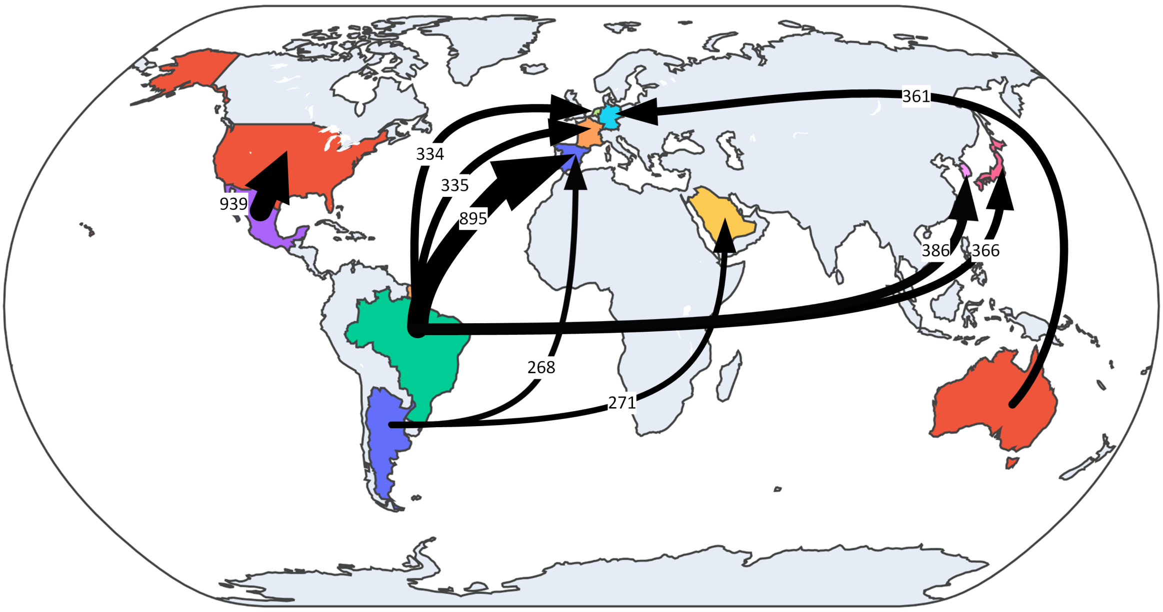

Figure 8: Highest ten international trade flows in kha of higher priority (CP = high + very high) land use under the diet scenario with 54 consuming high-income countries. The se ten flows represent about 40% of international trade produced in higher priority land use.

atively low compared to the study by D'Odorico et al. (2014) who found international trade to be 23% of global caloric production, and Wilting et al. (2017), which found international trade to be associated with 50% biodiversity loss measured in Mean Species Abundance. The different indicator could be a valid justification for the difference. For priority land use there is a larger proportion associated with international trade: 17.1% for the business-as-usual scenario and 11.6% for the diet scenario. This suggests that the diet scenario effectively decreases traded priority land use, whereas overall traded land use remains largely unchanged between the scenarios.

What is surprising is that the largest flows are covering a very large distance (Figure 8); there is just one intercontinental flow amongst these largest flows. Obviously, the distance that food has to travel can be very important for the environmental burden it brings along. Note that biodiversity loss will not be the main impact of this burden.

4 Discussion

This study quantifies the impact on land use in higher conservation priority area in case of a widespread adoption of the EAT-Lancet diet. The findings indicate a substantial reduction, approximately a third of the land use in high and very high conservation priority area. Following the land use framework by Hoang et al. (2023), this study shows how the type of land use that is reduced in case of a diet change differs between countries. This study reveals that for almost all countries the diet adoption seems to be effective for almost all countries in lowering high and very high conservation priority land use.

The diet change leads to decreased land use. This study finds how the main absolute gains from the diet change for high and very high CP areas take place in a few countries: U.S.A., Australia, Brazil, Chile and Argentina, and Spain and Italy. The high concentration of this change provides both challenges and opportunities. This change would include a high economic shift in these countries and therefore instability and uncertainty. This also includes the risk of rebound effects when farmers lower their prices and find other places to sell cattle. However, the high concentration also brings opportunities for targeted policies to compensate those that are affected and to plan this economic shift. In addition to these findings, the most important trade flows are identified. These provide additional space in reducing land use through sourcing from countries with lower production related conservation priority land use.

Moreover, the study reveals that adopting the diet, mainly in the Northern hemisphere, leads to reductions in priority land use mainly in the southern hemisphere. Even with a full adoption of the EAT-Lancet diet by 54 high-income countries, these countries still have remaining consumption related to production in priority land use areas. Therefore, additional solutions are required. Two possible solutions could be preferential sourcing and increasing efficiency. Whereas the first solution has the risk of increasing environmental burdens due to longer distance transportations, the latter has the risk of increasing environmental burdens due to more intensive farming methods which include heavy machinery, higher fertilizer and pesticide use, which then should be balanced with the alternative of more land us e.

4.1 Diet scenario

The EAT-Lancet (Willett et al., 2019) is perhaps the most renowned sustainable diet and therefore there is much critique on the diet too. First of all, it ignores the relationship between culture and food by assuming a uniform diet adoption. It also ignores the likelihood of uniform adoption of countries of a diet, which is also a big part of this study for 54 high-income countries. However, this model does give a good sense of what a plant-based diet transformation would mean in terms of land use. The adoption of the Lancet diet could also have negative environmental consequences such as an increased impact for some regions in terms of water scarcity (Tuninetti et al., 2022).

Also within countries there is a variety of low- and high-impact consumers depending on e.g. household income (Chen et al., 2024; Csutora & Vetőné Mózner, 2014; Taherzadeh & Kanemoto, 2022). Studying the effects of the diet change for high-impact consumers would open up opportunities for an even more targeted approach in fighting biodiversity loss. However, this would require very detailed consumption data.

4.2 Conservation priority land use

The conservation priority ratings are based mainly on species richness and therefore many important aspects of biodiversity loss are ignored, like population size, habitat fragmentation, phylogenetic diversity and trait diversity. These aspects are to a high level correlated, but can also be in contrast: e.g., when population size is increasing, but only with a few species. Therefore, the connection with biodiversity loss could be improved when these aspects are taken into account as well. This would then improve the validity of the model.

The ratings are linked to cooccurrence of agricultural practices and a certain degree of species richness, however this assumes that this cooccurrence always leads to conflict, while this is not necessarily true. To widen the issue, there is no distinction between various cultivation practices which could lead to more (or less) biodiversity loss while there are indeed many differences (De Graaff et al., 2019). This could make our results less accurate. Including data farming practices, or averages on farm-size in the conservation priority profiles could therefore improve the model.

Another limitation of the conservation priority rating is that plant species and fungi are not taken into account. In theory this could mean that based on our conclusions we could select parts of the world to reduce or increase food production based on its relation with species loss while the area is indeed not important to other species that could play a more important role in the future wellbeing of the planet and food security. Therefore, improvements on the conservation priority ratings by including plants and fungi would improve this type of study. On top of that, the impact on all but terrestrial biodiversity is ignored: neither aquatic biodiversity nor the impact of blue food production and consumption is taken into account. This would mean our results underestimated the reduction of biodiversity loss especially for those countries with a high consumption of blue foods, like Japan.

4.3 Trade model

The Leontief demand-pull model lacks production boundaries. Therefore, when a change in final demand is analyzed the model increases or decrease production without limit in order to match a change in final demand. Therefore, unrealistic production values may arise. Even if other sectors are producing less, this can not always be substituted by another sector: In for example peat lands it can be challenging to grow crops instead of cattle (Liu et al., 2023). This could be avoided by setting a production boundary based on maximum yield potential related for example to production efficiency gaps. If the model predicts production output that exceeds this maximum yield potential, this overestimated output should be redistributed to countries where the maximum yield potential has not yet been reached. The redistribution could be based on nearest producers or strongest existing trade links. Most of the changes induced by the diet change are reductions of production output which makes that the implemented diet scenario suffers only a little from the described problem.

The trade model assumes that changing consumption patterns will change production accordingly, thereby keeping trade relations the way they are. However, following the laws of supply and demand, decreased demand will lead to a decrease in price which would then lead to an increase of consumption. If the diet is adopted in part of the world there is the risk of other countries increasing consumption of those products that are avoided thus creating a rebound-effect. Furthermore, due to the concept of stickiness producers will not always react to commitments: in Brazil especially larger traders did not adhere to zero-deforestation agreements (Reis et al., 2020). Other than changing offset markets, there is also the risk of spillover effects where avoided land use reduction for food production is now replaced by biomass production (Gatto et al., 2023). This is analyzed in the study by Cederberg et al. (2011), where it is shown how deforestation can be attributed to export, even when the export produced does not happen in deforested areas. Therefore, the outcomes of the model are probably too optimistic.

Embedded in MRIO data processing is the problem of time lag. The input-output data that is part of the model will never be fully up to date as it requires much work to gather data and fix issues. The data used in this study from input-output database FABIO (Bruckner & Kuschnig, 2020) is based on the year 2019. The most recent year is 2021, but this year could be skewed due to the global covid-19 crisis. Therefore, 2019 is taken as a reference year.

Although the predictions of the model are just for the year 2019, we hope that this gives a reasonable idea of the relations between diet shift and priority land use for the coming years too. The extent to which this is true is hard to establish as a result of changing production methods, shifting production types (among others due to climate change), international conflicts and international policies like the European Union's Deforestation Regulation (Directorate-General for Environment (European Commission), 2023). Climate change might amplify these effects even further (Intergovernmental Panel On Climate Change, 2023). Therefore, the results of this study should undergo extra scrutiny when extrapolating to the future. Repeating the study by modelling other years could give more information about possibilities to extrapolate results to the future. The conservation priority ratings (Hoang et al., 2023) we used to disaggregate land use are calculated with data from MapSPAM from 2010 and thus not up to date either. Recently the MapSPAM database received a global update to the year 2020. This provides opportunity to recalculate the conservation priority ratings (Institute, 2024) and compare changes over time.

Gathering and processing all data needed for a global database like FABIO requires many data sources which can have slightly different approaches and might not always be closely related to actual empirical data (Bruckner et al., 2019). This leads to uncertainties in the outcome of FABIO. The underlying data of FABIO is mainly sourced from FAOSTAT. This data is gathered based on official trade and tax data. However, this excludes the informal sector production and trade which could make up a significant share of the food sector (E. Alexander et al., 2011). Furthermore, since typical accounting systems are not made to distinguish between feed crops and human consumption this is one of the points where there is much uncertainty in FABIO. As part of the construction of the FABIO database allocation of processes had to be done. Two approaches were chosen based on mass and on value. In some cases these two approaches can lead to very different results (Bruckner et al., 2019). Lastly, environmental impacts, like land use, are highly variable and therefore there remains much uncertainty when calculating them with input-output databases (Poore & Nemecek, 2018)

Unfortunately, no concordance table was available for the sectors between the FABIO database (Bruckner & Kuschnig, 2020) and the conservation priority proportions from Hoang et al. (2023). Therefore, the concordance table had to be made manually. For some products this was easy as the sectors were very similar, but for some products the concordance was not obvious, and some sectors could not be matched at all. This brings some uncertainty in the model when a FABIO sector is matched with a MapSPAM sector (the underlying database of the study by Hoang et al. (2023)) while the former is also overlapping with other sectors in MapSPAM.

4.4 Future research

There are currently not always enough valid alternatives available in case of a diet shift to substitute the animal-based food with local plant-based food. Therefore, this could also lead to an increase in trade. In the long run however, production practices can be quite flexible and adapt to new demands. If there were an increased demand for certain nuts instead of animal products, this can also attract development of new technologies and options on how to grow them in areas where this is currently not deemed viable. Navarre et al. (2023) showed how for 95% of the world population there exist pathways to self sufficiency. However, it is important to treat this with caution as for some countries this could lead to more land use in high conservation priority areas.

As final remark, the results show how even with the adoption of the EAT-Lancet diet there remains much land use in higher conservation priority areas. Part of this is also related to trade. Reducing this trade related land use, or changing the trade patterns through preferential sourcing could be the next step in decreasing priority land use. It would be interesting to find out more about the relation between self-sufficiency and a further decrease in high priority land use, including an assessment of conflicts between these factors in relation to balancing sourcing from areas with low conservation priority over domestic production.

5 Conclusion

This study highlights the potential of adoption of the EAT-Lancet diet to reduce land use in areas with high conservation priority, thereby mitigating biodiversity loss. By modeling the adoption of the EAT-Lancet diet in 54 high-income countries, we demonstrate that a shift towards more plant-based diets leads to reductions in land use in those areas with more conservation priority.

The findings show that dietary shifts can significantly decrease land use in countries like the U.S., Australia, Brazil, Chile, Argentina, Spain, and Italy. These regions account for the majority of the absolute gains in reducing land use in high and very high conservation priority areas. This concentration offers both challenges and opportunities. Economically, it could cause instability and uncertainty for local farmers, who might experience reduced demand for livestock products. This could lead to lower prices and potential rebound effects if farmers seek alternative markets. Taking these effects into account with the right policies is key.

One major concern is the potential burden on lower-income populations if price policies are used to drive dietary changes. Higher food prices would disproportionately impact low-income households, making healthy diets less affordable and increasing food insecurity. Furthermore, reduced demand for livestock products might lead to lower labor demand in the agricultural sector, affecting wages and employment opportunities for low-income workers (Gatto et al., 2023). Therefore, policies like investments in sustainable agriculture, and social safety nets could reduce these social impacts.

Consumer resistance is another critical factor to consider. Payró et al. (2023) found consumer motivation in general to be too low for a strong national diet change. This emphasizes the need for policies to enforce this change. To further reduce land use in high conservation priority areas, strategies beyond dietary shifts are necessary. Preferential sourcing from regions with lower conservation priority can help, although this may increase environmental burdens due to longer transportation distances. Enhancing agricultural efficiency through sustainable practices can also contribute, but it risks higher environmental impacts from intensified farming. Balancing these approaches requires careful planning and robust policies that prioritize both conservation and sustainability.

The EAT-Lancet diet presents a promising pathway to reduce biodiversity loss through decreased land use in high conservation priority areas. This contributes to the scientific knowledge on the impact of diet-changes and further emphasizes the need for diet change. Our results also show how additional strategies are needed to further decrease conservation priority land use.

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Supporting information

Input:

- FABIO: https://zenodo.org/records/2577067
- Hoang et al. (2023)
- Sun et al. (2022)
- Population data: https://data.worldbank.org/indicator/SP.POP.TOTL

Code: https://drive.google.com/open?id=133mDHQSbJ8GJ486NQxk8juDiP4jDm8be&usp=drive_fs

Output:

- Land use impact for BAU and diet scenario with 167 regions and 49 sectors, spread over 5 CP land use, calculated with production-based and consumption-based accounting method.
- Land use impact for BAU and diet scenario with 167 regions and 49 sectors including only high and very high CP land use and with intermediate production numbers to identify trade relations.

Appendix

Table 2: Concordance table from sectors in FABIO to sectors in MapSPAM used in the paper from Hoang et al. (2023)

FABIO item code	FABIO items	Hoang
c001	Rice and products	Rice
c002	Wheat and products	Wheat
c003	Barley and products	Barley
c004	Maize and products	Maize
c005	Rye and products	Other cereals
c006	Oats	Other cereals
c007	Millet and products	Pearl millet
c008	Sorghum and products	Sorghum
c009	Cereals, Other	Other cereals
c010	Potatoes and products	Potato
c011	Cassava and products	Cassava
c012	Sweet potatoes	Sweet potato
c013	Roots, Other	Other roots
c014	Yams	Yams
c015	Sugar cane	Sugar cane
c016	Sugar beet	Sugar cane
c017	Beans	Bean
c018	Peas	Chickpea
c019	Pulses, Other and products	Other pulses
c020	Nuts and products	undefined
c021	Soyabeans	Soybean
c022	Groundnuts	Groundnut
c023	Sunflower seed	Sunflower
c024	Rape and Mustardseed	Rapeseed
c025	Seed cotton	Cotton
c026	Coconuts - Incl Copra	Coconut
c027	Sesame seed	Sesame seeds
c028	Oil, palm fruit	Oil palm
c029	Olives (including preserved)	Other oil crops
c030	Oilcrops, Other	Other oil crops
c031	Tomatoes and products	Temperate fruit
c032	Onions	Vegetables
c033	Vegetables, Other	Vegetables
c034	Oranges, Mandarines	Tropical fruit
c035	Lemons, Limes and products	Tropical fruit
c036	Grapefruit and products	Tropical fruit
c037	Citrus, Other	Tropical fruit
c038	Bananas	Banana
c039	Plantains	Plantain
c040	Apples and products	Temperate fruit

c041	Pineapples and products	Tropical fruit
c042	Dates	Tropical fruit
c043	Grapes and products (excl wine)	Temperate fruit
c044	Fruits, Other	Tropical fruit
c045	Coffee and products	Robusta coffee
c046	Cocoa Beans and products	Cocoa
c047	Tea (including mate)	Tea
c048	Hops	Rest of crops
c049	Pepper	undefined
c050	Pimento	undefined
c051	Cloves	undefined
c052	Spices, Other	undefined
c053	Jute	Other fibre crops
c054	Jute-Like Fibres	Other fibre crops
c055	Soft-Fibres, Other	Other fibre crops
c056	Sisal	Other fibre crops
c057	Abaca	Other fibre crops
c058	Hard Fibres, Other	Other fibre crops
c059	Tobacco	Tobacco
c060	Rubber	undefined
c061	Fodder crops	undefined
c062	Grazing	undefined
c063	Cottonseed	Cotton
c064	Palm kernels	Oil palm
c065	Sugar non-centrifugal	Sugar beet
c066	Sugar (Raw Equivalent)	Sugar beet
c067	Sweeteners, Other	Sugar beet
c068	Soyabean Oil	Other oil crops
c069	Groundnut Oil	Other oil crops
c070	Sunflowerseed Oil	Other oil crops
c071	Rape and Mustard Oil	Other oil crops
c072	Cottonseed Oil	Other oil crops
c073	Palmkernel Oil	Other oil crops
c074	Palm Oil	Oil palm
c075	Coconut Oil	Coconut
c076	Sesameseed Oil	Sesame seeds
c077	Olive Oil	Other oil crops
c078	Ricebran Oil	Other oil crops
c079	Maize Germ Oil	Maize
c080	Oilcrops Oil, Other	Other oil crops
c081	Soyabean Cake	Soybean
c082	Groundnut Cake	Groundnut
c083	Sunflowerseed Cake	Sunflower
c084	Rape and Mustard Cake	Rapeseed
c085	Cottonseed Cake	Cotton
c086	Palmkernel Cake	undefined

c087	Copra Cake	undefined
c088	Sesameseed Cake	Sesame seeds
c089	Oilseed Cakes, Other	Other oil crops
c090	Wine	undefined
c091	Beer	Barley
c092	Beverages, Fermented	undefined
c093	Beverages, Alcoholic	undefined
c094	Alcohol, Non-Food	undefined
c095	Cotton lint	Cotton
c096	Cattle	Cattle
c097	Buffaloes	undefined
c098	Sheep	Sheep
c099	Goats	Goat
c100	Pigs	Pigs
c101	Poultry Birds	Chicken
c102	Horses	undefined
c103	Asses	undefined
c104	Mules	undefined
c105	Camels	undefined
c106	Camelids, other	undefined
c107	Rabbits and hares	undefined
c108	Rodents, other	undefined
c109	Milk - Excluding Butter	Cattle
c110	Butter, Ghee	Cattle
c111	Eggs	Chicken
c112	Wool (Clean Eq.)	Sheep
c113	Bovine Meat	Cattle
c114	Mutton & Goat Meat	Sheep
c115	Pigmeat	Pigs
c116	Poultry Meat	Chicken
c117	Meat, Other	undefined
c118	Offals, Edible	Cattle
c119	Fats, Animals, Raw	Cattle
c120	Hides and skins	undefined
c121	Honey	undefined
c122	Silk	undefined
c123	Fish, Seafood	undefined

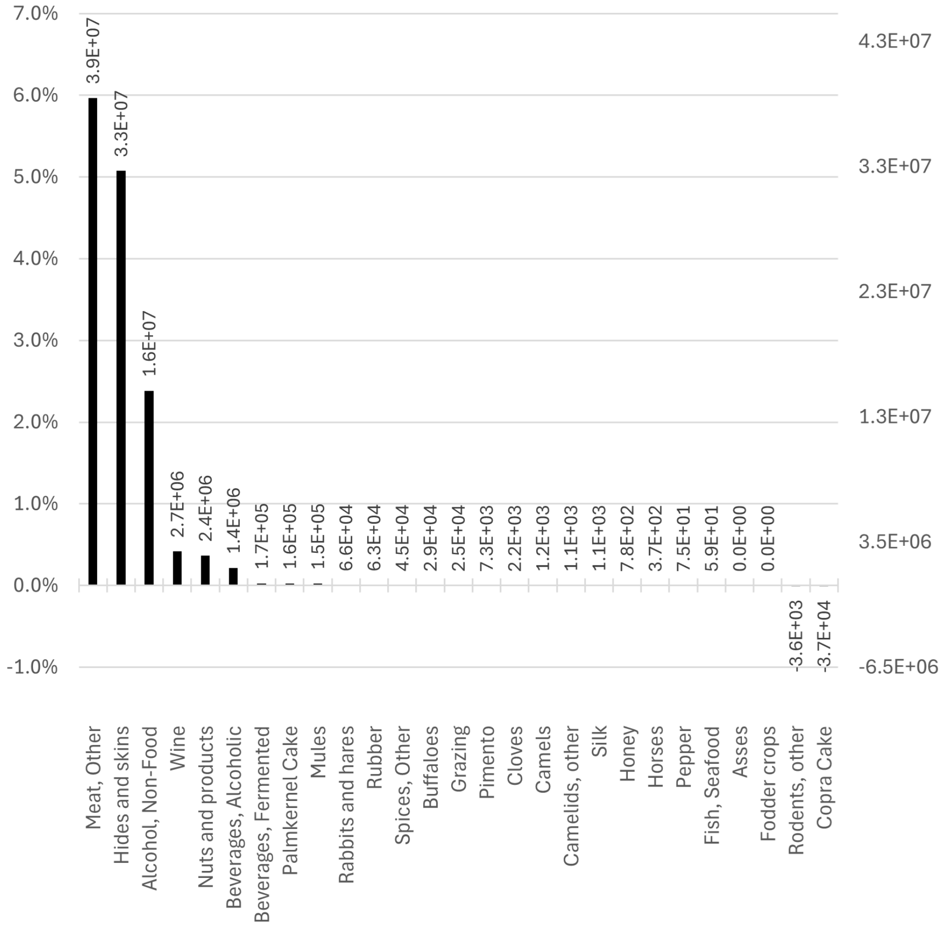

Figure 9: Land use in the sectors in FABIO without concordance to sectors in MapSPAM, related to the BAU consumption of the 54 countries part of the diet scenario.

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