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Deforestation-free trade: the impact of border regulations on trade, production and land use in the forestry and agricultural sectors

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Abstract
Trade regulations on high-deforestation commodities are increasingly used to curb tropical deforestation. To evaluate their actual impact, this paper analyzes trade regulations on high-deforestation commodities under three scenarios: two based on EU measures and one exploring a globally coordinated implementation of import regulations on countries with high deforestation risk (HDR). We use a policy assessment framework based on MAGNET, a global general equilibrium model, to analyze the impact on trade, production and land use change. Our results indicate that EU-only measures can substantially reduce HDR imports into the EU, but the global impact remains limited given the EU's modest share of world demand for products from countries with HDR. By contrast, a globally coordinated regulation targeting HDR countries would expand forest land in these countries and substantially reduce their production and trade, while shifting these activities to other parts of the world.

1. Introduction

As deforestation accelerates, trade regulations on products produced under high deforestation risk (HDR) have gained increasing attention as a tool to curb land-use change. Trade regulations targeting commodities linked to deforestation aim to reduce global demand for products from unsustainable sources, potentially incentivizing sustainable practices in high-deforestation regions (Lambin and Meyfroidt 2011). However, the key question arises regarding how to implement such regulations: what happens if one country or region alone or more countries enforce these measures? In this sense, present study assesses the effectiveness of global and EU-only trade regulation on forest and agricultural products from high-deforestation regions.

Policies like the EU Deforestation Regulation (EUDR) aim to restrict market access for deforestation-linked goods and promote more sustainable practices in high deforestation regions. The EUDR is expected to replace the EU Timber Regulation (EUTR), expanding its scope to address both legal and illegal logging and to cover additional commodities such as palm oil, soy, coffee, cocoa, and beef. Companies must ensure that their imports are 'deforestation-free', complying with local laws through due diligence, including geolocation data and proof that sourcing excludes land deforested after 2020 (European Commission 2021). The EUDR application dates, originally foreseen for 2024/2025, have already been formally postponed to 2025/2026, and further deferrals to 2026/2027 are currently under negotiation but not yet legally fixed. These postponements mainly respond to implementation and traceability challenges, including concerns about the readiness of IT systems, data availability (especially for smallholders), and potential disruptions to supply chains. While the EUDR aims to internalize environmental costs, its impact on supply chains and deforestation remains uncertain (Abman *et al* 2024). The successful implementation of this measure requires careful consideration of enforcement, cost-effectiveness, and adaptability. At the same time, the potential consequences of trade diversion must be considered to ensure that EU efforts to reduce deforestation are not undermined. In this respect, previous literature argues that effective tropical deforestation control requires trade regulations complemented by international support to strengthen territorial policies and social movements addressing forest loss (Fuchs *et al* 2024, Muradian *et al* 2025). Yet, it remains unclear how effective these regulations are when applied regionally versus globally, a gap this study seeks to address

Whereas theoretical work (Robalino *et al* 2009, Gardiner 2022) examines how trade regulations reshape commodity flows and deforestation, global modeling studies (Busch *et al* 2022, Villoria *et al* 2022, Leijten *et al* 2023, Heimann *et al* 2024, Yarlagadda *et al* 2025) quantify land-use impacts of specific policies. Our study contributes to this literature in two ways: (i) by covering the full EUDR commodity set rather than focusing only on single products, and (ii) by comparing EU-only with global adoption to capture the effect of policy scale. While previous studies (e.g. Yarlagadda *et al* 2025) provide more detailed estimates of emissions and macroeconomic outcomes, our emphasis is on comparative land-use responses across commodities and implementation regimes.

This analysis provides new insights into the trade-offs between regional and global regulation, helping policymakers to understand the potential effectiveness and unintended consequences of trade-based deforestation measures. To this end, the following approach is adopted: we first estimate the level of regulations based on existing EUTR and extend this to additional products because there are no other comprehensive estimates available regarding the actual costs associated with the EUDR. We then incorporate these estimates into the computable general equilibrium (CGE) model Modular Applied General Equilibrium Tool (MAGNET) and conduct simulations under three scenarios: (1) EU-wide regulations on deforestation-related commodities from all countries, (2) EU regulations targeting only high-deforestation regions, and (3) global regulations on deforestation-linked commodities from HDR countries.

2. Literature review: the impact of EU trade regulations on deforestation

Trade regulations on deforestation-linked commodities aim to curb global deforestation by reducing demand for products like palm oil, soy, beef, and timber from high-deforestation regions. Grounded in economic theory, these policies address market failures by internalizing environmental costs (Pigou 1920). Empirical evidence supports the effectiveness of trade regulations, but their impact depends on enforcement. Prestemon (2015) documents that amendments to the US Lacey Act led to a 30%–40% rise in import prices and reduced timber imports, demonstrating a supply contraction effect. However, enforcement challenges and market shift complicate outcomes. To maximize impact, robust enforcement and international cooperation are crucial. Meyfroidt *et al* (2010) show that trade regulations often divert exports to less-regulated markets, reducing net environmental benefits.

Global studies highlight the complex effects of trade policies on deforestation. Beckman *et al* (2017) used a general equilibrium model to show that removing tariffs on forest-risk products can exacerbate deforestation, while banning illegal timber exports globally can help curb it. Tsurumi and Managi (2014) report that while trade liberalization accelerates deforestation in developing countries, it mitigates deforestation in wealthier nations due to regulatory differences. These findings stress the importance of context in evaluating trade policies.

The theory of comparative advantage (Ricardo 1817) explains why countries like Brazil and Indonesia specialize in land-intensive commodities. EU trade regulations disrupt these patterns by limiting market access, potentially lowering deforestation due to reduced profitability (Angelsen and Kaimowitz 1999). However, environmental leakage remains a concern. Strict regulations in one region often shift production to areas with weaker policies rather than reducing global deforestation (Meyfroidt *et al* 2010). Peters *et al* (2011) find that carbon tariffs lead to emissions relocating to less-regulated regions, a trend seen in forest product trade restrictions. Exporters frequently turn to alternative markets, such as China and the United States, where demand for deforestation-linked commodities remains high. Without synchronized policies across major consumer markets, trade regulations risk having a limited global impact (Fedoseeva and Zeidan 2022, Sun *et al* 2023).

Gilbert (2024) notes that commodities like beef, rubber, palm oil, and soybeans may be redirected to other markets, undermining the EUDR. Muradian *et al* (2025) similarly argue that the EUDR primarily influences EU consumption rather than global deforestation trends. The effectiveness of trade restrictions depends on international cooperation, particularly with China, a major importer of deforestation-linked commodities. In this sense, Beckman *et al* (2017) show that rising soybean demand in Asia drives deforestation, while Vasconcelo *et al* (2024) warn that the EUDR could push exports toward less-regulated markets. Although China's food security policies limit alignment with EU standards, market incentives and collaboration could encourage partial convergence. Coordinated global action is necessary for trade regulations to effectively combat deforestation.

Environmental leakage is further driven by price and income effects. A decline in EU demand could lower world prices for deforestation-linked commodities, making them more affordable elsewhere and potentially increasing land-use conversion in less-regulated countries (Persson *et al* 2014). This could undermine the EUDR's intended benefits. Meanwhile, European consumers may face higher prices for compliant commodities, especially coffee and cocoa, for which EU market shares are significant. Over time, improved compliance systems could mitigate these costs (Gilbert 2024).

Despite trade regulations' potential, several critical gaps remain. Global coordination is necessary to prevent trade diversion, but major importers like China and the United States have yet to adopt similar regulations. While environmental leakage is widely recognized, its scale and specific impact on deforestation require further study. Moreover, most research focuses on short-term outcomes, leaving long-term effects on production practices, governance, and sustainability underexplored. Addressing these gaps is crucial for designing trade policies that achieve lasting deforestation reductions.

3. Method and data

3.1. MAGNET model

This study employs the MAGNET to evaluate the global economic effects of trade regulation scenarios. MAGNET is a global, multi-sector, multi-region, comparative static CGE model, developed as an extension of the Global Trade Analysis Project (GTAP) model[3]. It retains GTAP's core economic structure, including nested constant elasticity of substitution production functions, Armington trade specifications, and a representative household per region, while introducing a modular architecture that enhances its analytical scope. The modular design enables the incorporation of detailed behavioral and structural features relevant to agri-food systems, land use, and environmental processes. Key extensions include modules for endogenous land supply, bioenergy demand, dietary change, greenhouse gas emissions accounting, and labor market dynamics (Woltjer and Kuiper 2014, Philippidis *et al* 2016).

MAGNET has been widely adopted by researchers and policy institutions to evaluate the economic impacts of agri-food trade, environmental policies, and land-use changes (e.g. Frank *et al* 2021, Freund *et al* 2025). The GTAP Data Base provides the benchmark equilibrium for the MAGNET model. It offers a comprehensive representation of domestic economic activity, bilateral trade flows, international transport margins, and trade protection measures across countries and regions and is documented on the GTAP website[4]. For each country or region, the Data Base reports the value of production, intermediate inputs, and final consumption of goods and services, expressed in millions of U.S. dollars. In addition to capturing international trade linkages, the GTAP Data Base includes detailed information on domestic policy instruments such as value-added taxes, production subsidies, and consumption taxes (Aguiar *et al* 2016).

Behavioral responses of economic agents are derived from constrained optimization, subject to standard assumptions such as homothetic separability. These assumptions support a nested structure of demand and production decisions that remain analytically tractable. Firms are assumed to operate under conditions of perfect competition and constant returns to scale. A set of market-clearing and accounting identities ensures that income, expenditure, and output are balanced within each region. Savings are modeled as a fixed share of regional income, while investment allocation is driven by relative changes in regional rates of return. A neoclassical closure rule links capital and current accounts, ensuring that imbalances in savings and investment are offset by trade flows, thereby maintaining a zero balance of payments (Philippidis *et al* 2016).

MAGNET and similar CGE models represent economic systems as large sets of equations defined for a given year t. Formally, the model is expressed as:

$$F(X) = 0 \quad (1)$$

where X is a vector of endogenous variables for year t (e.g. prices, quantities, technology levels, preference parameters, and inventory stocks), and F is a vector of nonlinear functions representing the system constraints (e.g. excess demand, price-cost gaps, and stock-flow balances) within the same period (Dixon and Rimmer 2025). Appendix C provides details of the land-use modeling in MAGNET.

3.2. Data and scenario design

For this paper, we apply the latest available GTAP Data Base, Version 11, using 2017 as the base year. This version comprises 65 economic sectors across 141 countries and 19 regions, covering the vast majority of global GDP (99.1%) and population (96.4%), making it well suited for comprehensive economy-wide analyses (Aguiar *et al* 2022). MAGNET disaggregates the GTAP database into 155 sectors. Since

[3] For a comprehensive explanation of the MAGNET model, see Woltjer and Kuiper (2014) and for the GTAP model, see Hertel (1997) and Corong *et al* (2017), who refactored the GTAP model code into the standardized GTAP-v7 architecture and implemented significant enhancements ('facelifts') such as improved domestic trade and transport margin modules.

[4] See www.gtap.org

Figure 1. Regions with high or moderate deforestation rates.
Source: Map created with mapchart.net CC BY-SA 4.0, based on Pacheco *et al* (2021).

this level of detail is not operational for our purposes, the sectors are aggregated into 78 sectors to reflect the specific priorities of our study. In the baseline, we project the data forward from 2024 to 2034. We build on the SSP2 (Shared Socioeconomic Pathways), which represents a 'middle-of-the-road' development path (Fricko *et al* 2017). In the baseline, the trade relationships from the initial Data Base evolve in response to exogenous assumptions from the SSP2 pathway, such as GDP growth, population dynamics, and productivity trends. Changes in relative prices and trade policies then determine how imports and exports are reallocated across regions over time.

Future demand for commodities, including deforestation-linked commodities (e.g. oilseeds, beef, forestry products), is projected endogenously, reflecting shifts in population and income, as well as changes in consumption patterns and production structures. Additionally, sectoral and regional productivity assumptions influence both the domestic supply response and the resulting trade flows of these commodities in the baseline. The baseline scenario indicates that Asia (excluding China) is the main destination for HDR countries exports of beef and vegetable oil, while China is the primary destination for oilseeds and forest products. Our aggregated region EFTA-UK (European Free Trade Association and United Kingdom) is the main destination for wood and paper products. Here we assume that the imports mainly come from the UK rather than from EFTA, since this reflects a historical trade pattern (see appendix A). Future consumption for deforestation-linked commodities is projected as the sum of domestic production, net imports, and exports. Global consumption between 2024 and 2034 increases by about 8%–10% for agricultural commodities and 17%–23% for forest and wood products (see appendix B).

Using the framework from Pacheco *et al* (2021), we categorize countries by deforestation rates, with a specific focus on HDR regions as primary exporters of commodities associated with deforestation (figure 1). Next, we identified key deforestation-linked products from the EUDR's official list, which classifies products using harmonized system (HS) codes. These commodities include palm oil, oilseeds, beef, and timber, among others.

Figure 2 presents our analysis framework. Since specific ad valorem tariff equivalents for EUDR-related non-tariff measures (NTMs) are not available, we use the EUTR as a proxy. We identify the common HS code between EUTR and EUDR based on the EU official regulations. Using World Bank data[5], we drive the ad valorem tariff equivalents for the relevant trade regulations, hereinafter referred to as NTMs. The data indicates a maximum tariff equivalent of 150% for NTMs on products comparable to those covered by the EUDR, which we applied as an upper bound in our analysis. The EUDR regulation is designed based on the detailed level of tariff lines. However, to evaluate policies, we first needed to calculate trade-weighted tariff rates based on MAGNET sectors. To incorporate these HS-coded products into the MAGNET model in the next step, we utilized the Tariff Analytical and Simulation Tool for Economists (TASTE), a software initially developed by Horridge and Laborde (2008) to process and aggregate tariff data from the MAcMapHS6

[5] *Ad Valorem Equivalent of Non-Tariff Measures: AVE estimates at GTAP sector* [Dataset]. World Bank Data Catalog. Available at: https://datacatalog.worldbank.org/search/dataset/0040437. We use the approach proposed by Walmsley and Strutt (2021) to convert tariff rates into AMS shocks in MAGNET. The AMS rates are available upon request.

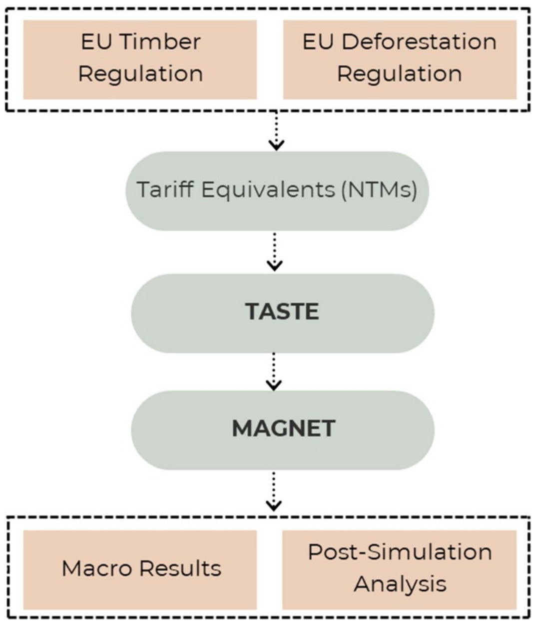

Figure 2. Analysis framework.
Source: own presentation.

dataset, and subsequently updated by Pelikan *et al* (2020). TASTE allows us to incorporate and aggregate the EUDR regulations into our scenario framework at a more detailed level than the model typically allows. Using trade weights, this maximum tariff rate of 150% effectively translates to an import restriction of approximately 2%–60% on deforestation-linked goods. The main advantage of using trade weights is that they reflect the actual economic relevance of each product in bilateral trade flows. High-volume imports receive greater weight, while rarely traded goods contribute proportionally less to the overall NTM. This ensures that the aggregated tariff measure corresponds closely to the effective burden faced by each trading partner and product. Nevertheless, trade-weighted aggregation is not without limitations. One concern is endogeneity: if NTMs are set prohibitively high, trade volumes may collapse, leading to a zero or negligible weight for precisely those products where protection is strongest. This can cause the aggregated measure to underestimate the true level of protection. Furthermore, trade weights are inherently backward-looking, since they reflect current trade patterns, which may themselves be shaped by existing tariffs rather than underlying comparative advantage.

In order to assess the robustness of our findings, we perform a sensitivity analysis to simulate the impact of a global trade restriction equivalent to a 50% increase in the ad valorem tariff rate[6].

Finally, we developed three scenarios plus baseline to assess the impact of trade regulations:

Baseline (SSP2): A reference scenario following the Shared Socioeconomic Pathway 2 (SSP2), representing a 'business-as-usual' trajectory with no additional deforestation-related trade regulations.

Global Trade Regulations (GLOB_HDR): A scenario imposing a 150% tariff equivalent (EQV) on all deforestation-linked commodity imports from HDR region worldwide, simulating a global application of an EUDR-like policy (with a country classification based on deforestation risk).

EU-Wide Trade Regulations (EU_GLOB): A 150% tariff EQV applied to all deforestation-linked commodity imports into the EU27, regardless of their country of origin.

Targeted EU Trade Regulations (EU_HDR): A 150% tariff EQV imposed only on imports from HDR region into the EU27, representing a more focused approach to restricting trade with countries exhibiting significant deforestation rates.

4. Results

4.1. Trade effects

Figure 3 presents the 2034 projections of changes in net exports (exports minus imports) for six deforestation-related agricultural and forestry commodities across major regions under three policy scenarios. As mentioned above, the GLOB_HDR scenario illustrates the effect of a coordinated global regulation on imports of commodities originating from HDR. Under this scenario, HDR countries experience sharp declines in net exports across several sectors, most notably in oilseeds, vegetable oils, and paper. In contrast, countries imposing the regulations see corresponding gains. The largest increase is observed in the United States and Canada, where oilseed net exports rise by USD 22.8 billion, primarily to China, Asia, and the EU27[7], driven almost entirely by higher export volumes rather than reductions in imports. Conversely, net exports for Asia and China fall in oilseeds by USD 1.1 billion and USD 5.3 billion, respectively, reflecting higher imports from North America. In vegetable oils, Asia's net exports increase by USD 8 billion, largely due to a USD 6.6 billion reduction in imports, suggesting import substitution through domestic production. China's paper sector records a USD 7.6 billion net export gain, evenly split between higher exports and lower imports, indicating a strong domestic supply response to shifting global demand.

Under the GLOB_HDR scenario, global net export balances remain relatively unchanged, driven by simultaneous declines in global imports and exports for all commodities, except oilseeds. The

[6] To maintain generality, we limit the sensitivity analysis to the first scenario. Results for the other scenarios are available upon request.

[7] According to our analysis, North American exports increase by an additional USD 19 billion to China, USA 3.1 billion to Asia, and USD 0.1 billion to the EU27 relative to the baseline. Detailed bilateral trade flow results are available upon request.

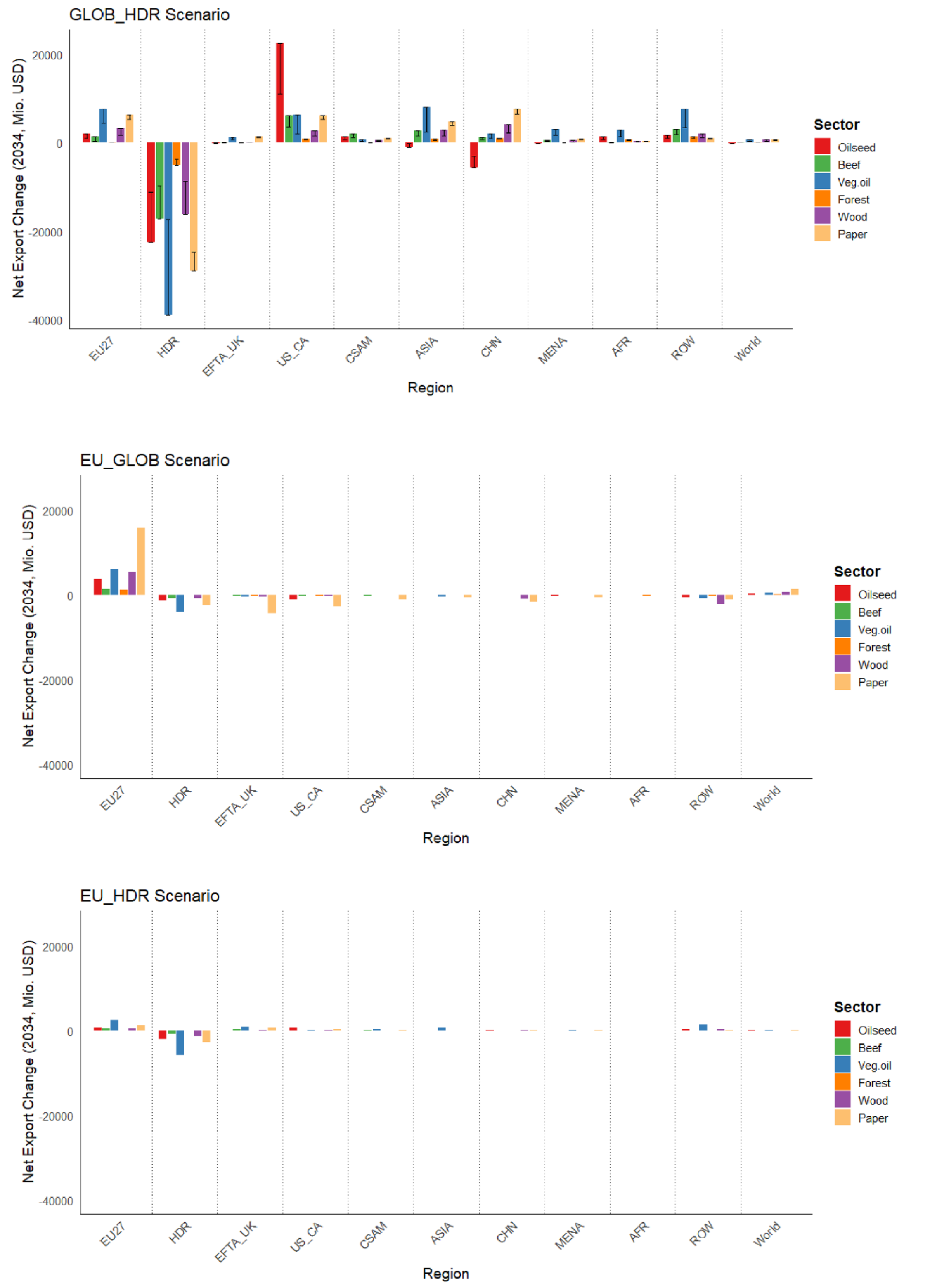

Figure 3. Net export change compared to the baseline in 2034 (in Mio. USD).
Note: the sensitivity range in the GLOB_HDR scenario graph simulates the impact of a global trade restriction equivalent to a 50% ad valorem tariff. EU27—European Union with 27 member states, HDR (high deforestation risk countries), EFTA-UK (European Free Trade Association countries plus the United Kingdom), US-CA (United States and Canada), CSAM (Central and South America), ASIA (Asia excluding China), CHN (China), MENA (Middle East and North Africa), AFR (Africa), and ROW (Rest of World).
Source: Our calculation using MAGNET.

total value of global exports and imports drops by about 24% for vegetable oils, 23% for beef, about 6% for forest products, wood, and for paper. In contrast to other commodities, global oilseed imports and exports increase by approximately 8% under the GLOB_HDR scenario (see appendix D). When HDR-origin supplies are restricted, importers such as China redirect purchases toward non-HDR exporters, most notably the US and Canada, which can offer oilseeds at lower prices than other suppliers due to competitive production costs and land use changes. Overall, oilseed imports and exports increase by around 7.2%, reflecting a shift in global demand toward commodities not subject to regulations. These findings are consistent with previous research highlighting how NTMs change trade flows and reallocate market shares among exporting countries (Bouët *et al* 2010, Cadot *et al* 2012).

In the EU_GLOB scenario (figure 3), the EU27 imposes import regulations on all deforestation-linked commodities, regardless of origin. The impact of this scenario on global trade is relatively muted compared to the GLOB_HDR scenario. Most regions outside the EU exhibit only marginal changes in net exports, reflecting the EU's comparatively small share of global demand for these products. However, within the EU, the effects are more significant. EU net exports of paper increase markedly, and imports of all six commodities decline. Specifically, oilseed imports fall by 34%, beef by 66%, vegetable oils by 47%, forest products by 40%, and paper by 80%. These changes are substantial relative to the size of the EU market, even though they do not significantly shift global trade flows. The limited global impact of the EU_GLOB scenario does not reflect policy ineffectiveness, but rather the relatively small share of EU demand in total global trade and the limited scope for redirecting HDR exports to other regions.

In the EU_HDR scenario, where the EU27 imposes regulations only on commodities originating from HDR regions, the global effects are minimal. Net exports across non-EU regions remain largely unchanged. Within the EU, however, import reductions are still evident, although smaller in scale. Under this scenario, EU imports decline by 8% for oilseeds, 27% for beef, 2% for vegetable oils, 4.5% for forest products, and 5.7% for paper. The reduced magnitude of change, relative to the EU_GLOB scenario, reflects the EU's limited reliance on HDR-origin inputs, particularly in the forest and paper sectors. Nonetheless, even these targeted regulations influence EU import patterns and signal adjustments in sourcing strategies and supply chain configurations.

To assess the robustness of these findings, a sensitivity analysis was conducted for the GLOB_HDR scenario. The results, shown with the error bars in figure 4, maintain the same directional trends across regions and commodities, though with lower magnitudes. This consistency demonstrates the structural stability of the results and confirms that the key insights are not sensitive to the precise magnitude of the NTM assumptions. For clarity and consistency across the manuscript, this sensitivity analysis is presented only for the GLOB_HDR scenario, as it represents the most comprehensive and globally coordinated case. To better understand the dynamics underlying our results, it is important to assess how EU import regulations influence HDR exports and whether these flows are redirected to other markets. Appendix E presents the changes in commodity exports from the HDR region and the corresponding changes in EU imports relative to the baseline.

4.2. Production effects

Regulations on deforestation-linked imports from HDR regions reduce production in HDR countries by lowering external demand while increasing production in importing regions as they substitute with domestic output. Table 1 reports percentage changes in agricultural and forestry production in 2034 relative to the SSP2 baseline. As expected, across all scenarios, regulations increase production in the EU27 and reduce output in HDR regions. The magnitude of these shifts is greatest under the globally coordinated regulation (GLOB_HDR) and smallest under the EU-only regulation. Under EU_GLOB, where the EU27 bans all deforestation-linked imports regardless of origin, the largest production gains occur within the EU itself, particularly in oilseeds (+20.78), vegetable oils (+33.69), and forest products (+7.68). These gains reflect import substitution, with domestic output expanding to compensate for lost external supply. Other non-HDR exporters, such as US-Canada, EFTA-UK, and CSAM, show small to moderate increases, with the most notable being EFTA-UK in vegetable oils (+31.91), reflecting its competitiveness in meeting redirected EU demand. By contrast, HDR producers experience modest declines across sectors (e.g.—0.53 oilseeds,—4.11 vegetable oils), consistent with reduced access to the EU market. At the global level, production changes remain marginal, indicating that EU_GLOB primarily drives internal adjustments within the EU rather than major reconfigurations of world production.

The slight increase in global output (world) in all scenarios seems counterintuitive but reflects the reallocation: restrictions on deforestation-linked exports raise relative prices and induce an expansion of output in regions and supply chains that are not directly constrained by the regulation. As a consequence, the contraction in high-risk suppliers is more than offset by increased production in other regions, so that aggregate world output rises even though the composition of production shifts away from high-risk sources.

Our results reflect the EU's varying dependence on HDR-origin commodities across sectors. In the baseline, HDR products account for approximately 40% of the EU's oilseed imports, 70% of vegetable oils, 9% of beef, 58% of forest products, 18% of wood, and 16% of paper. These dependency levels explain the heterogeneous responses observed under the EU_GLOB and EU_HDR scenarios. In sectors with high HDR import shares, most notably vegetable oils, the EUDR like policy displaces a substantial

Table 1. Percentage change in agricultural and forestry commodity productions compared to baseline (2034).

Country	Scenario	Oilseed	Beef	Veg. oil	Forest	Wood	Paper
EU27	EU_GLOB	20.78	4.60	33.69	7.68	5.50	7.04
	EU_HDR	5.66	2.33	14.19	0.50	0.52	0.55
	GLOB_HDR	13.19	3.98	32.52	2.15	2.65	2.11
		[6.79]	[2.55]	[16.84]	[1.37]	[1.41]	[1.73]
HDR	EU_GLOB	−0.53	−0.65	−4.11	−0.35	−0.68	−1.29
	EU_HDR	−2.11	−0.72	−5.83	−0.25	−0.80	−1.49
	GLOB_HDR	−22.51	−16.24	−42.30	−10.96	−13.51	−16.49
		[−9.19]	[−9.44]	[−19.48]	[−7.22]	[−6.91]	[−13.98]
EFTA-UK	EU_GLOB	−2.25	−1.58	−16.68	−7.01	−1.09	−9.05
	EU_HDR	5.92	2.37	31.91	0.70	0.35	1.50
	GLOB_HDR	14.03	4.89	53.11	2.32	1.73	3.67
		[7.08]	[3.03]	[25.17]	[1.53]	[0.92]	[2.96]
US-CA	EU_GLOB	−1.21	−0.17	0.23	−0.28	−0.24	−0.87
	EU_HDR	1.09	0.00	0.32	0.04	0.04	0.12
	GLOB_HDR	30.02	5.61	14.97	2.56	2.68	2.32
		[13.98]	[3.39]	[6.72]	[1.70]	[1.44]	[1.96]
CSAM	EU_GLOB	−0.50	−1.97	−4.18	−1.43	−0.29	−5.86
	EU_HDR	0.85	1.60	8.96	0.04	−0.16	0.73
	GLOB_HDR	29.93	27.00	33.33	5.30	6.60	7.80
		[13.70]	[15.23]	[15.97]	[3.64]	[3.35]	[6.84]
ASIA	EU_GLOB	0.06	−0.15	−0.70	−0.04	−0.02	−0.16
	EU_HDR	0.33	−0.63	1.45	−0.03	−0.05	0.01
	GLOB_HDR	12.07	18.67	36.40	1.63	3.93	2.53
		[6.42]	[11.82]	[18.55]	[1.09]	[2.07]	[2.12]
CHN	EU_GLOB	−0.20	−0.07	0.15	−0.16	−0.30	−0.36
	EU_HDR	−0.16	−0.05	0.08	0.01	0.03	0.04
	GLOB_HDR	16.54	4.42	2.49	2.59	1.57	2.33
		[8.28]	[2.86]	[1.39]	[1.84]	[0.85]	[1.99]
MENA	EU_GLOB	0.07	−0.20	−0.65	−0.28	0.11	−1.13
	EU_HDR	1.27	−0.23	1.47	0.05	−0.02	0.23
	GLOB_HDR	16.73	5.65	47.68	1.07	1.80	3.02
		[8.53]	[3.94]	[24.20]	[0.72]	[1.01]	[2.49]
AFR	EU_GLOB	−0.09	0.00	−0.03	−0.33	−0.22	−0.40
	EU_HDR	0.09	0.00	−0.14	−0.01	−0.01	0.00
	GLOB_HDR	9.12	0.48	29.53	1.22	2.50	3.21
		[4.22]	[0.30]	[15.74]	[0.86]	[1.31]	[2.81]
ROW	EU_GLOB	−1.37	−0.19	−4.75	−2.32	−5.82	−2.60
	EU_HDR	5.93	−0.20	9.35	0.16	1.04	0.41
	GLOB_HDR	31.77	10.86	56.63	7.08	5.65	3.74
		[15.28]	[6.24]	[26.71]	[4.89]	[2.89]	[2.78]
World	EU_GLOB	1.76	0.18	1.12	0.51	0.44	0.59
	EU_HDR	0.49	0.11	0.49	0.03	0.05	0.06
	GLOB_HDR	5.63	1.18	4.00	0.57	0.67	0.61
		[3.30]	[0.84]	[2.45]	[0.42]	[0.39]	[0.50]

Note: The sensitivity range in the GLOB_HDR scenario simulates the impact of a global trade restriction equivalent to a 50% ad valorem tariff. EU27—European Union with 27 member states, HDR (high deforestation risk countries), EFTA-UK (European Free Trade Association countries plus the United Kingdom), US-CA (United States and Canada), CSAM (Central and South America), ASIA (Asia excluding China), CHN (China), MENA (Middle East and North Africa), AFR (Africa), and ROW (Rest of World). *Source*: Our calculation using MAGNET.

portion of the EU's import base, driving significant domestic production growth, such as the 33.69% increase in vegetable oils under EU_GLOB.

In the EU_HDR scenario, which targets only HDR-origin imports, the effects are more moderate. EU production still increases, but less than under

Table 2. Global land use change (Mio. ha).

Land use category	GLOB_HDR	EU_GLOB	EU_HDR
Unmanaged forest land	14.5	1.0	2.7
Managed forest land	−18.1	−1.7	−1.5
Pastureland	−16.7	0.5	−2.9
Cropland	11.2	−0.2	0.2

Source: Our calculation using MAGNET.

EU_GLOB (+5.66 in oilseeds and +14.19 in vegetable oils). HDR countries experience modest declines, particularly in vegetable oils (–5.83), while non-HDR exporters such as US-Canada and the rest of the world absorb part of the displaced demand. At the global level, however, changes remain limited, reflecting the narrower scope of the regulation.

The GLOB_HDR scenario generates the most pronounced shifts. HDR countries face large production losses, especially in vegetable oils (–42.30) and oilseeds (–22.51), due to the loss of access to all major markets. These declines are offset by substantial production gains among competitive non-HDR suppliers: US-Canada oilseeds rise by +30.02, CSAM beef by +27.00, Asia vegetable oils by +36.40, and ROW vegetable oils by +56.63. These increases closely mirror the sectors where HDR countries had previously dominated, underscoring a broad redirection of production toward alternative exporters with the capacity to expand output.

Overall, a narrow EU-only regulation, whether EU_GLOB or EU_HDR, produces significant adjustments within the EU but limited changes globally, reflecting the EU's relatively small share of world demand. This suggests that the EUDR can meaningfully reduce the EU's own reliance on deforestation-linked commodities, particularly in highly dependent sectors such as vegetable oils and forest products. However, on its own it is unlikely to drive large-scale reductions in global HDR-linked production. Broader participation from other major importing regions, combined with complementary supply-side measures, would be necessary to achieve wider global impacts.

4.3. Land-use changes

Table 2 shows the global land use changes under all three scenarios. In the GLOB_HDR scenario (global regulations on HDR exports), land-use patterns shift markedly. Managed forests contract strongly (−18.1 Mha), while unmanaged forests expand by +14.5 Mha. At the same time, cropland increases by +11.2 Mha, whereas pastureland declines substantially (−16.7 Mha). This shows the reallocation of land across competing uses, with unmanaged forests and cropland gaining area primarily at the expense of managed forests and pasture.

In the EU_GLOB scenario, managed forest area shows a modest decline (–1.7 Mha), contrasted by a simultaneous increase in unmanaged forests (+1.0 Mha). Meanwhile, cropland declines slightly (−0.2 Mha), and pastureland increases by +0.5 Mha, suggesting a global shift of land use toward grazing areas outside the EU in response to EU-only regulations. Finally, in the EU_HDR scenario, managed forests decline by −1.5 Mha, unmanaged forests increase by +2.7 Mha, reflecting intra-forest conversion dynamics. Cropland expands marginally (+0.2 Mha), while pasture contracts by −2.9 Mha.

Figure 4 illustrates the changes in land use under all three scenarios for the analyzed regions. It shows that the global land use changes presented in table 2 are mainly driven by changes occurring in HDR regions. In the GLOB_HDR scenario, it becomes evident that outside HDR regions, several areas such as the USA and Canada, China, Africa, and the rest of the world experience increases in cropland. These increases are consistent with oilseed trade and production reallocation patterns discussed in previous sections.

Trade regulation reduces forest product rents in HDR regions, leading to a decline in managed forest area and a shift toward unmanaged forests. In the EU_HDR scenario, the policy introduces an origin-specific demand shock, diverting EU import demand away from HDR regions and toward non-HDR suppliers. This shift lowers export prices and forest rents in HDR regions, triggering measurable land-use changes—including reductions in managed forests and increases in unmanaged forest land.

In contrast, the EU_GLOB scenario applies the EU-regulation uniformly to all origins. As a result, the decrease in EU demand is shared across global exporters, which dampens the relative impact on HDR regions. Consequently, the land-use effects in HDR regions under this scenario are more modest compared to the origin-specific disruption seen in the EU_HDR case.

Across all three scenarios, unmanaged forest areas increase globally. This increase results mainly from the conversion of managed forests into unmanaged forests, as lower forest-product rents reduce the incentives for active forest management.

5. Limitations

Some limitations of our analysis may guide future research in this field. The principal limitation concerns the estimation of tariff equivalents for NTMs. Since trade under the EUDR has not yet taken place,

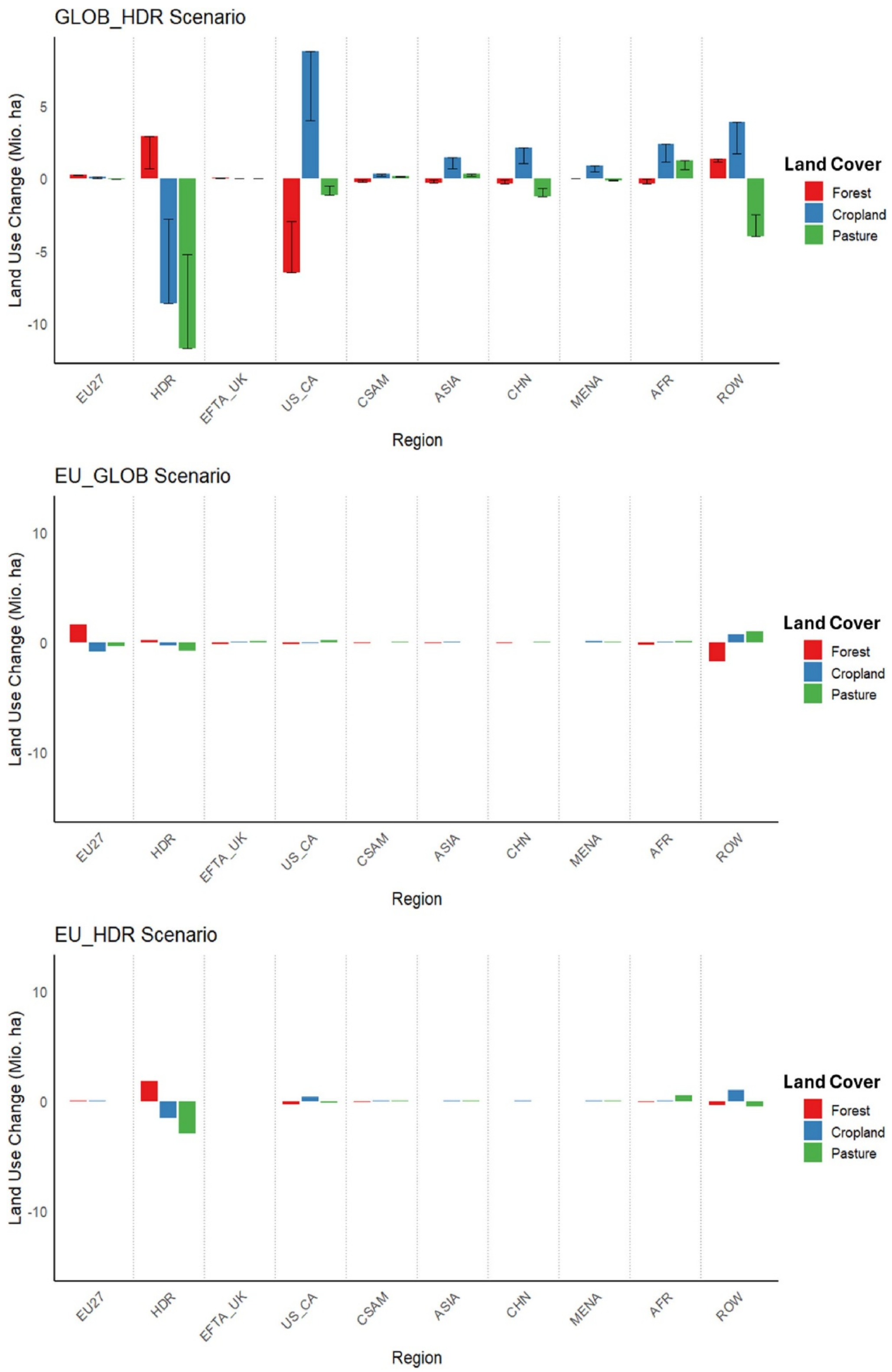

Figure 4. Absolute change in land use compared to baseline.
Note: The graph represents the total forest area, which includes both managed and unmanaged forests. Expansion of managed land uses is modeled to draw partly from savanna, shrubland, and unmanaged forest land. The sensitivity range in the GLOB_HDR scenario graph simulates the impact of a global trade restriction equivalent to a 50% ad valorem tariff. EU27—European Union with 27 member states, HDR (high deforestation risk countries), EFTA-UK (European Free Trade Association countries plus the United Kingdom), US-CA (United States and Canada), CSAM (Central and South America), ASIA (Asia excluding China), CHN (China), MENA (Middle East and North Africa), AFR (Africa), and ROW (Rest of World).
Source: Our calculation using MAGNET.

it is not possible to derive an ad valorem tariff equivalent specific to the regulation at the time of this analysis. To address this gap, we rely on proxies based on the EUTR. In our scenarios, we adopt the maximum available rate from the EUTR estimates, implying that our results likely represent the upper bound of the potential impact of an EUDR like trade restriction. As trade data under the EUDR becomes available, future research could refine these estimates by calculating regulation-specific tariff equivalents[8].

From a policy perspective, our analysis is subject to a limitation stemming from the design of the EUDR. The current version of the EUDR would require that EU supply chains for EUDR-covered products are not linked to deforestation. This applies to imports and exports from and to any country in the world, as well as to domestic consumption within the EU. Countries are only subject to different levels of due diligence and control mechanisms depending on their risk classification. This differs from our scenarios, which restrict imports of products from high-risk countries but still allow for deforestation to occur. This situation might change if the ongoing calls for a no-risk category were adopted, under which no due diligence and control mechanisms would be required for these countries. Thus, under the current institutional setting, the EU_Glob scenario is closer to the existing EUDR design with controls for all countries, whereas EU_HDR more closely resembles a situation with the introduction of a no-risk category.

From a methodological perspective, our analysis faces the following limitations: The regulation is incorporated into the model via the technical coefficient mechanism, modeling them as iceberg-type trade costs. This widely used approach but it assumes costs that are strictly proportional to trade volumes and overlooks changes in product quality perceptions or consumer preferences. As Walmsley and Strutt (2021) note, this approach is most suitable when NTMs act as pure non-fiscal trade costs, as is the case with the EUDR. Another limitation of our analysis relates to land-use change. GTAP-based models are essentially economic models built on equilibrium conditions. Most versions of GTAP, as well as other forest optimization models, account only for managed forest land. In MAGNET, we address this gap by incorporating additional land-use types, such as unmanaged forest, cropland, and pasture by allowing for substitution between them through a post-simulation procedure. Nevertheless, the results remain approximate and should not be interpreted as highly precise estimates.

[8] Recently, the European Commission released an updated list of countries classified as high deforestation risk, which differs in several respects from our list. We re-ran our analysis with this list; the dynamic results and our overall conclusions remain unchanged. Detailed results are available upon request.

6. Conclusion

This paper evaluates the impacts of trade regulations on deforestation-related commodities and their implications for global trade, production and land use in the forestry and agricultural sectors. Using the latest version of MAGNET, a global CGE model, we evaluate scenarios inspired by the EUDR. The analysis considers three scenarios: regulations imposed by the EU on HDR regions alone and on all countries, as well as global regulations on HDR commodities imports from HDR regions. Given the lack of specific data to estimate the potential trade costs of the EUDR, we adopt the ad valorem equivalent of trade regulation for similar products under the EUTR to design our scenarios.

Our trade-policy scenarios are inspired by the principles of the EUDR, but they do not simulate the regulation in its legal form. With respect to trade, our findings show that regulations on deforestation-linked commodities (explicitly modeled as NTMs) reshape global trade flows and reallocate market shares. The EU_HDR scenario represents a case where only high-deforestation-risk countries are subject to such controls, whereas EU_GLOB reflects a broader, global application. This structure allows us to explore how varying the geographic scope of control mechanisms (similar to the presence or absence of a zero-risk category under the EUDR) affects global production and trade outcomes. Global regulations on products from regions with HDRs sharply reduce HDR countries net exports, particularly in oilseeds, vegetable oils, and paper, while creating significant export opportunities for producers and risks of ecosystem degradation in other regions such as the United States and Canada. In contrast, EU-only regulations have more limited global repercussions, reflecting the EU's smaller share of global demand.

Turning to production, trade regulations reduce output in HDR countries while boosting production in importing and non-HDR exporting regions. In sectors with high HDR import shares, notably vegetable oils, the EUDR displaces a large share of EU imports, driving sharp domestic growth (+33.7% under EU_GLOB). These effects are largest with global regulations, where substantial declines in HDR countries oilseed and vegetable oil production are accompanied by increases in North America, Central and South America, Asia, and the rest of the world. Under EU-only scenarios, the main adjustments occur within the EU, particularly in sectors with high reliance on HDR inputs such as vegetable oils and forest products, while global production patterns remain largely unchanged. Taken together, the results indicate that EU regulations can meaningfully reduce reliance on commodities from HDR regions domestically, but broader international participation would be necessary to drive significant reduction in production of those products.

Regarding land use, the results reveal a consistent increase in unmanaged forest area across all scenarios, though the magnitude differs. A global regulation leads to 14.5 million hectares of additional unmanaged forest, reduces pasture, and increases cropland. However, the gain in unmanaged forest land is outweighed by forest losses of managed forest area converted to unmanaged forest and other land uses. When the EU imposes the regulation only on HDR countries, unmanaged forest areas increase more than in a scenario where the EU applies the regulations globally, because of the EU's modest share in the global market and the resulting limited trade diversion. Our analysis shows that border measures alone are unlikely to secure net forest conservation and should be coupled with domestic regulations that limit cropland expansion into managed forest. Although the EUDR aims not only to curb deforestation but also the degradation of managed forests, its scope is limited to export-oriented commodities. As a result, it remains possible for products that are consumed domestically or exported to other regions to convert managed forest to other land uses.

In line with previous literature (e.g. Yarlagadda *et al* 2025), our results suggest that EU-only regulations can substantially reduce HDR-linked imports relative to the EU's own consumption, especially in sectors with high HDR dependence, but their global impact is limited by the EU's modest share in world demand. Lack of control mechanisms in the EU and other non-HDR countries may partially offset the intended effects of restrictions on HDR countries, calling for maintaining due diligence obligations and control mechanisms from all countries while a globally coordinated regulation would substantially curb HDR production and trade, it would not automatically translate into greater global forest conservation. Instead, pressures would shift elsewhere, driving managed forest-to-cropland conversion in other regions. To be truly effective, the EUDR must therefore be embedded in a broader framework of complementary domestic policies, keeping due diligence and control mechanisms beyond HDR countries, to ensure lasting protection of the world's forests.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Acknowledgments

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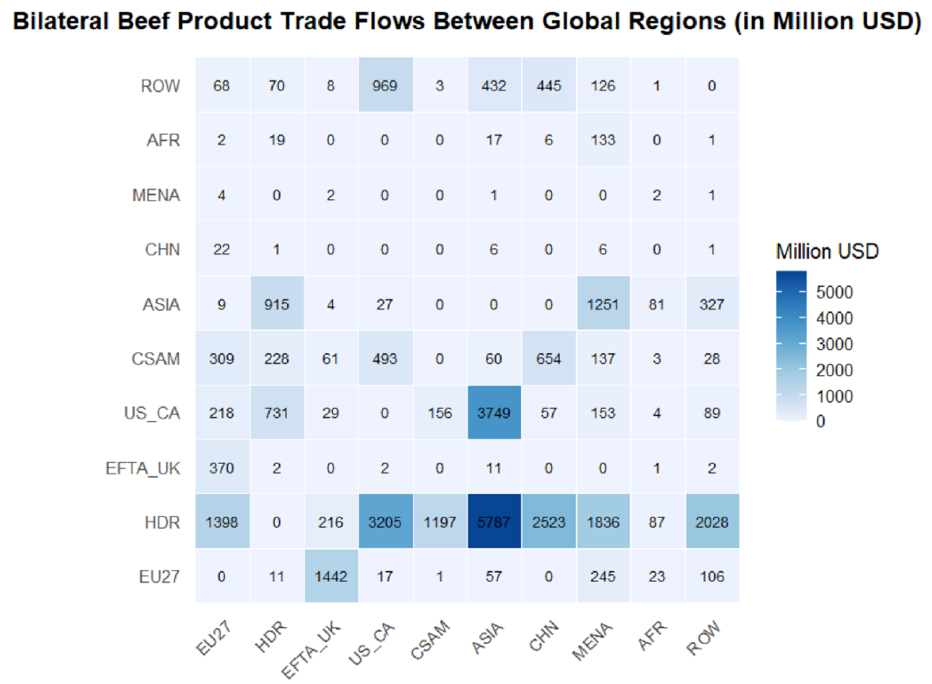
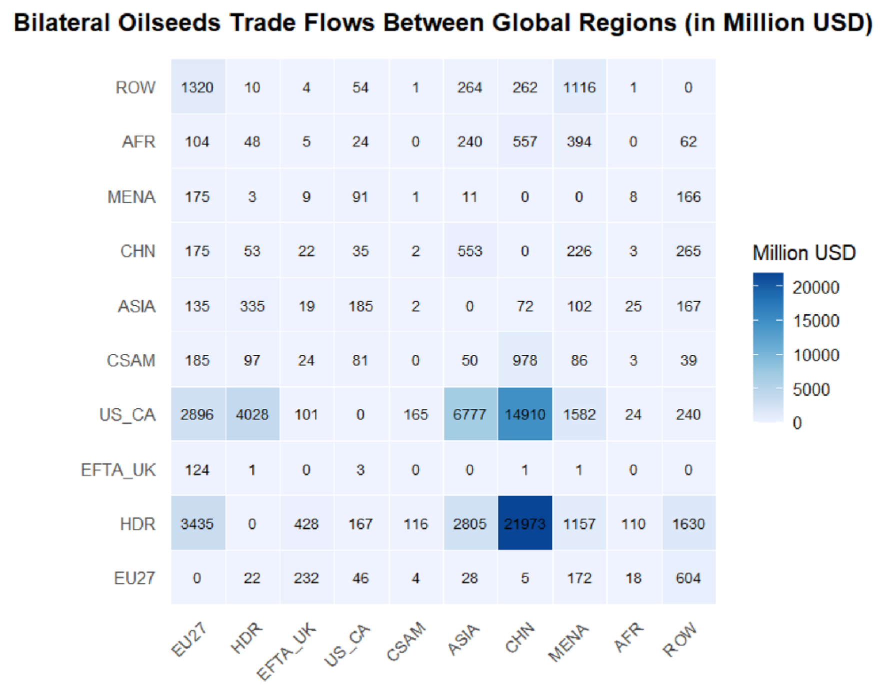
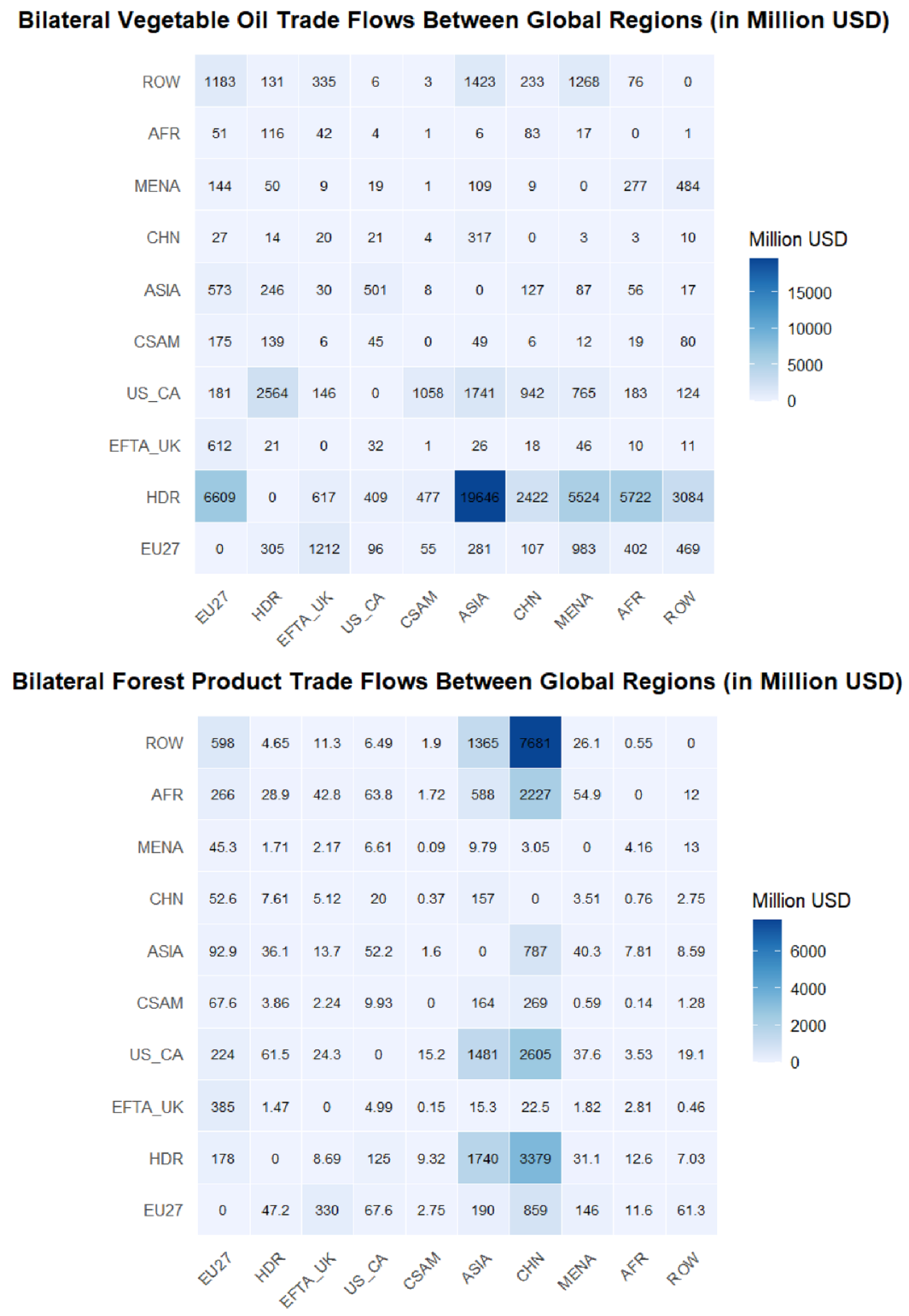
Appendix A. Bilateral trade flows in 2034 (Million USD): exports from the *Y*-axis country to the *X*-axis country






Bilateral Vegetable Oil Trade Flows Between Global Regions (in Million USD)
ROW 1183 131 335 6 3 1423 233 1268 76 0
AFR 51 116 42 4 1 6 83 17 0 1
MENA 144 50 9 19 1 109 9 0 277 484
CHN 27 14 20 21 4 317 0 3 3 10
ASIA 573 246 30 501 8 0 127 87 56 17
CSAM 175 139 6 45 0 49 6 12 19 80
US_CA 181 2564 146 0 1058 1741 942 765 183 124
EFTA_UK 612 21 0 32 1 26 18 46 10 11
HDR 6609 0 617 409 477 19646 2422 5524 5722 3084
EU27 0 305 1212 96 55 281 107 983 402 469
EU27 HDR EFTA_UK US_CA CSAM ASIA CHN MENA AFR ROW
Million USD
15000
10000
5000
0
Bilateral Forest Product Trade Flows Between Global Regions (in Million USD)
ROW 598 4.65 11.3 6.49 1.9 1365 7681 26.1 0.55 0
AFR 266 28.9 42.8 63.8 1.72 588 2227 54.9 0 12
MENA 45.3 1.71 2.17 6.61 0.09 9.79 3.05 0 4.16 13
CHN 52.6 7.61 5.12 20 0.37 157 0 3.51 0.76 2.75
ASIA 92.9 36.1 13.7 52.2 1.6 0 787 40.3 7.81 8.59
CSAM 67.6 3.86 2.24 9.93 0 164 269 0.59 0.14 1.28
US_CA 224 61.5 24.3 0 15.2 1481 2605 37.6 3.53 19.1
EFTA_UK 385 1.47 0 4.99 0.15 15.3 22.5 1.82 2.81 0.46
HDR 178 0 8.69 125 9.32 1740 3379 31.1 12.6 7.03
EU27 0 47.2 330 67.6 2.75 190 859 146 11.6 61.3
EU27 HDR EFTA_UK US_CA CSAM ASIA CHN MENA AFR ROW
Million USD
6000
4000
2000
0

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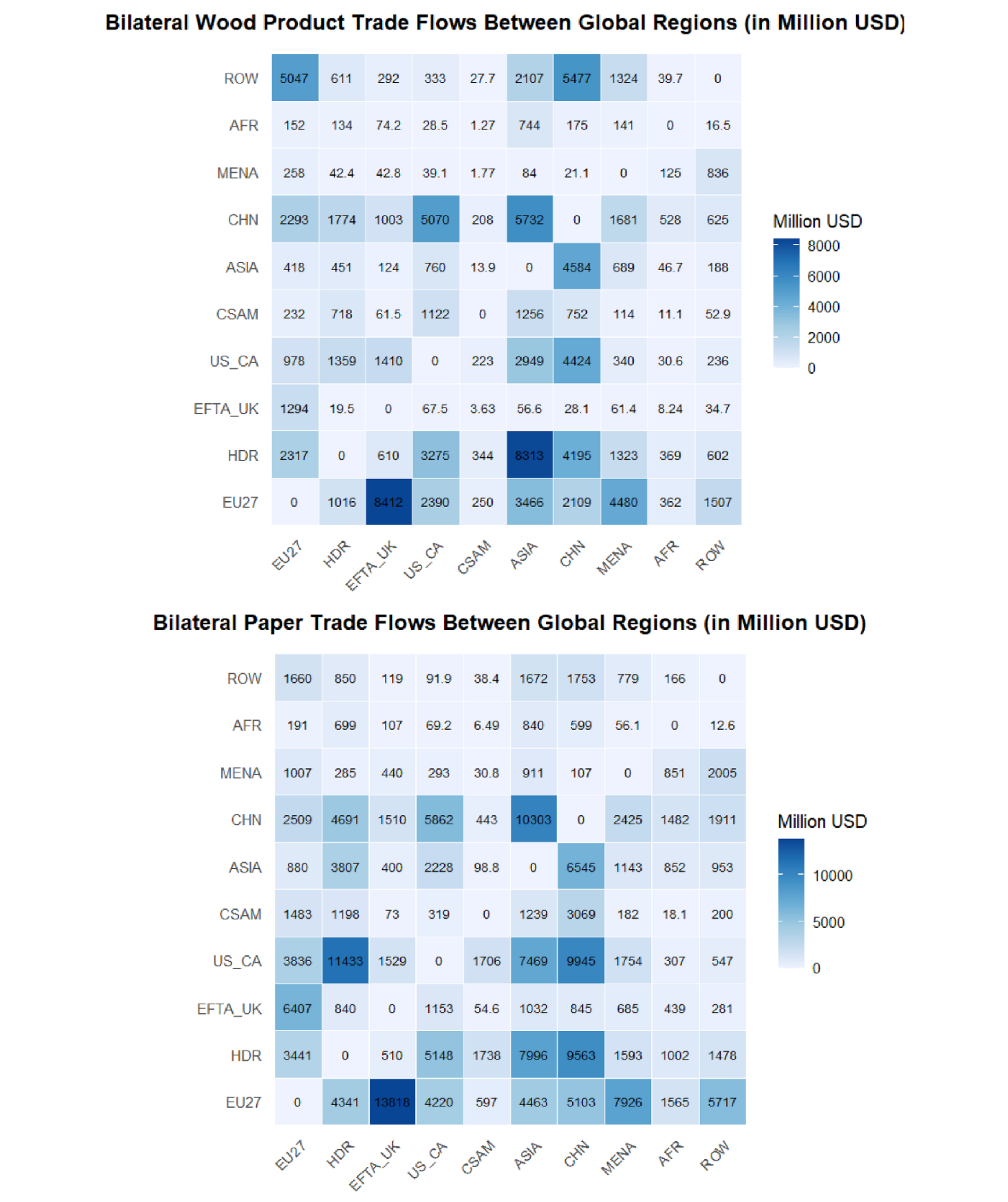

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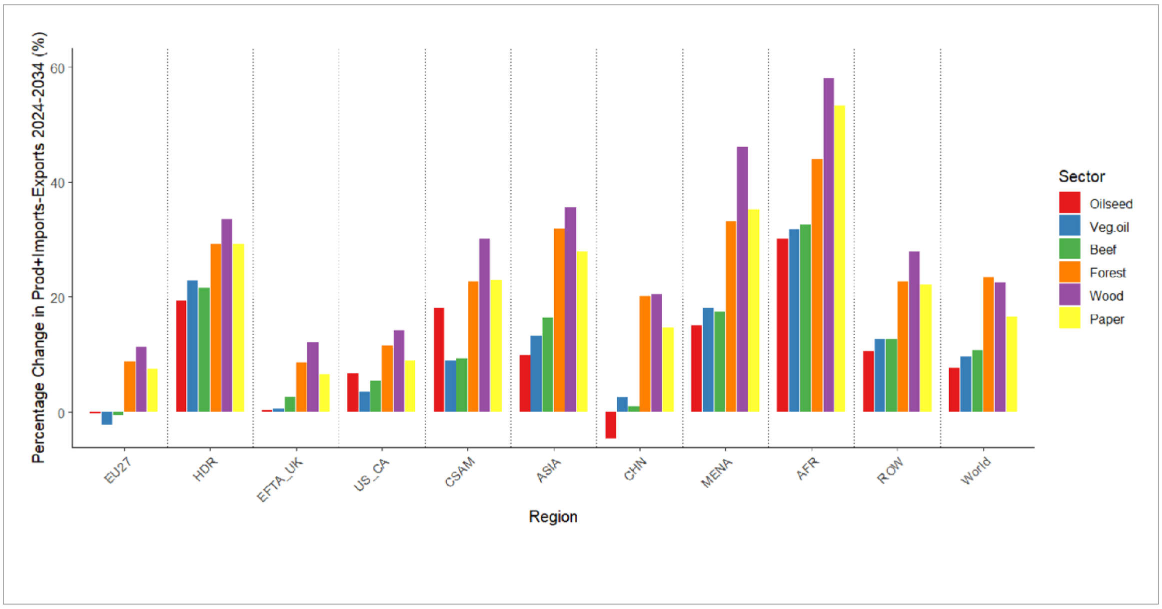
Source: Own calculations. MAGNET with SSP2 Baseline.

Appendix B. Percentage change in consumption (calculated as production—exports + imports, 2024–2034, %)



Source: Own calculations. MAGNET with SSP2 Baseline.

Appendix C. Land use modeling in MAGNET

The MAGNET model extends the standard GTAP framework by incorporating a land use module composed of three integrated components: land allocation, land supply, and land demand. At the core of this module is a nested constant elasticity of transformation (CET) structure which allows for a more detailed representation of land-use dynamics. In the original GTAP model, land is allocated among agricultural uses (such as crops, livestock, and forestry) using a single-level CET function. This setup captures the imperfect substitutability between different land uses, recognizing that shifting land from one activity to another is subject to economic and physical constraints (Hertel and Tsigas 1997).

MAGNET extends this by implementing a three-level nested CET structure. This approach allows for differentiated substitution elasticities between land use categories, enabling a more granular and realistic modeling of land-use change. For instance, land can be reallocated more easily between similar crop types (e.g. cereals and oilseeds) but is much less flexible between cropland and pasture. This hierarchy of substitutability makes MAGNET particularly suited for analyzing how land-use patterns respond to market signals or policy interventions (van Meijl *et al* 2006, Banse *et al* 2011).

A key innovation in MAGNET is its treatment of land supply. In contrast to many approaches that assume a fixed land supply, the MAGNET model implements land supply in which land availability adjusts endogenously in response to changes in real land rents. Eickhout *et al* (2009).

Figure C1 represents the land market in MAGNET. In this framework, the supply of land is modeled as a function of the real rental price of land, represented as (Dixon *et al* 2016):

$$P = F(L;\Omega)\,. \tag{A1}$$

In this equation, P denotes the real rental price of land, L represents the land supply allocated for different activities. D in figure C1 shows the demand for land, and Ω is the land asymptote. Function F is an increasing function of L, meaning that as the land supply L approaches the upper limit Ω, the real rental price P rises significantly, potentially approaching infinity. Then, it allocates this determined land among different agricultural activities using an optimization problem, ensuring an efficient distribution of land across uses. This combination allows for a dynamic and realistic representation of land supply and allocation in agricultural modeling.

Although land-use change for cropland, pasture, and managed forest land is modeled endogenously within MAGNET, the model also incorporates data on additional land types, including savanna, shrubland, unmanaged forest land, built-up areas, and other land, for post-simulation analysis. Cropland data is sourced

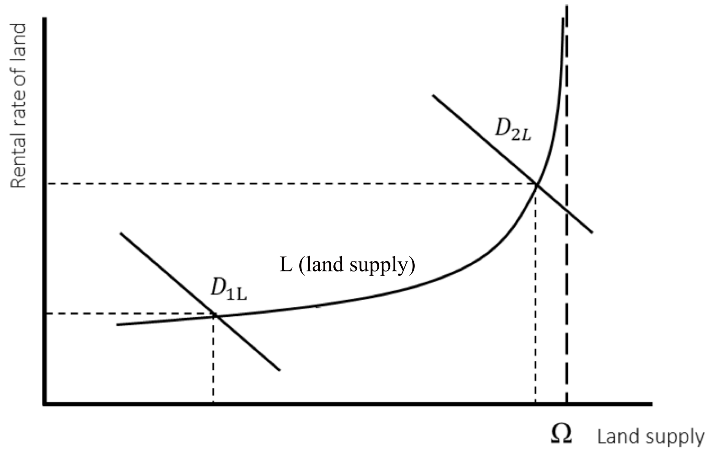
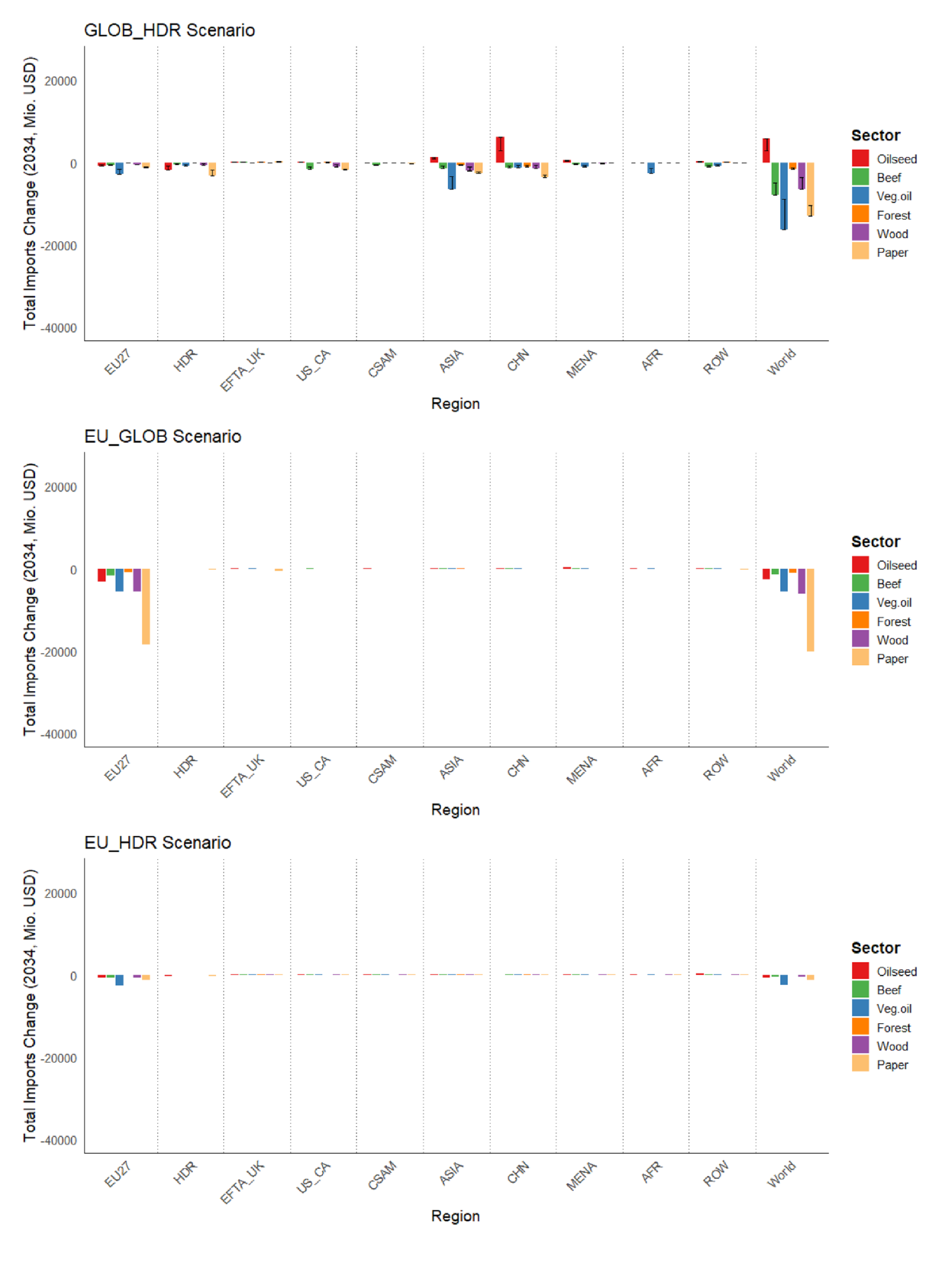
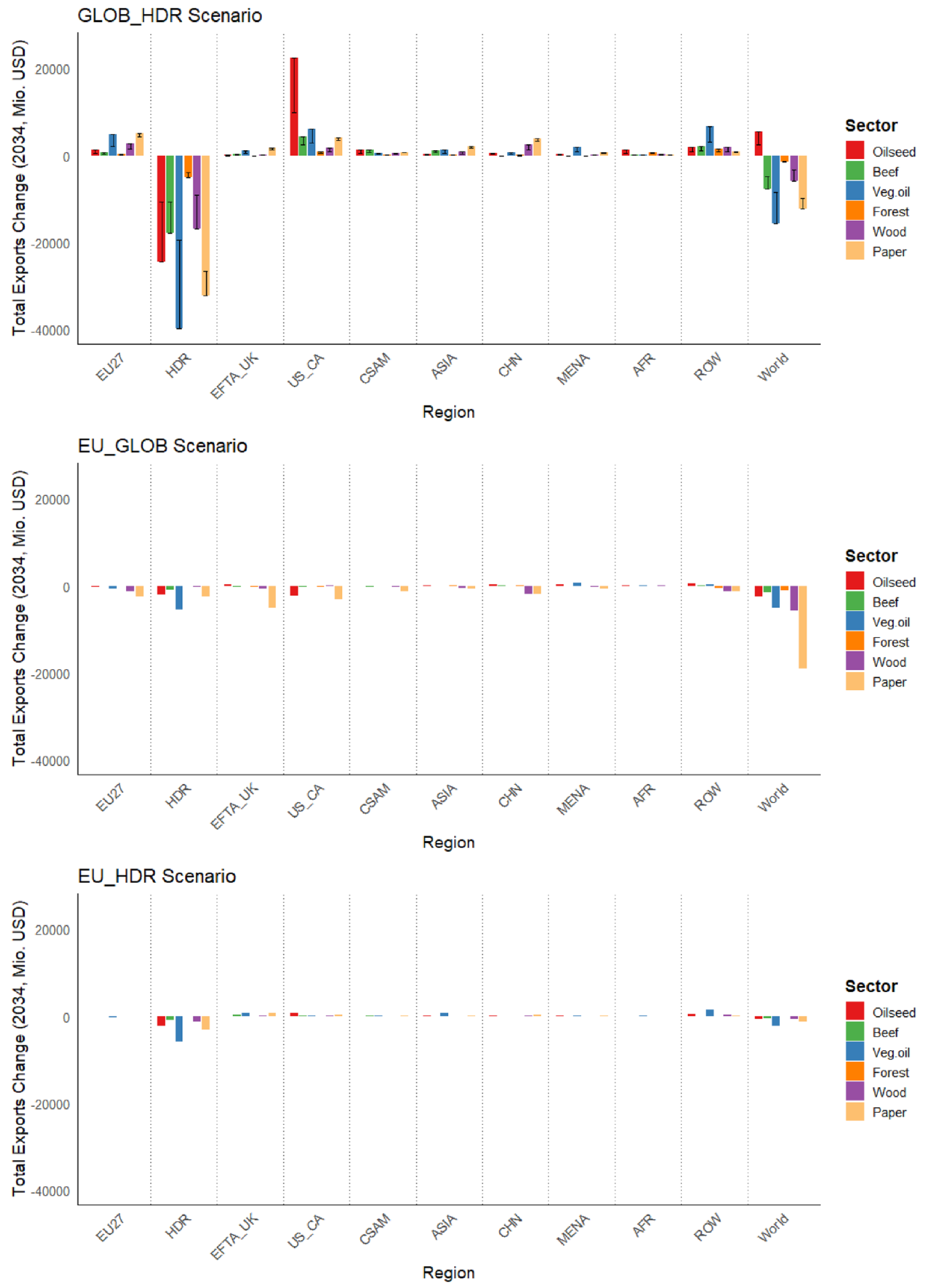


Figure C1. Land supply curve determining land conversion in MAGNET.
Source: own presentation based on Woltjer *et al* (2014).

from FAO-STAT, while the remaining land categories are based on Integrated Model to Assess the Global Environment data provided by PBL Netherlands Environmental Assessment Agency. Expansion of managed land uses is modeled to draw partly from savanna, shrubland, and unmanaged forest land. This transition is designed so that total national land area remains constant.

Appendix D. Total imports and exports change





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Appendix E. Change in commodity exports from HDR regions and change in EU imports compared to baseline

Figure E1 shows that some diversion occurs, but it is limited. For example, oilseed exports to China increase by only USD 0.5 billion and vegetable oil exports to Asia by USD 0.2 billion, amounts that are negligible compared to the losses in the EU market. Under the EU_HDR scenario, where regulations apply solely to HDR-origin

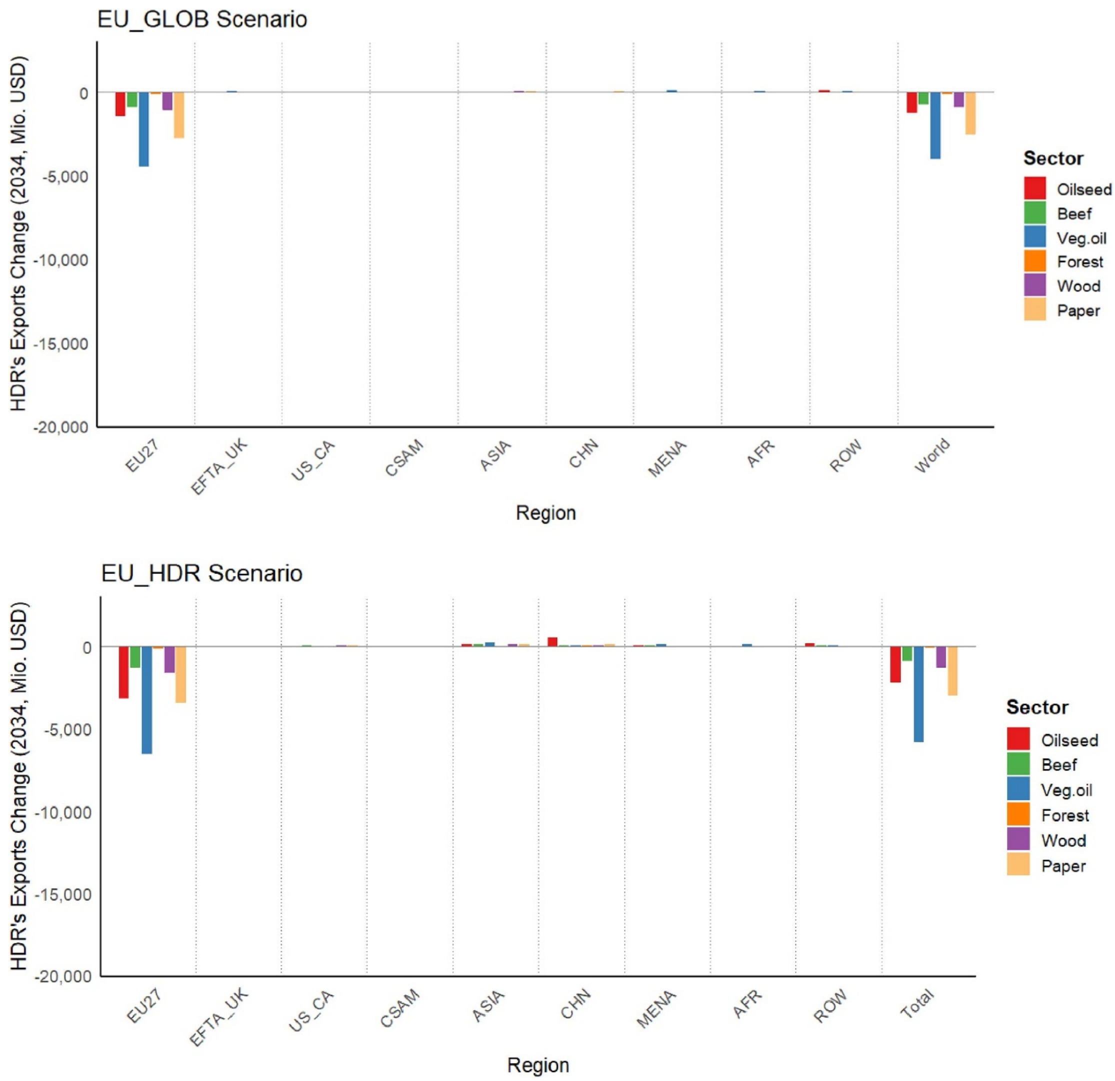

Figure E1. Change in commodity exports from high-deforestation regions compared to baseline in 2034.
Note: EU27—European Union with 27 member states, HDR (high deforestation risk countries), EFTA-UK (European Free Trade Association countries plus the United Kingdom), US-CA (United States and Canada), CSAM (Central and South America), ASIA (Asia excluding China), CHN (China), MENA (Middle East and North Africa), AFR (Africa), and ROW (Rest of World).
Source: our calculation using MAGNET.

commodities, exports to the EU also fall across the same sectors, though the declines are less pronounced than under EU_GLOB.

Figure E2 illustrates how EU import sources may shift under the scenarios. When the EU enforces regulations on imports from HDR countries (EU_HDR scenario), total imports in the oilseed market decline by USD 0.7 billion. However, imports from the US and Canada increase by approximately USD 1.5 billion, underscoring their role as key substitute suppliers. These shifts are less pronounced under the EU_GLOB scenario, where regulations apply to all origins, resulting in a larger reduction of about USD 4 billion in total EU imports. For vegetable oils, the EU compensates by sourcing more from Asia, EFTA-UK, and other regions (about USD 0.8 billion from each), reflecting the sector's flexibility and the presence of multiple global suppliers. Similar substitution is observed in paper and wood, where additional volumes come from EFTA-UK, China, and North America.

Overall, despite this capacity for adjustment, the EU's total imports still decline relative to the baseline, with reductions from HDR countries outweighing the increases from alternative suppliers. This indicates that while substitution mitigates some trade disruption, it cannot fully offset the loss of HDR-origin imports. Moreover, the ability to substitute varies across sectors: in oilseeds, compensation is relatively strong due to the presence of competitive non-HDR exporters, whereas in vegetable oils the more concentrated supplier base leaves the EU more exposed to supply constraints.

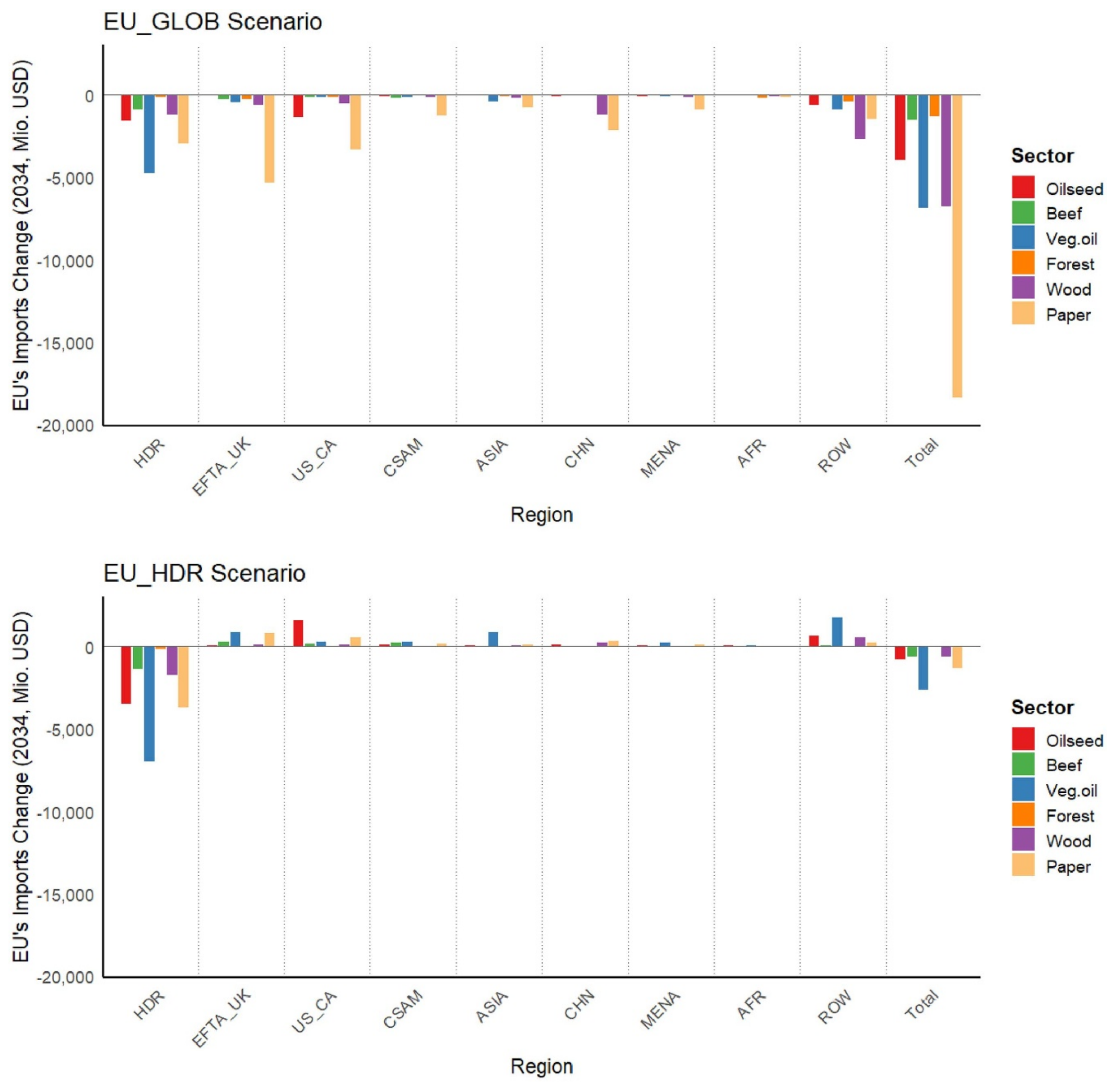

Figure E2. Change in EU imports compared to baseline under EU regulations on global imports (EU_GLOB) and on high-deforestation region imports (EU_HDR) in 2034.
Note: EU27—European Union with 27 member states, HDR (high deforestation risk countries), EFTA-UK (European Free Trade Association countries plus the United Kingdom), US-CA (United States and Canada), CSAM (Central and South America), ASIA (Asia excluding China), CHN (China), MENA (Middle East and North Africa), AFR (Africa), and ROW (Rest of World).
Source: Our calculation using MAGNET.

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