CLEVER

CREATING LEVERAGE TO ENHANCE BIODIVERSITY OUTCOMES
OF GLOBAL BIOMASS TRADE

Modelling the Impacts of International Trade Policies on Biodiversity

Deliverable 7.1: Co-designed Modelling Framework for Supply Chain Governance Initiatives

Summary

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Authors	Michelle Harrison, Heli Sihvonen and Juan Manuel Vargas, UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), United Kingdom.
Contributors	Jan Börner, Yaghoob Jafari and Fernanda Martinelli, Rheinische Friedrich-Wilhelms-Universitat Bonn | María Nieves Sanjuan Pellicer and Francisco Javier Ribal Sanchis, Universitat Politècnica de València | Ubirajara Oliveira, Universidade Federal de Minas Gerais | David Leclère, International Institute for Applied Systems Analysis (IIASA)

About CLEVER

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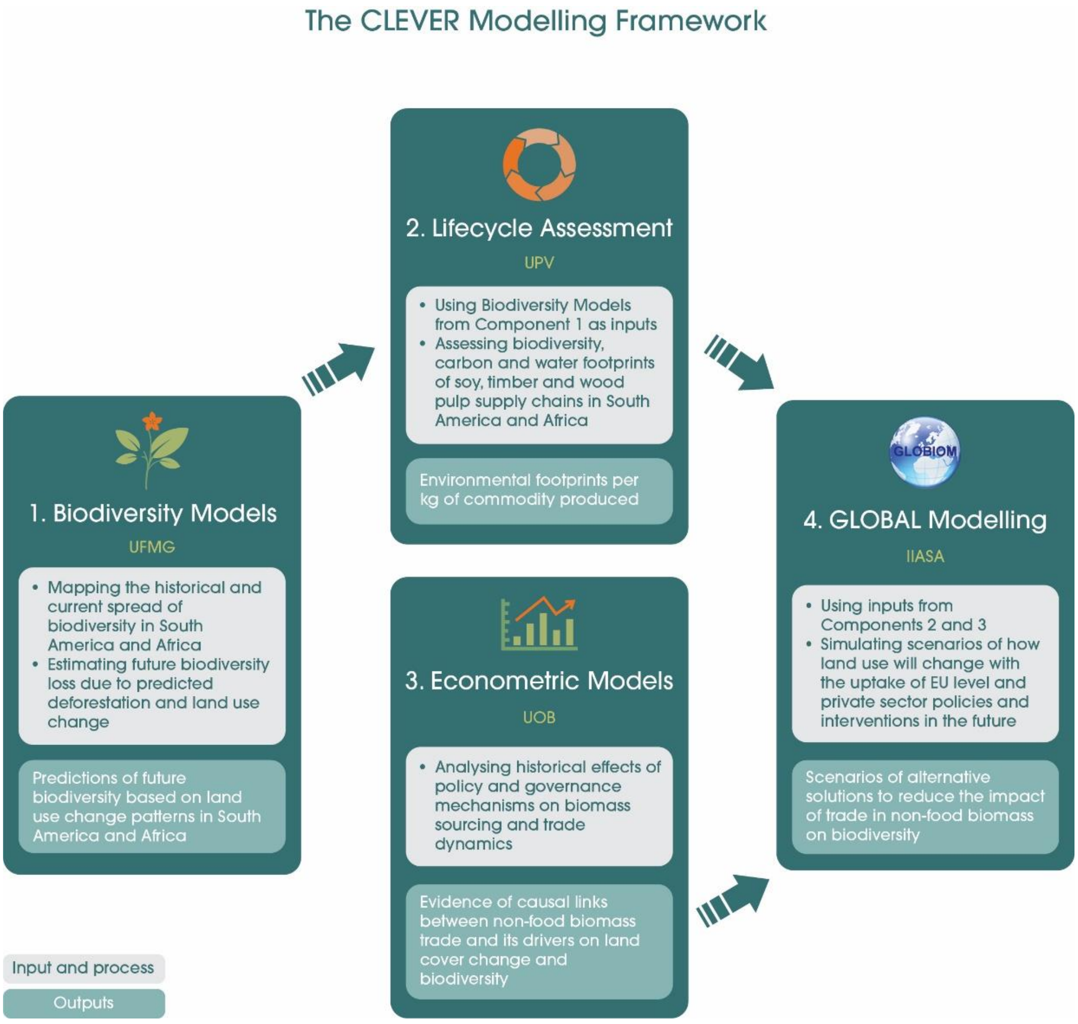
Contents

1. Executive Summary

Modelling in CLEVER aims to provide a holistic perspective on the relationship between the international trade of non-food crops, forest commodities and fishmeal and their impacts on biodiversity. The primary aim of the simulations is to understand the influence of trade-related interventions, both private and policy-driven, on biodiversity outcomes, capitalizing on potential leverage points. This occurs through collaboration with a diverse group of research bodies, using varying methodologies, coupled with stakeholder co-design and participation. The aim of this report is to make the modelling framework of CLEVER clearer for its stakeholders enabling them to contribute to research. Modelling in CLEVER is based on four components presented in Figure 1:



1. Biodiversity Models

UFMG

- Mapping the historical and current spread of biodiversity in South America and Africa
- Estimating future biodiversity loss due to predicted deforestation and land use change

Predictions of future biodiversity based on land use change patterns in South America and Africa

2. Lifecycle Assessment

UPV

- Using Biodiversity Models from Component 1 as inputs
- Assessing biodiversity, carbon and water footprints of soy, timber and wood pulp supply chains in South America and Africa

Environmental footprints per kg of commodity produced

3. Econometric Models

UOB

- Analysing historical effects of policy and governance mechanisms on biomass sourcing and trade dynamics

Evidence of causal links between non-food biomass trade and its drivers on land cover change and biodiversity

4. GLOBAL Modelling

IIASA

- Using inputs from Components 2 and 3
- Simulating scenarios of how land use will change with the uptake of EU level and private sector policies and interventions in the future

Scenarios of alternative solutions to reduce the impact of trade in non-food biomass on biodiversity

Figure 1 Modelling Components of CLEVER and the research bodies leading them. UFMG = Universidade Federal De Minas Gerais, UPV = Universitat Politecnica De Valencia, UBO = Rheinische Friedrich-Wilhelms-Universitat Bonn, IIASA = International Institute for Applied Systems Analysis. Design by Rosa Castañeda (European Forest Institute).

1. **Biodiversity models map local species and their current and predicted loss according to land use change patterns.**
   Universidade Federal de Minas Gerais

Component 1 models spatial patterns of biodiversity, producing maps of the potential and current spatial variation of biodiversity indicators for South America and Africa, as well as the estimated biodiversity loss due to deforestation and land use change. It will deliver predictions of future biodiversity loss based on land use change scenarios.

2. **Lifecycle assessment departs from land use, carbon, and water footprint measures of the commodities to deliver an indicator of biodiversity loss per kilogram produced.**
   Universitat Politècnica de València

Using the biodiversity models created for Component 1, as well as previous scientific research, Component 2 tracks the lifecycle of commodities, generating biodiversity loss estimates, land use changes, carbon, and water footprints for soy, timber and wood pulp across South America and Africa. The main outcomes are indicators of biodiversity loss per kilogram of commodity produced.

3. **Econometric models analyse historical policy effects over trade dynamics and produce more accurate elasticities to inform the next component on how sensitive certain factors are to each other.**
   Rheinische Friedrich-Wilhelms-Universitat Bonn

Component 3 will carry out a historical or ex-post analysis of the effects of policy and governance mechanisms on biomass sourcing and trade dynamics. This will generate evidence of the causal links between trade in non-food crops, forest commodities and fishmeal and policy mechanisms. One of the key factors analysed here is how trader stickiness, or the tendency for private actors to change their behaviour at different paces, mediates the effectiveness of agricultural and environmental policies. Important outcomes from this component are improved estimates of critical model parameters, such as supply and demand elasticities that influence the results to the global modelling in Component 4.

4. **Global modelling simulates future land use change in different public and private policy scenarios shedding light on their biodiversity outcomes and pointing towards the most effective pathways.**
   International Institute for Applied Systems Analysis

Using the data and parameter estimates from the previous components, Component 4 will model how land use will change with the uptake of EU-level and private sector policies and interventions on the international trade of the focal commodities. The outcome of this component is a set of scenarios depicting the impact of trade in non-food biomass, under various policy changes, on biodiversity. This will help CLEVER to identify leverage points for transformative change as well as provide scientific evidence for the potential public and private policy paths that will maximize positive biodiversity outcomes.

2. Introduction

Scientists from a wide variety of fields have been working together to develop powerful tools to better understand the relationship of humankind and nature. Simulations models are one if these tools. They allow researchers to study and simulate the behaviour of systems under various scenarios of change in human demography, socioeconomics, business activity, or public policy, among others. Ideally, these scenarios are based on real-world data so that simulations are informed by plausible trends in factors such as population growth, economic development, energy use, land use, or policy changes. Therefore, models are tools to answer "what if" questions, such as how a trade agreement between the EU and the Mercosur could affect global land use patterns. Changes in land use patterns can then be translated into impacts on greenhouse gas emissions or biodiversity.

However, models can get very complex and require vast amounts of data. They also require many assumptions about uncertain relationships, and are thus often informed by statistical methods and, more recently, machine learning. Hence, modelling requires specialised scientific knowledge, often turning simulations into "black boxes" that are not accessible for broader audiences. For these reasons, this report aims to make the modelling framework of CLEVER clearer for the key stakeholders involved in the system under study in order to enable them to contribute to research. The framework presented in this report can be developed dynamically by gradually adding new knowledge to this version as modelling progresses and new information becomes available. Additional features to the framework could include information on the capabilities and constraints of modelling. The following sections delve into the specifics of the modelling framework of CLEVER, discussing its components and their respective contributions: (1) biodiversity modelling, (2) lifecycle assessment, (3) econometric modelling, and (4) global modelling.

The authors of this report would like to acknowledge the CLEVER partners at the Federal University of Minas Gerais, the Polytechnic University of Valencia, the University of Bonn, and the International Institute for Applied Systems Analysis who are involved in the modelling work of CLEVER and provided valuable input to this report.

Regarding data gaps, the models will not include statistical data related to people (e.g., disaggregated by age, gender, or population group) that could support analyses regarding groups of people that are considered most vulnerable to environmental degradation and climate change (i.e., women, Indigenous Peoples and local communities, or youth) given the low data availability and the scope of modelling components.

3. Objectives

The objective of this report is to provide internal and external stakeholders with a transparent presentation of the modelling framework used in CLEVER. The report can be used a communication tool to exchange information with the project's partners and in the co-design process with stakeholders. This will facilitate their involvement in co-design, so that several groups can work together to validate, and brainstorm on the assumptions and policy interventions simulated.

Besides, an effective communication of the model will manage expectations and inform discussions about the potential scope and feasibility of scenario-based assessments in CLEVER.

4. Components of the Modelling Framework

Component 1: Biodiversity Modelling

Research body: Universidade Federal De Minas Gerais, Brazil (UFMG)
Geographical focus: South America and Africa
Inputs from other modelling components: None, as this is the 1st modelling component.
Final outputs: Maps of biodiversity change and predicted future biodiversity for species richness, species composition and endemism in South America and Africa

Background and aim

The aim of Component 1 in the CLEVER modelling framework is to quantify the impact of land use and land cover change on a variety of biodiversity indicators. To the extent that land cover change can be linked to the CLEVER products (soy, forest products), it also seeks to quantify the effects of soy expansion or logging on biodiversity. The modelling is currently done for the whole of South America and Africa (see also CLEVER deliverable D2.2).

Mapping the historical and current spread of biodiversity in South America and Africa

Creating maps of potential and current vegetation

The first step of the process is to estimate current vegetation structure, which is used as a predictor variable to model potential (natural) vegetation patterns. To do this, remotely sensed data on the Normalized Difference Vegetation Index (NDVI) and canopy height is used. These variables are summarised into a single variable representing vegetation structure using a Principal Components Analysis.

A predictive model is constructed with the first principal component of vegetation structure as the dependent variable. A range of bioclimatic and soil variables are tested as predictor variables for vegetation structure, including soil pH, acidity, proportion of sand, silt and clay. A set of 19 climatic variables is summarised into four principal components for input into the model. Topographic variables such as altitude, terrain and slope are also included. To establish a good estimation of the relationship between vegetation structure and the predictor variables, predictive models are trained with data from geographical areas that contain remnants of native natural vegetation.

Various modelling approaches are used to determine the best predictive model. This selection process is based on cross-validation using multiple subsets of the available data on natural areas, to test how well the model predicts vegetation patterns from real data. This final model is used to make predictions of original vegetation structure, prior to any human influence, for South America and Africa. This prediction represents an estimation of the potential natural vegetation structure in these areas, i.e. disregarding land use or anthropogenic influence.

Modelling biodiversity patterns

Current biodiversity data is taken from Global Biodiversity Information Facility (GBIF). The dataset includes data for birds, mammals, reptiles, amphibians, bees, butterflies and plants from the Fabaceae, Solanaceae, Poaceae and Malpighiaceae families. Only occurrences in Africa and South America are included and co-ordinates are spatially validated by cross-referencing sites with location databases such as OpenStreetMap. Species names are also validated against taxonomic reference databases such as Species 2000.

Biodiversity models are constructed for species richness, endemism and species composition. The predictor variables in these models are vegetation structure (based on a PCA of NDVI and canopy height); four climatic variables (based on a PCA on the 19 bioclimatic CHELSA variables), altitude, terrain orientation and slope. The biodiversity models are trained using current vegetation and biodiversity data from the same period. Various modelling approaches are used to determine the best model structure. This selection process is based on cross-validation using multiple subsets of the available data on natural areas, to test how well the model predicted biodiversity patterns from real data. Coefficients from these models are then projected on to maps of current vegetation for 2021, providing up-to-date maps of biodiversity patterns.

Creating maps of original biodiversity

Biodiversity model coefficients can be projected onto the maps of original vegetation to provide maps of the historical distribution of biodiversity, prior to human intervention, across South America and Africa. These projections are performed for all metrics providing past spatial predictions of where species richness and endemism would have been likely to occur. To estimate the original biodiversity (without the major effects of international trade), these models are projected into past scenarios using historical climate data from 1900 to 2000 (CHELSA) and the original vegetation model.

Estimating future biodiversity loss due to predicted deforestation and land use change

Estimating loss of biodiversity
By comparing maps of historical and current spatial distributions of biodiversity, estimates of biodiversity loss can be made. These are calculated by overlaying the original species composition on to maps of current species composition and taking percentage loss per pixel. The same methodology is applied with endemism and species composition.

Predicting future biodiversity loss
Future biodiversity patterns are modelled based on the patterns of future vegetation structure that will occur under different LULCC and climate change scenarios. Several scenarios are modelled including realistic trajectories, but also more pessimistic versions for both land use change and climate change. At least two scenarios are considered: one modelling the impact of strong environmental policies, the other accounting for weak environmental policies. These scenarios project to 2050 and 2070.

A series of species distribution models are used to project habitat loss under various scenarios. For this purpose, the models are trained using vegetation structure data (as described above) for the baseline scenario (original vegetation) and projected onto land use change data (scenarios). To achieve this, the relationship between land use change and vegetation structure is modelled to use as predictor variable in modelling the land use change scenarios.

Component 2: Life Cycle Assessment

Research body: Universitat Politecnica De Valencia, Spain (UPV)
Geographical focus: South America and Africa
Inputs from other modelling components: The biodiversity models from Component 1 input into the refinement of characterization factors in Component 2
Final outputs: Biodiversity loss, carbon and water footprints associated with the export supply of soy and timber

Background and aim

The aim of Component 2 in the CLEVER modelling framework is to assess the environmental impact of specific biomass supply chains. This is achieved by undertaking a Life Cycle Assessment (LCA), which measures environmental impacts at different stages of production, processing and service-provisioning for a commodity. The resource use, including materials and energy associated with each stage of the life cycle can be assessed, as can the resulting emissions from each phase. Resource use and emissions are associated with a wide range of environmental impacts, such as climate change, land degradation, eutrophication and freshwater consumption, all of which can be modelled and the wider implications for human health, biodiversity and resource depletion assessed. The LCA associates emissions and resource use along the product life cycle with a series of environmental impact categories (e.g., climate change, eutrophication, biodiversity loss). To derive impact scores, the emissions and resource use associated with production are quantified and multiplied by specific characterization factors (CFs) for each of the environmental impact categories.

Within the CLEVER framework, the focal commodities are soy in South America and timber in Africa, and the impact categories assessed are biodiversity loss and water and carbon footprints. The methods to assess the carbon and water footprints of a product using an LCA are well established. Biodiversity assessment is more complex. Biodiversity loss is often driven by land use but is also indirectly affected by environmental degradation such as climate change, terrestrial acidification or pollution. Current approaches to assess land use-driven biodiversity loss only capture species richness, disregarding measures such as endemism, species abundance, species composition, or community structure.

Using Biodiversity Models from Component 1 as inputs

Development of improved land use-driven characterization factors (CFs)

Human pressure on land can be described as: a) land occupation or land use (LU) and b) land transformation or land use change (LUC). Both land use and land use change are global drivers of biodiversity loss. Chaudhary and Brooks (2018) developed a set of CFs to quantify the loss of species that occurs due to LU and LUC. They used the countryside-Species Area Relationship model to estimate the eventual number of species that will remain with certain LU or LUC relative to the original (pristine), considering the ability of species to adjust to habitat loss. They did this for five taxa across six different land use types, for 804 terrestrial ecosystems.

These CFs can be used to calculate an impact score for land use-driven biodiversity loss. CFs (occupation) give the potential species loss after the conversion of natural pristine habitat to the current land use. CFs (transformation) give the marginal species loss due to a marginal increase in human-used area.

The outputs from Component 1 are maps of the original vegetation structure and estimations of the current spatial distribution of biodiversity for South America and Africa. Biodiversity is presented as maps of species richness, endemism and species composition. By superimposing this spatial data onto existing land use maps, a new comprehensive set of CFs for land-use-driven biodiversity impact is developed in Component 2. These CFs consider the same LU types and intensities as Chaudhary and Brooks (2018) with a new taxon, arthropods, being included in the analysis.

Assessing biodiversity, carbon and water footprints

Conducting the Life Cycle Assessment

The aim for Component 2 is to estimate regionalised indicators of carbon and water footprints and biodiversity impacts for soybean supply chains from South America and timber from Africa. A bottom-up approach is applied to assess the supply chains embedded in EU imports of the two commodities.

To estimate the impacts of soybean supply chains, data from the TRASE database is used. TRASE provides annual data on several variables linked to soy production such as quantities of soy, land use change, the value of exports, deforestation exposures, main exporting and importing ports. These variables can be mapped to biome, state or municipality, as well as to exporting companies and importing countries. By matching this data with the maps produced in Component 1, biodiversity losses can be associated with soy production in each jurisdiction whether that be at the biome, state or municipality level. Other data sources to assess the impacts of soybean supply chains are also incorporated. Statistics at the regional level are used to quantify the use of agricultural inputs, and the Ecoinvent database provides the impacts of stages such as processing or transportation.

Similar data is required to estimate the impact indicators of the representative timber supply chains in Africa. As these data are not available in TRASE, they are obtained from official data providers (e.g., FAOstat, National Ministries of Forestry). The data needed for the LCA is on the main harvested forest species, volume harvested, financial flow, main importing countries and companies, origin and destination ports. In addition, data from specific companies is gathered to understand the process of timber harvesting and processing and the associated impacts.

Using this data, and the CFs for the environmental impacts, a bottom-up LCA for each representative supply chain embedded in EU imports (or in the whole export supply of each country) is carried out. From these assessments, impact indicators per tonne of product per supply chain is estimated. The bottom-up LCAs estimate emissions from land use change, crop production, intermediate processing and transport with the desired level of resolution. By multiplying the indicators per tonne by the quantity of each supply chain exported each year, the biodiversity loss, carbon and water footprints associated with the export supply of each product are determined.

References

Chaudhary, A., & Brooks, T. M. (2018). Land use intensity-specific global characterisation factors to assess product biodiversity footprints. Environmental science & technology, 52(9), 5094-5104.

Component 3: Econometric Analysis

Research body: University of Bonn, Germany (UBO)
Geographical focus: South America and Africa (supply), Europe (demand)
Inputs from other modelling components: None
Final outputs: Evidence of causal links between non-food biomass trade and its drivers on land cover change and biodiversity

Background and aim

Component 3 of the CLEVER modelling framework comprises ex-post analyses of the relationship between international trade (and trade-related policies) and changes in non-food biomass production as well as related land use changes. It focuses on the following three challenges:

(1) Quantification of the relationship between international trade dynamics (specifically trade with the EU and China) and deforestation (as a proxy for biodiversity loss) in different municipalities in Brazil.

(2) Quantifying the determinants of the behaviour of key value chain actors, such as traders, in major non-food biomass value chains. This analysis focuses on shifts in agricultural commodity sourcing in response to sustainability-oriented value chain governance initiatives and policies, using Brazil as a case study. One of the key indicators used here is trader "stickiness", i.e. the mobility of traders across sourcing regions and export destinations.

(3) Quantifying the impact of trade policies, including tariff and non-tariff measures, on freshwater aquaculture production globally and at the country level.

Quantifying historical effects of trade and related policies on land cover change and biodiversity

Model-based scenario analyses, such as those proposed in Component 4 typically require many assumptions on mechanistic relationships in the trade system. Econometrics and other empirical methods based on historical data can help to corroborate these assumptions and make modelling and simulation studies more reliable and policy relevant. Important knowledge gaps that will be addressed by econometric analyses in CLEVER include the strength of the relationship between changes in trade flows and biodiversity-relevant land use and land cover change (challenge 1), the behavioural response of key value chain actors to changes in trade dynamics and related policies (challenge 2), and the response of non-food biomass producers to trade policies (challenge 3). Methodologically, the challenge in addressing these knowledge gaps lies in finding statistical proof for causal linkages between the hypothesized drivers and outcomes of the relationships under study. If such proof can be provided, it will enable Component 4 to identify leverage points for biodiversity conservation with greater precision and credibility.

We address challenge 1 with a focus on Brazil, because Brazil is the most important producer of soy, one of the focus commodities in CLEVER, with soy still being produced in a number of regions subject to deforestation pressure and corresponding risks of biodiversity loss. Challenge 2 is addressed in the same regional context in order for us to provide component 4 with consistent information about trade impacts and the role of actors in mediating these impacts. Moreover, this regional focus also allows us to translate results from component 3 into biodiversity loss based on results from component 1. We address challenge 3 in a difference context, namely aquaculture production, which has been criticized as a major driver behind biodiversity loss especially in Southeast Asia.

Component 4: Scenario Modelling

Research body: International Institute for Applied Systems Analysis, Austria (IIASA)
Geographical focus: South America (supply), Europe (demand)

Inputs from other components: Indicators of biodiversity loss intensity per kg of commodity from Component 2; indicators of changes in land use with uptake of policies from Component 3
Final outputs: Projections of multiple socioeconomic and environmental indicators and maps, including land use change and biodiversity, under various scenarios related to international supply-chains future developments and policy options for their governance.

Background and aim

The aim of Component 4 in the CLEVER modelling framework is to explore with models and scenarios the potential future developments in international supply chains of soybean, plantation forest and fishmeal products, and their impacts on biodiversity, as well as the potential for alternative supply-chain governance options to lower these. This work is conducted in three steps:

- First, selected improvements to the GLOBIOM modelling framework are conducted to improve the realism of how these supply chains and their governance are represented in the modelling framework.
- Then, scenarios about alternative futures for these supply chains are designed, based on projections of future changes in the demand, trade and supply of various products (in relation to changes in climate, technology, population, consumer preference, interventions towards climate and biodiversity goals) and assumptions about supply chains governance options, covering both international trade (e.g., EU-MERCOSUR, EU deforestation-free supply chain initiatives) and domestic policies (e.g., conservation policies, Brazil's forest code and soy moratorium).
- Finally, these scenarios are quantified using the GLOBIOM modelling framework, to translate scenario assumptions into expected developments in demand, trade and supply of various products, as well as land use changes, and various environmental and socio-economic indicators. Outcomes are analysed and disseminated.

About GLOBIOM

The Global Biosphere Management Model (GLOBIOM) is a global partial equilibrium that integrates the agricultural, bioenergy, forestry and aquaculture sectors to provide policy analysis on global issues concerning land use. It covers 50 world regions, including the 27 individual EU Member States, and other countries represented as single-country regions (e.g., Brazil, Argentina or USA) or multi-country regions. In contrary to a general equilibrium model, it does not incorporate all economic sectors in a country or region, but instead focuses specifically on agriculture, forestry, bioenergy and aquaculture sectors. These focal sectors are modelled in a detailed way accounting for production, trade and consumption for markets relying on 18 globally most important crops, a range of livestock production activities, forestry commodities as well as different energy transformation pathways and aquaculture products. The model simulates competition for land between different uses driven by price and productivity changes, as well as market dynamics through bilateral trade and consumption levels in reaction to policies, price, trade costs, population and dietary preferences. It is used for applications ranging from global scale projections to the end of the 21st century to explore land use pathways towards climate and biodiversity goals, to projections focused on the next 5 to 10 years in one country to explore the impact of specific policies. While a full model documentation is available here, we here provide a summary of main features relevant the representation of international supply chains:

- **Demand projections.** The demand for agricultural, forestry, bioenergy and aquaculture products is modelled in primary product-equivalent at the regional level. Future projections depend on the one hand on exogenous scenarios of future population and consumer preferences (as affected by e.g., income level or assumed transition towards specific diets), waste reduction, demand for energy and non-energy forest biomass, and on the other hand on market dynamics simulated by the model (with product-specific demand responsiveness to price levels).
- **Trade projections.** Physical bilateral trade flows (i.e., the quantities of each commodity traded between each region) are modelled, as well as related trade costs (based on tariffs and non-tariff measures as well as non-linear transport costs). Future projections of bilateral trade flows react to changes in demand, supply and prices across regions, and assumptions about trade costs and regulations.
- **Production, land use and land use change projections.** The distribution of different land uses (e.g., cropland, pasture, managed and unmanaged forest, other natural land, settlements), their allocation to various production activities (and resulting production levels) and land use-changes (e.g., conversion from forest ti cropland) are modelled at subnational scale. In addition to regional production, demand and trade, the model is calibrated to reproduce the land use in year 2000, estimated from remote sensing and national to subnational official statistics. Projected future land use and land use change depends on future demand and price levels, as well as competition for land between alternative land uses, including changes in land allocation to various crop, livestock or forestry production systems, non-linear land use change costs and rigidity constraints. While the model routinely reports land use and land use change outcomes at the regional level, these can also be reported at higher spatial resolution (up to 10km) including using downscaling algorithms.
- **Production activities.** Production systems are linked to land and water resources through their resource use. Cropland systems vary in terms of crops grown (e.g., individual crops, multicropping) as well as productivity and input level (from low productivity subsistence to highly productive commercial irrigated and fertilized systems), livestock systems vary in terms of species (e.g., bovine, sheep and goats, pigs, poultry) and feed rations (e.g., extensive vs mixed systems for ruminants) and the forestry systems consist in forest plantations versus managed forests. The parameterization of alternative production systems in GLOBIOM relies on several biophysical models such as EPIC (for crops), RUMINANT (livestock) and G4M and 3PGmix (forestry), and side data on the initial distribution of production systems in the year 2000.For example, the EPIC model provides maps of productivity and input use (nitrogen, irrigation water) under various management intensities (from subsistence to fertilized and irrigated systems) for 18 global crops that represents around 84% of the total harvested area in the world. This dataset is combined with

IFPRI's SPAM dataset of subnational harvested areas by management systems and crop for the year 2000. Although marine catch and fish reduction is not endogenously modelled in GLOBIOM, the model represents the fishmeal inputs (as protein) to the livestock and aquaculture sectors and can account for alternative scenarios in the protein markets.

- **Environmental and socioeconomic SDG-relevant impacts.** Based on the representation of the dynamics of land and water use (including production systems and their input use) and land use change (including conversions between different natural and managed land covers) at subnational resolution, the model can provide estimates of land, water, and reactive nitrogen input use for the production of each commodity in each region (and with even finer resolution), as well as land use changes and related carbon emissions and removals. A detailed GHG accounting module also allows to report agricultural methane and nitrous oxide GHG emissions, while a detailed biodiversity module translates land use and land use change outcomes in terms of intactness and extinction risk metrics. Based on the link between production, trade and consumption, the environmental aspects embedded in the trade and consumption of various commodities can be reported, and a broader set of socioeconomic metrics related to consumers (e.g., food availability, food price, number of people at risk of hunger) as well as producers (e.g., value added in different sectors) can be reported.
- **Global vs regional model versions.** The model covers the globe, and most of the applications run at global scale and are parameterized with global datasets. However, the model can also be tailored specifically to regions, incorporating mode detailed representations of land uses and policies relevant for the geographical location, and making use of more accurate regional datasets. This is for example the case for Brazil, Argentina and the EU, for which applications related to these regions have been relying on dedicated model versions.

GLOBIOM improvements within CLEVER

For the CLEVER project, the representation of individual supply chains and the impact of alternative governance interventions will be improved. The model implementation will draw on a most recent trunk model version, subsequently improved for increased relevance to the CLEVER case studies. Preliminary thoughts on model improvements priorities are the following:

- **Improved parameterization of soy and wood production systems.** In order to increase the realism of producer behaviour in these supply chains, IIASA will generate new data on the productivity and input use for soy production systems in Latin America (using the EPIC crop model, with explicit modelling of multiple cropping systems and sustainable practices in Brazil and impacts of future climate change), as well as forest plantations in the tropics (using the 3PGmix model, with calibration of various species under alternative management practices and future projections under alternative climate change scenarios). New projections for the FLAM model will also inform on where fires are likely to occur, providing spatial data of burnt areas in Latin America under alternative future climate change scenarios. In addition to biophysical model estimates, additional spatially explicit data will be collected by IIASA on relevant parameters such as the area of soy cropping systems and forest plantation, as well as plantation forest production costs, and implemented in the model.

- **Improved representation of exports in soy and wood trade patterns:** data on trade flows, provided by the University of Bonn, will be used to inform the modelled response of destination countries to fluctuations in the market and change in policy. In addition, SEI data from the TRASE dataset may be used to refine the link between bilateral trade flows for export from supply countries and subnational patterns.
- **Improved representation of supply chain actors and governance:** the representation of key countries (e.g., Brazil) in the model may be consolidated based on available regional versions. This will better represent supply chain dynamics, as well as model response to specific governance interventions such as Brazil's Forest Code, Soy Moratorium (and a potential expansion to Cerrado), EU deforestation-free supply chain initiative and EU-MERCOSUR. This will also make use of the data from Component 3 on land use change under different policies is used to inform future land use response to policy change that is modelled within GLOBIOM.
- **Improved representation of biodiversity indicators:** data from Component 2, which includes recent LCA-based indicators of biodiversity loss intensity per unit of commodity, is used to derive implications of modelled scenarios of policy change on the environment.

Developing scenarios of land use change with the uptake of EU level and private sector policies and interventions

Scenarios of land use change under various policies will be developed. These scenarios take the form of narrative drafts that are refined with input from other stakeholders within the modelling framework. For each commodity, soy, timber or fishmeal, several major scenarios are developed showing the trajectory of land use change with the implementation of significant policies, such as the EU deforestation-free policy. These scenarios project to 2030-2050.

The identification of leverage points for the mitigation of biodiversity loss is based on an examination of the current literature and input from relevant stakeholders. This covers trade policies that are still in the discussion phase (e.g., EU-MERCOSUR), those that have been recently implemented (e.g., EU deforestation-free) as well as domestic interventions (e.g., Soy Moratorium). By modelling land use response to these policies, and assessing the associated impact on biotic patterns, we can understand where policy can be leveraged to improve outcomes for biodiversity.

5. Conclusions

In conclusion, this document serves as a tool to transparently present the CLEVER modelling framework that seeks to study the links between the international trade of non-food crops and biodiversity impacts. Through collaborative action encompassing diverse research institutions, CLEVER's four modelling components collectively shed light on critical dimensions:

- **Biodiversity Mapping (Component 1 - Universidade Federal de Minas Gerais)** employs spatial analyses to delineate current and potential biodiversity variations in South America and Africa. By forecasting biodiversity loss due to deforestation and land use shifts, it delivers a tangible assessment of ecological impact.

- **Lifecycle Assessment (Component 2 - Universitat Politècnica de València)** scrutinizes the entire lifecycle of commodities. Drawing from Component 1's biodiversity models, it quantifies biodiversity loss, along with carbon and water footprints, per kilogram of soy, timber, and wood pulp produced.

- **Econometric Analysis (Component 3 - Rheinische Friedrich-Wilhelms-Universitat Bonn)** evaluates historical policies' influence on trade dynamics. By assessing the interplay between policy mechanisms and private sector behaviour, it illuminates how policy effectiveness can mediate the trade-environment relationship.

- **Global Scenario Modelling (Component 4 - International Institute for Applied Systems Analysis)** employs data from the preceding components to simulate diverse policy scenarios' impact on land use. These projections spotlight potential pathways for trade-related policies to engender positive biodiversity outcomes.

The framework's vision, as enhanced by this report, empowers stakeholders to engage meaningfully and contribute to refining research. Through its pragmatic delineation of these components, CLEVER underscores the imperative of evidence-based insights, stakeholder engagement, and informed policy direction in fostering sustainable trade practices that harmonize with biodiversity conservation.