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Preface

The Pan-African Network for economic Analysis of Policies (PANAP) brings together academic, research and institutional partners that develop research on agro-economics and policy issues. It was established in 2019 under the aegis of the African Union (AU) - European Union (EU) partnership. The network is co-hosted by the European Commission - Joint Research Centre (JRC), the African Union Commission - Agriculture, Rural Development, Blue Economy, and Sustainable Environment (ARBE), and the Forum for Agricultural Research in Africa (FARA).

PANAP aims to strengthen the liaison between researchers, scientists, and policymakers in Africa, and to stimulate their cooperation on selected topics linked to policy priorities that reinforce the stability and enhance the development of African agrifood systems. PANAP contributes to address scientific issues in the fields of agriculture and food security, with the aim of supporting effective policies and achieving sustainability of the agri-food systems and to enhance food and nutrition security. These efforts are in alignment with the Malabo Declaration Commitment 3, which aims to end hunger in Africa by 2025, as well as Sustainable Development Goal (SDG) 1 and SDG 2.

This Working Paper series (JRC Working Papers on Economic Analysis of Policies in Africa) collects works to support continental, regional and national policymakers in Africa in designing, assessing ex-ante and evaluating ex-post the impacts of agricultural policies. It also includes works related to the construction and analysis of databases and description of model developments to provide evidence-based policy support to partner countries. The series serves the objective to share the knowledge produced within PANAP related to micro and macro data, models/economic tools, and to disseminate results and create a common knowledge base and practices on the topic of economic analysis of policy.

The main audience for this series is a diverse spectrum of stakeholders with a shared objective: to foster evidence-based policy decision-making in Africa. This audience encompasses statistical offices, researchers, modellers, data analysts, policy makers and other key stakeholders from both national and multilateral institutions.

Abstract

Through the Deforestation Regulation (EUDR), the European Union recognises its responsibility for the deforestation and associated carbon dioxide (CO_2) emissions and biodiversity loss originating from products consumed by its citizens. For a defined set of products associated with high deforestation risk, including cocoa, the regulation requires proof that the covered products, if sold on or from the EU market, are not linked to recent deforestation and are produced in accordance with the national laws of the countries of origin. Given the EU's status as a major global consumer of cocoa products, the regulation could profoundly affect the entire supply chain, impacting numerous actors across many countries.

This study applies a global market model for cocoa and cocoa products to conceptualise and quantify the impact of the regulation on markets, farmer welfare, deforestation and CO_2 emissions. The results of simulating alternative scenarios of how cocoa producing and consuming countries respond to the EUDR indicate large shifts in trade flows and a reduction in global cocoa production, while farmer welfare increases. Cocoa-related deforestation declines, but much less than the initial deforestation figures suggest due to leakage. However, the deforestation reduction effect will increase overproportionally if other major consumer countries adopt similar policies.

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1. Introduction

Agricultural land expansion is the main driver of deforestation, accounting for 90% of global deforestation (FAO, 2022), most of it in the tropics (FAO, 2020). This contributes significantly to greenhouse gas (GHG) emissions and biodiversity loss. 57% of agriculture-related deforestation is attributed to the production of cattle, cocoa, coffee, oil palm, rubber, soya and wood (WRI, 2024). As a major consumer of these commodities and derived products, the European Union (EU) shares responsibility for the associated deforestation. The EU has been accused of outsourcing environmental costs to developing countries (Fuchs, Brown and Rounsevell, 2020). There are calls for the EU to take responsibility for the environment footprint of its global consumption (Wedeux and Schulmeister-Oldenhove, 2021; Marín Durán and Scott, 2022). To meet its responsibilities and minimise deforestation and forest degradation caused by its citizens, the EU, as part of its flagship policy framework called the European Green Deal, has adopted the "Regulation on Deforestation-free Products" (EU 2023/1115), also known as the EU deforestation regulation or EUDR, which entered into force on 29 June 2023.

In essence, the EUDR requires importers (and exporters) of the above commodities and derived products, such as leather, tyres and chocolate, to demonstrate that the raw materials are not linked to deforestation and have not contributed to forest degradation. To do this, importers must provide a due diligence statement covering the entire supply chain of the commodity, from the field to the EU border. Using GPS coordinates, the importer must demonstrate that the commodity does not originate from land that has been deforested after 31 December 2020. This includes any conversion of forests to agricultural land, including agroforestry systems. In addition, the EUDR requires that products are produced in compliance with the national laws of the country of origin, such as land, environmental, labour and human rights laws. Entry to the EU market for commodities that do not comply with the EUDR will be prohibited from 30 December 2025[1] for large and medium-sized companies and from 30 June 2026 for micro and small companies. For verification purposes, each piece of produce must be traceable back to the land on which it was grown.

The EUDR could potentially have a strong and far-reaching impact on producers and trade in these products. Cocoa is produced exclusively in tropical rainforest regions, which are recognised as biodiversity hotspots (Clough, Faust and Tscharntke, 2009), and these rainforests play an essential role in mitigating climate change (FAO, 2022). Côte d'Ivoire and Ghana, the world's largest cocoa producers, have already lost most of their forests and cocoa farming is closely linked to this continuing deforestation. Cocoa is mainly produced by poor smallholder farmers who depend heavily on cocoa sales. Cocoa trees are traditionally planted on virgin forest land and are economically viable for a lifespan of about 30 to 40 years (Somarriba *et al.*, 2021), after which the farmer would convert another piece of forest land into a new plantation due to the depletion of soil nutrients and the increasing susceptibility of the plot to disease (Clough, Faust and Tscharntke, 2009). The EUDR stipulates that this is no longer possible if the crop is to be sold to the EU. Moreover, it is not uncommon for cocoa farms to be located in protected areas, but this is in violation of national law and their products are therefore non-compliant.

This study investigates the impact of the EUDR in the context of the cocoa supply chain, focusing on cocoa markets, trade and deforestation. It constructs a partial equilibrium model representing global markets for and trade in cocoa beans and cocoa products. The model builds on approaches from the literature to analyse the impacts of deforestation and associated CO_2 emissions. Using this framework, the effects of the EUDR are simulated in a series of scenarios that differ in their assumptions about how producer and consumer country governments respond to the EUDR with policies. This study contributes to the literature by conceptualising the impact channels of the EUDR and providing the first detailed market model-based assessment of the impact of the EUDR on cocoa markets, farmers, trade patterns and deforestation.

[1] These are the postponed dates according to Regulation (EU) 2024/3234.

The remainder of this study is organised as follows: Section 2 describes the EUDR in more detail, discusses the potential impacts and reviews the relevant literature. Section 3 presents the partial equilibrium model and the corresponding data, together with the specifications of the simulation scenarios, before analysing the results in Section 4. Finally, Section 5 discusses the results and draws conclusions.

2. Background

2.1 Description of the EUDR

The EUDR is described in detail in EU (2023) and entered into force on 29 June 2023. It requires that each product – from a set of selected products – produced in, imported into and exported from the EU is (a) deforestation-free, (b) in compliance with the producing country's relevant legislation, and (c) covered by a due diligence statement. The EUDR therefore does not discriminate on the basis of the country of origin of the product. It applies to the commodities cattle, cocoa, coffee, palm oil, rubber, soya, wood and certain products derived from these commodities.[2]

Important definitions are set out in EU (2023), Article 2. Forest is defined as land covering "…more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10%, or trees able to reach those thresholds in situ, excluding land that is predominantly under agricultural or urban land use;" (EU, 2023, Article 2 (4)). The definition is based on the one of the Food and Agriculture Organisation of the United Nations (FAO) but includes all agricultural uses, including agricultural plantations and agroforestry systems, as non-forest, thereby also cocoa plantations. The term "deforestation-free" in the EUDR means that after 31 December 2020, the production of the product will be associated neither with deforestation nor with forest degradation (EU, 2023, Article 2 (13)).

For cocoa, the EUDR covers all cocoa products, such as beans, paste, butter, powder and chocolate. As cocoa beans are not produced within the EU market, we will mainly discuss the regulation from the perspective of imports into the EU, although it also applies to all cocoa sold in or exported from the EU.

In order to place cocoa products on the EU market, the EUDR requires an accompanying due diligence statement to demonstrate that the product is deforestation-free and has been produced in compliance with all national laws of the producing country, including environmental, human rights and labour laws. The due diligence statement has three sections: A full documentation of the trace of the product throughout the supply chain, an assessment of the risk that the product does not comply with the EUDR, and a description of measures taken to mitigate the identified risks so that the remaining risk is zero or negligible. This means that the product must be fully traceable throughout the supply chain, starting with the geo-location coordinates of the land on which the cocoa beans were grown, together with the dates and the suppliers and recipients at each stage of the chain. It also means that EUDR-compliant products must be kept segregated from non-compliant products during storage, transport and processing throughout the chain.

The due diligence obligations for products differ according to the risk category of non-compliance of the country or sub-national region. For this purpose, the European Commission classifies each country or region according to its overall risk of deforestation or forest degradation as low, standard and high risk, based on three main criteria: the rate of deforestation and the rate of agricultural land expansion, and the production trends of relevant products. However, additional factors may be taken into account, such as agreements, policies, or laws that limit or mitigate the future risk of violating the EUDR.

Compliance of products with the EUDR is verified by the competent authorities of the EU member states. The risk category of the country of origin determines the minimum proportion of operators placing EUDR-relevant products on the market (or exporting from) to be checked, which is 9, 3 and 1% of operators sourcing from high, standard and low risk origins, respectively. For high-risk origins, additionally a minimum of 9% of the quantity must be checked. The EUDR allows for simplified due diligence for operators sourcing from low-risk origins.

[2] See Annex I in EU (2023) for the complete list of products.

The regulation will be reviewed after one and two years, and at least every five years, and may be adjusted and extended to improve its effectiveness in achieving its objectives. It explicitly mentions the impact on least developed countries and the corresponding support for trade facilitation instruments. Furthermore, the document mentions that "…reasonable efforts should be undertaken to ensure that a fair price is paid to producers, in particular smallholders, so as to enable a living income…" (EU, 2023, para. (50), p. 214) when sourcing products. Consequently, the EUDR recognises all three sustainability issues commonly associated with cocoa farming: deforestation, child labour and low farmer incomes (Boysen *et al.*, 2023). The first two are addressed by the EUDR's zero deforestation and legality requirements. However, the third, fair prices, is not repeated in the regulation itself.

Companies that violate the EUDR face severe penalties, including fines of up to 4% of their annual EU-wide turnover and the confiscation of all related products and revenues (EU, 2023, Article 25 (2)).

2.1.1 The potential impact of the EUDR

The EUDR's demand-side approach to reducing the deforestation footprint of EU consumption is an attempt to resolve a dilemma: the EU can only control the production process and associated environmental impacts within its borders, but it is also indirectly responsible for environmental degradation occurring elsewhere, as EU consumers buy products for which non-EU producers may have cleared or degraded forests and violated human rights or labour laws. The problem arises when the products' origin countries have less stringent or no regulations due to different priorities or values, or weak institutions that fail to monitor and enforce regulations. For some, the EUDR approach of proactively taking action to limit these harms is essential while for others it represents an interference in the national sovereignty of producer countries, or even a new form of imperialism (Gilbert, 2024b).

The EUDR is a novel EU policy instrument designed to also influence production conditions in distant, non-EU countries from the demand side, i.e. indirectly with complex channels of influence through multiple and very heterogeneous actors in a complex supply chain. In the cocoa supply chain, with its many stages and actors, the beans and the products made from them change hands and are mixed and aggregated many times.

A typical cocoa supply chain starts with smallholder farmers who grow the cocoa, ferment and dry the beans, and then sell them to local traders or cooperatives who collect and aggregate the beans from multiple farms. These in turn sell the aggregated beans to exporters who transport the beans to major ports where they are shipped – further aggregated from different traders – to consuming countries, often in Europe or North America, using shipping lines and logistics providers. At the destination ports, the beans are received by cocoa processors and transformed in a series of steps, including cleaning, roasting, winnowing to separate the shells from the nibs, grinding the nibs into chocolate liquor, pressing the liquor to produce cocoa butter and cocoa cake, and then grinding the cake into powder. This yields the three main intermediate cocoa products – liquor, butter and powder – which are then further processed, usually by different companies, into chocolate, confectionery, beverages and other consumer products. Some or all of this processing may take place in the countries of origin, but more often in the countries of consumption. A company may be involved in only one stage of the chain, but often in several.

The structure of the cocoa market resembles an hourglass, with millions of farmers at the top, a small number of intermediate processors in the middle and a large number of manufacturing companies at the bottom that turn the liquor, butter and powder into finished products such as chocolate, bakery products and chocolate drinks (Gilbert, 2024a). This description of the supply chain illustrates the complexity of monitoring it and achieving traceability of beans from the EU border back to a farm's plot.

The EUDR is hailed by some as a step in the right direction to reduce the deforestation footprint of EU consumption (e.g. Marín Durán and Scott, 2022), but condemned by producer country governments and manufacturing companies who see it as interference in national affairs, "regulatory imperialism", unfair trade barriers and unjustified bureaucratic burdens, and harm to smallholder farmers (e.g., Suroyo, Sulaiman and Teresia, 2023; Meijer and Angel, 2024).

As the EUDR has not yet been implemented, there is little evidence and much speculation about its potential impacts. An a priori assessment of the economic impacts of the EUDR is inherently difficult without precedent, and therefore the debate on how the policy will affect the different actors in the supply chain, consumers and sustainability is rather emotional.

Supporters of the EUDR emphasise

- The significant leverage the EU has as a major consumer of forest risk products to reduce global deforestation and forest degradation.
- The benefits for biodiversity, maintenance of ecosystem services, and mitigation of climate change. The reduction in CO_2 emissions associated with deforestation also helps countries to meet their domestic GHG reduction targets.
- Greater transparency and accountability throughout the supply chain, which could also improve conditions for smallholders.
- The additional monitoring of legality including labour laws and human rights, which can lead to better living conditions and health for farmers and improve their prospects, especially for children.

Opponents of the EUDR point to

- The new, protectionist trade barriers imposed by the EUDR (Meijer and Angel, 2024).
- The extra costs for producers (high transaction costs), especially smallholders, who may struggle to comply with the EUDR.
- The EU imposing its green standards on other countries, thereby interfering with national sovereignty.
- The administrative complexity of the due diligence requirements which could be particularly burdensome for small and medium-sized enterprises.
- The potential for leakage effects, i.e. where, for example, deforestation or child labour associated with the production of the products covered by the EUDR is reduced, but then increased for other products or locations. Current cropland could be converted to cocoa, pushing non-EUDR crops into forests (Zhunusova *et al.*, 2022).
- The potential impact on deforestation may be limited as non-compliant supplies may simply be diverted to non-EU markets. Such responses have been observed in the context of the EU Timber Regulation (Partzsch, Müller and Sacherer, 2023).
- The possible exclusion of some farmers, especially small and remote farmers and indigenous peoples, from EUDR-compliant supply chains as compliance costs are likely higher (Zhunusova *et al.*, 2022; Gilbert, 2024b). EU importers could simplify and shorten their supply chains by sourcing from larger farms. This is particularly relevant for cocoa, given that a large proportion of it is grown by smallholders in West Africa, a region that exports most of its cocoa to the EU. If they are categorised as "high risk" under the EUDR, this threat could apply to entire countries.
- Shortening and simplifying supply chains can encourage large-scale farmers to increase production and lead to land conflicts with smallholders where land tenure rights are weak (Zhunusova *et al.*, 2022).
- Higher prices for EU consumers. This could reduce overall demand on the world market, depressing world market prices and thereby reducing farm incomes.

2.1.2 Literature assessing the economic impact of the EUDR

Evidence of the EUDR's potential impact could come from the experience of similar legislation already in place, or from ex-ante assessments based on economic modelling. Measures such as EU bans on growth hormone-treated beef, chlorine-washed chicken or genetically modified soya and wheat have led to similar bans on imports of specific products into the EU and other countries. However, most of these measures were introduced to improve food and animal safety and the foreign products were in direct competition with those produced in the EU. Moreover, the EU was one of many producers and consumers in these markets. Cocoa beans, on the other hand, are not produced in the EU and the EU is the dominant consumer of cocoa, sourcing it mainly from a few West African countries.

The closest policy to the EUDR is the EU Timber Regulation or EUTR (EU, 2010). The EUTR aims to eliminate illegal logging from the EU supply chain. However, it is not directly comparable with the EUDR as the EUDR extends the scope to more products and beyond illegal logging to zero deforestation. The EUDR also attempts to address some of the weaknesses identified in the EUTR and will repeal the EUTR (EU, 2023). However, Partzsch, Müller and Sacherer (2023) found that while the EUTR has not been very effective due to implementation problems, producer countries have indeed shifted exports away from the EU to less regulated trading partners in response to the EUTR.

To date, only a few studies have attempted to assess the magnitude or direction of the economic effects of the EUDR using economic models.

Wolfmayr *et al.* (2024) provide an ex-ante assessment of the EUDR. They estimate the impact of the EUTR on EU trade in timber and timber products using historical bilateral trade data and an econometric gravity model. They find that the EUTR has reduced corresponding EU trade by 0.13% but note that this is a lower bound for the impact of the EUDR, which is more comprehensive. This figure is then used to simulate the EUDR in a computable general equilibrium (CGE) model based on aggregated product groups. To account for this aggregation, the authors apply the estimated reduction to the share of EUDR-relevant products in each import trade flow to the EU. The analysis shows negligible but negative welfare and income effects for the EU, probably due to higher prices. Similarly, welfare in other regions is only minimally reduced, as is total trade. In fact, the EUDR is more comprehensive than the EUTR, not only in terms of products covered, but also because it prohibits not only illegal but also legal deforestation and violations of national laws, and adds more rules to close loopholes. While the CGE model covers all linkages of EUDR products with other economic sectors and factor markets, it does not explicitly distinguish between EUDR compliant and non-compliant products, but only includes products in larger aggregates. This means that products are not properly tracked as they move through the supply chain as inputs. This approach is likely to attenuate the effects and details on specific EUDR products are not available. Furthermore, since the proportion of EUDR-relevant products in each import flow remains constant, this does not take into account the rerouteing of trade between countries caused by the EUDR. The authors note that the results should be interpreted as a lower bound on the impact of the EUDR.

Calvo *et al.* (2024) quantify the potential impact of the EUDR on Argentina using a comparative-static single-country CGE model. The EUDR is simulated by reducing export quantities to the EU, with aggregate product groups reduced by the share of EUDR-relevant products included. The authors note that they are simulating a worst-case scenario in terms of export reduction by assuming 100% non-compliance. For this extreme case, they find that Argentina's GDP falls by about 0.2%. However, apart from the likely adjustment of production to partially comply with the EUDR, the single-country nature of the study also neglects feedback effects with international markets and trade shifts between other countries, potentially leading to higher demand for non-compliant products from non-EU countries and affecting world market prices. The same limitations regarding aggregate product groups apply as in the study by Wolfmayr *et al.* (2024).

Vega (2024) also assesses the impact of the EUDR on Argentina, but uses a recursive-dynamic single-country CGE model. The model distinguishes between several EUDR-relevant product groups and whether the products were produced on deforested land or not. The EUDR is simulated between

2025 and 2030 by assuming a reduction in the international price of non-compliant products, a cessation of non-compliant exports to the EU and an increase in the cost of exports of compliant products to the EU. The results show an average reduction in GDP by 0.5%, small reductions in domestic production of between 0.2 and 1.6% and a reduction in deforested area of 6.6%. The same limitations regarding the use of a single-country model apply as in the study by Calvo *et al.* (2024).

Gilbert (2024b) analyses the impact of the EUDR on EU prices and welfare in a graph-based model, focusing explicitly on the costs of EUDR compliance and trade diversion. The model assumes that world production and EU and non-EU consumption are unaffected, and hence the non-EU market price. It is further assumed that (1) the EUDR leads to a premium on the EU price over the international market price, (2) the cost for EUDR compliance varies between current EU importers, and (3) the additional cost for diverting trade away from non-EU countries varies between potential EU importers. The author finds a welfare loss for consumers, a gain for current EU suppliers who comply, and a loss for those who do not. These changes add up to an overall welfare loss for the EU. Due to the EU's high share of the global cocoa and coffee markets and substitution possibilities, the author expects a higher EU market premium for these products relative to other EUDR products.

Another strand of literature assesses the deforestation associated with EU consumption using primary commodity production data together with bilateral trade data, which helps to provide an idea of the EUDR's potential impact on deforestation. Pendrill, Persson, Godar, Kastner, Moran, *et al.* (2019) and Goldman *et al.* (2020) attributed global deforestation to agriculture and crops. More recently, a review by Pendrill *et al.* (2022) evaluated these results along with those from some country-specific studies. Singh and Persson (2024b) aim to improve the completeness and quality of such data with the DeDuCE database (Singh and Persson, 2024a) by overlaying and combining several sets of remote sensing and agricultural statistics data.

Amongst others, Pendrill, Persson, Godar and Kastner (2019) have taken a further step and attributed deforestation in the country of origin of the primary product to consumption of final product to estimate the deforestation footprint of consumption following an approach presented by Kastner, Kastner and Nonhebel (2011). Using the same approach, Zinngrebe *et al.* (2024) examined the link specifically for the EU and found that the EU has relatively high leverage, measured as the share of exports to the EU in total production of a product, for cocoa and coffee in terms of import value, land footprint and deforestation. According to their figures, cocoa is responsible for 28.4% of deforestation imported into the EU.

Using the same approach, Laroche *et al.* (2024) analysed the importance of including derived processed products up to the consumer level in the EUDR in order to reduce the risk of deforestation. Using rubber and bovine hides as examples, they showed that accounting for raw rubber would sufficiently minimise the associated deforestation risk, as rubber is mainly imported in its raw form and then processed in the EU. By contrast, the inclusion of finished products made from bovine hides is important. The authors suggest that such facts could help to focus and reduce unnecessary costs that the EUDR may create.

3. Methods and data

In order to compare several what-if scenarios of the EUDR, we develop a global partial equilibrium (PE) model for cocoa and semi-processed cocoa products in Section 3.1. Sections 3.2 and 3.3 describe the construction of the corresponding data set and scenario specifications, respectively. It is justified to use the PE model of cocoa beans and derived products while neglecting other sectors because, in most countries, the production and consumption of cocoa and chocolate products represent only a small part of the economy, meaning the links with other sectors are weak. There are also no close substitutes for cocoa in terms of consumption. In addition, a global CGE model would require significantly more data to single out cocoa and chocolate production and consumption, which are typically not available at the level of detail required to adequately represent the EUDR.[3]

3.1 The global partial equilibrium model

The model represents each region by four markets: one for cocoa beans and one each for the processed products liquor, fat and powder. The outputs of each processing stage are linked to the input by fixed extraction coefficients. In the first processing stage, cocoa beans are ground into cocoa liquor. The liquor can be used directly in chocolate production or it can be further processed by pressing the liquor, yielding cocoa butter and pulverising the remaining cake to cocoa powder. In absence of data on the consumption of chocolate and other finished cocoa products, the demand for processed products is governed by a constant elasticity of substitution (CES) function.[4] It aggregates the three products into a final bundle and restricts the shift between the shares of the products by an elasticity of substitution, mimicking that the composition of ingredients for finished cocoa products and product portfolios do not change easily.

The demand for the final bundle is given by an iso-elastic demand function. The demand for cocoa beans is derived from the demand for processed products. Total domestic demand for each product consists of intermediate demand for beans, intermediate and final demand for liquor, and only final demand for fat and powder.

Total domestic demand is satisfied by supply from domestic or imported production, which are aggregated by a CES function and are thus imperfect substitutes according to the so-called Armington assumption (Armington, 1969). Imports from different origins are bundled into an import aggregate by an additional CES function, again assuming imperfect substitution. Total domestic supply plus exports equals total domestic production. Total exports of a product from a region must reflect the sum of imports from other regions. All raw and processed products are traded.

The above structure is largely duplicated to model EUDR-compliant products, which require segregation from non-compliant products throughout the supply chain. However, the markets for EUDR-compliant and non-compliant product variants are linked by (a) the available factor input bundle, which farmers allocate between compliant and non-compliant variants according to the relative price difference between the variants[5], and (b) consumers, who can choose between the two variants. Although the compliant and non-compliant variants may be physically identical, consumers may perceive them as imperfect substitutes for sustainability reasons. This is established by bundling the two variants via a CES function. The quantity demanded of this bundle of variants is then determined by the final demand structure described above. The input bundle used in the production

[3] If cocoa is grouped together with other products, a simulated EUDR ban would affect the entire product group and all products derived from it. This would create a large bias as the group enters as input into more and more products as it progresses through the stages of the supply chain. Applying a ban on a fixed share of the product group would also ignore the trade-diverting effects of the EUDR.

[4] Note that all CES functions implemented are of the additive variant presented in Mensbrugghe and Peters (2020). It guarantees that physical input quantities sum up to the output quantity of the function.

[5] The share of the input bundle allocated to each variant is represented by a logistic function relating to the relative price between the two variants. This implies that price elasticity of the share allocated to compliant cocoa is high close to the initial price ratio and decreases with increasing price ratio.

of each variant, representing land, labour and other inputs, increases with the farmgate price according to an iso-elastic function. The function represents both area and yield changes.

3.2 Data

The data are compiled from various sources for the 2019/20 crop year, which runs from October 2019 to September 2020, and for all producing and consuming countries for cocoa beans, liquor, butter and powder. It is then further cleaned and processed to meet the requirements of the model. Note that data on chocolate, confectionery, beverages and other products containing cocoa are generally unavailable. Where such data are available, e.g. trade data, the cocoa content is not specified. We have therefore decided to ignore finished cocoa-containing products in the analysis.

3.2.1 Quantity and price data

Quantity data on cocoa bean production and grindings by country, as well as bilateral imports and exports of cocoa beans and products at the Harmonised System (HS) 6-digit level were provided by the ICCO through personal communication. This dataset also includes data from Euromonitor on the quantities consumed by country of the semi-finished products liquor, butter and powder as used by the food industry.

The remaining quantities can be derived from the above data. The quantities supplied of cocoa liquor, butter and powder supplied are calculated using input-output coefficients.[6] Grindings correspond to the intermediate demand for beans, which determines the domestic production of liquor. Together with imports of liquor, minus exports and final demand for liquor, this determines the input for pressing, which yields butter and powder in a fixed ratio.

Price data distinguish between farmgate (producer) prices, export prices (free on board, FOB) and import prices (cost, insurance and freight, CIF). National farmgate prices for cocoa beans were obtained from various official national statistics for Brazil, Ghana, Côte d'Ivoire, Columbia, Nigeria and Cameroon. These prices have been converted to US$ using IMF (2023) exchange rates. Farmgate prices for additional countries[7] were taken from FAOSTAT (2024). Where farmgate prices were not available, export prices were used instead.

Bilateral export and import prices for the four products are calculated as unit values based on FAOSTAT (2023) trade data. Corresponding bilateral import tariffs are derived from the UNCTAD TRAINS database (UNCTAD, 2023). Import prices are assumed to differ by origin, but there is only one export price for each country of origin. Transport costs are multiplicative.

3.2.2 Data processing

Quantity data are adjusted to remove re-exports, i.e. where the same product enters and leaves a country without significant transformation, and stock movements, i.e. all additions and withdrawals from cocoa beans and products held in stocks. Re-exports are eliminated as they occur for reasons outside the scope of our model, such as export zones or recording methods. As our model is comparative-static and thus represents the long run, we assume that stocks remain constant at a long-run target level and are therefore exogenous to the model.[8]

[6] These coefficients are derived from the International Cocoa Organization (ICCO)'s official conversion factors (UNCTAD, 2010, Article 34(1)). One ton of cocoa beans yields 0.8 tons of liquor. One ton of liquor yields 0.47 tons of butter and 0.53 tons of powder.

[7] These are Belize, Dominican Republic, Ecuador, Fiji, Guinea, Grenada, Indonesia, Jamaica, Saint Lucia, Sri Lanka, Mexico, Malaysia, Nicaragua, Peru, Philippines, El Salvador, and Togo.

[8] The share of stocks being traceable or EUDR-compliant is unknown. For example, it is not possible to infer the origin of a stock calculated for Switzerland and thus to determine whether the products produced in Switzerland from the stocks are traceable or EUDR-compliant.

The first step is to net out re-exports. If exports of a product are greater than its domestic production, the excess exports must come from imports (or stocks). Therefore, exports and imports are reduced by this excess quantity, leaving net exports unchanged. The excess quantity is then added to the direct trade link between the country of origin of this import and the country of destination of the export. The necessary adjustments to imports and exports are allocated proportionally to the new regions of origin and destination. This is done by applying the same proportions to all import and export partners, respectively. However, it is ensured that imports remain nonnegative. The import and export prices of the country in focus are used to calculate new weighted average prices for the trade link's origin and destination countries. As these changes may result in new re-exports, the procedure is repeated for all countries and products until there are no further re-exports.

Finally, the quantity data are made consistent in terms of market balances and trade by mathematical optimisation, which minimises the squared deviations of the final quantities from the raw quantities constructed above. A system of equations ensures that, for each country, production plus imports equals consumption plus exports, and that trade links between countries are consistent and re-exports are avoided. All quantities are constrained to be non-negative. This mainly removes stocks and stock movements from the data.

This leaves a dataset that includes only cocoa and cocoa products produced and consumed in the 2019/20 harvest year, corrected for re-exports, i.e. only trade in goods that are substantially transformed between their import and subsequent export is retained.

3.2.3 The *status quo* of cocoa beans traceability

To reflect the current state of traceability in the dataset, we split all quantity data into traceable and non-traceable. We assume that the corresponding proportion of cocoa can easily be made compliant with the EUDR. Prices for both types of product are initially assumed to be identical.

We use data from the Chocolate Scorecard's[9] 2023 assessment as this is the most recent and detailed data available. Their study, coordinated by the NGO Be Slavery Free, surveyed 85 companies representing over 90% of global cocoa purchases and found that 51% of cocoa beans were traceable to farm level in 2023. In addition to the published data, we obtained additional rough country-level aggregates from their survey data through direct communication.[10] These are the only country-level data available, but should be treated as a 'best guess' due to the large uncertainty associated with these estimates.[11] These data only include those companies that also answered the question on the top three countries of origin for beans. The overall average of 44% of beans traceable to the farm seems plausible when compared with the results of Renier *et al.* (2023) and Fountain and Hütz-Adams (2022).

Renier *et al.* (2023) found, based on information published by the companies themselves, that 43.6% of the cocoa exported by Côte d'Ivoire in 2019 was traceable to the source cooperative and department. Data presented in the Cocoa Barometer 2022 (Fountain and Hütz-Adams, 2022, p. 79) on nine major trading and processing companies suggest that 37% of the cocoa beans used were traceable to the farm in 2021.[12]

[9] 5th edition, accessed on 6 July 2024 at https://www.chocolatescorecard.com/insights/.

[10] This data is not publicly available.

[11] The Chocolate Scorecard questionnaire asked the companies to provide their total quantity of beans purchased, the share of their total beans traceable to the farmer level, their top three bean source countries, and the share of their beans sourced from each of those. It is then assumed that the share traceable is the same for all of a company's source countries, but this could be inaccurate. Additionally, many countries were listed only one to five times and thus offered few observations, resulting in weak statistics. This included Brazil and Indonesia, whose extreme figures we deemed implausible, so we replaced them with the average.

[12] A study by the Cooper *et al.* (2024) does not report average traceability for the 11 large retailers operating in the EU and UK covered. However, it mentions that traceability in 2023 in their direct and indirect supply chains averages 71% and 22%, respectively. They note that the share of the indirect supply chain varies widely between retailers.

3.2.4 Other parameters

In addition, the model relies on elasticity parameters from external sources that determine the responsiveness of demand, supply and substitution to price changes. The price elasticity of supply of cocoa bean of 0.57 is taken from the econometric estimates of Tothmihaly (2018).

The demand for the processed products bundle of cocoa liquor, butter and powder is derived from Kox (2000) who estimated price elasticities of demand for cocoa powder for several countries ranging from -0.51 to -0.11. The average is -0.256.[13] As the demand for processed products is derived from the demand for final consumption products, and assuming that the bundle of final consumption products and the recipes of the products remain fairly stable, we expect a similar elasticity for cocoa liquor. We also expect the elasticity for cocoa butter to be similar, but slightly higher, as it can be substituted to some extent by other fats. Taking this into account, we choose an elasticity of -0.3 for the demand for the bundle of the three products.

For the remaining elasticities, we have chosen values according to plausibility considerations. Chocolate manufacturers do not easily change their product portfolio or the recipes of their products, which is reflected in a low elasticity of substitution of 0.5 between the demand for liquor, butter and powder. In addition, consumers are generally assumed to be rather indifferent between EUDR-compliant and non-compliant products, switching easily between them with a substitution elasticity of 10.[14]

Elasticities of substitution between imports of HS 6-digit cocoa products from different origins are taken from Fontagné, Guimbard and Orefice (2022). The Armington elasticities of substitution between domestic and imported products are assumed to be half of those between imports of different origins.[15]

The steepness parameter (k) of the logistic function for the allocation of land between compliant and non-compliant cocoa is set to 10, assuming that switching between the two is fairly frictionless around the initial division, apart from the additional costs already taken into account.

3.2.5 Aggregation

While the dataset includes all producing and consuming countries of cocoa and cocoa products, the countries are aggregated in a final step to the six larger regions – Côte d'Ivoire and Ghana (CG), EU, Northern America (NAm), Latin America (Lam), Rest of Africa (RoAfr), and Rest of the World (RoW) – according to common characteristics to facilitate a concise presentation and interpretation of the results.[16] We are also careful not to identify individual countries, to avoid giving the false impression that we can project precise impacts for specific countries, as some of our data are vague. The resulting aggregated data are then used to calibrate the global cocoa market model.

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[13] We only include those that are statistically significant at the 5% level and negative.

[14] Even though compliant and non-compliant products are physically identical, consumers may have a preference for sustainably or ethically produced chocolate and be willing to pay a premium for that. A meta-analysis by Piracci *et al.* (2024) found that consumers on average are willing to pay a 27% premium for labels certifying the sustainability on foods in general but with high variability.

[15] For a discussion on the "rule of two" adopted here, see Hertel *et al.* (2007), footnote 16.

[16] The six regions are EU (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden), NAm (Canada, United States), LAm (Argentina, Belize, Bolivia, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad & Tobago, Venezuela), CG (Côte d'Ivoire, Ghana), RoAfr (Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo - Brazzaville, Congo - Kinshasa, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Myanmar (Burma), Nigeria, Rwanda, São Tomé & Príncipe, Sierra Leone, South Sudan, Sudan, Tanzania, Togo, Uganda, Western Sahara, Yemen, Zambia), and RoW (all remaining countries).

3.2.6 Deforestation and associated CO_2 emissions

Recent research has developed methods and datasets to attribute deforestation to agricultural land use and specific crops, see Pendrill *et al.* (2022) for a review. This strand of literature measures deforestation in terms of the area deforested per year due to agriculture in general or specific crops. The analysis is largely based on remote sensing data. Here we use the DeDuCE database (Singh and Persson, 2024a), which combines different remote sensing datasets and agricultural statistics to improve the overall data quality. The methodology is described in Singh and Persson (2024b). This database provides the annual hectares of forest area cleared for cocoa production in producer countries and the associated CO_2 emissions.[17] For details on the assumptions behind the data, see Singh and Persson (2024b).

To attribute the number of hectares deforested in producer countries to the consumption of final products in other countries, we follow the approach presented by Kastner, Kastner and Nonhebel (2011), which uses the matrix algebraic logic of Leontief's input-output analysis (Leontief, 1936). Using as input data cocoa bean production and bilateral trade in cocoa, converted into cocoa bean-equivalent quantities, the approach traces the bean content fully back to the origin of the beans through multiple exports, while avoiding double counting. It implicitly assumes that each export destination contributes to deforestation in proportion to its share of the export quantity. The result is the annual deforestation in region r caused by consumption in region s.

This exercise combines data from the Singh and Persson (2024a) database with the above bilateral trade data in physical quantities, converted to bean equivalents using the official ICCO conversion factors.[18]

For our analysis, we assume that 'initially traceable' cocoa does not drive deforestation, as traceability is likely to be linked to sustainability schemes as part of certification or companies' own programmes, notably the Rainforest Alliance, which focuses on avoiding deforestation. We therefore assume that all deforestation is initially associated with the cultivation of non-traceable cocoa beans. In reality, however, neither all traceable cocoa will be linked to sustainability schemes, nor will all sustainability schemes achieve zero deforestation.

3.3 Scenario specification

The EUDR is a complex policy with several components, each of which affects various actors in the cocoa supply chain in different ways and through different pathways. This section outlines how the various changes introduced are translated into numerical values and the mechanisms by which they are imposed in the PE model. We use the best data available at the time of writing. Unfortunately, useful evidence on the potential magnitude of the changes caused is extremely scarce and, where it exists, it is often estimated for a single country, anecdotal, old, etc. In absence of better data, this often weak evidence is generalised anyway to complete the shocks for the scenarios. This significant drawback must be borne in mind when interpreting the simulation results. This means that even when precise figures are shown, they should only be taken as indications.

Note that all values presented in the context of the model should be interpreted as annual, recurring averages.

This section first discusses the different policy and adaptation components and their impact channels in isolation, before combining them into a series of counterfactual scenarios, all of which imply different assumptions about what reality could look like. Alongside each component, we discuss its theoretical direct effects in isolation. However, as the scenarios generally involve various reinforcing and counteracting effects and feedback channels through trade, the compound effects are an

[17] Specifically, we utilize the series "Deforestation risk, amortized (ha)" and "Deforestation emissions incl. peat drainage, amortized ($MtCO_2$)".

[18] Accordingly, one tonne of cocoa butter equals 1.33, cocoa cake and powder 1.18, and cocoa paste/liquor and nibs 1.25 tonnes of beans (UNCTAD, 2010, Article 34(1)).

empirical matter. These are assessed through numerical scenario simulations using the real-world data described above.

3.3.1 Scenario components

3.3.1.1 Component: The EU imposes prohibitive import tariffs on products not compliant with the EUDR

The EU applies a strict ban on products not compliant with the EUDR, including imports, exports and domestic production. To simulate this, it is sufficient to stop imports of cocoa and cocoa products into the EU, as no cocoa is grown in the EU. This is achieved by imposing a 200% tariff on all imports of cocoa products into the EU that do not comply with the EUDR. Initially, all traceable products will be presumed to be EUDR-compliant, with the cost of achieving compliance added through additional policy and adaptation channels.

The high import tariffs on non-compliant cocoa beans and products in the EU reduce these imports to virtually zero and consequently stop the processing of non-compliant products. Consumers substitute with compliant products, shifting the demand curve to the right and increasing prices and quantities. In non-EU countries, the prices and quantities of non-compliant beans must fall, but the price changes for other non-compliant cocoa products are an empirical matter, since the EU also exports them.

3.3.1.2 Component: Northern America imposes prohibitive import tariffs on products not compliant with the EUDR

This is identical to the previous component, but implemented for the Northern America region.

3.3.1.3 Component: Cost of traceability for EUDR compliance

In order to demonstrate compliance with the deforestation and legality requirements of the EUDR, cocoa products must be traceable back to the farm plot. Information on the costs of establishing traceability of cocoa throughout the supply chain from farm to shelf is scarce. Preliminary results from a draft study by Le Basic (unpublished) estimate the ongoing costs of EUDR compliance for private exports at between US$ 54.55 and US$ 98.86 per tonne (at 0.88 Euro per US$ at the 2020 exchange rate). O'Brien *et al.* (2022) state that cocoa traders have estimated the price of a traceability system at 0.5% to 2% of the recent cocoa price per tonne, which equates to US$ 11.99 to 47.96 per tonne at the ICCO reference price of US$ 2398 per tonne for the 2019/2020 harvest season.

The cost of segregated transport of soybeans has been estimated by one trader to increase by 35 to 40% per vessel if smaller vessels have to be used (O'Brien *et al.*, 2022). At an assumed freight cost from Ghana to Europe of € 60 or US$ 68.18 per tonne, this equates to US$ 23.86 to 27.27 per tonne.

Given this weak but fairly consistent evidence, we assume an annual running cost for the traceability system of US$ 75 per tonne, identical for all countries. This cost is assumed to be shared equally between the three stages of the supply chain. For beans, the cost is translated into a left shift in the supply curve using the corresponding price increase and price elasticity of supply. The two subsequent processing stages have associated processing cost parameters that are adjusted to reflect the cost increase.

The left shift of the supply curve of the compliant beans in all regions increases their prices and reduces their quantities, with the effects being passed on to the subsequent processing stages through higher input costs. In addition, these stages' shares of the traceability costs shift their supply curves further to the left. At each stage, the demand curve in the market for the input product is shifted to the left, further reducing the quantity traded at that stage, but also reducing the price. These latter effects accumulate upstream, with the largest reductions falling on farmers. Thus, while the quantities supplied are clearly reduced for all compliant products, the impact on producer prices is indeterminate, except for the powder and butter processing stage which does not experience a shock to the demand curve. Throughout the supply chain, farmers experience the least positive or even negative price effects.

3.3.1.4 Component: No forest land available for EUDR-compliant cocoa

Future EUDR-compliant cocoa plantations cannot be established on land that was forest at the end of 2020. As a result, they will not be able to benefit from the positive agronomic properties that freshly cleared virgin forest land provides for cocoa plants. To approximate the cost of not having such land available for new plantations, we build on the concept of the *differential forest rent* (Ruf and Yoddang, 2004): It is calculated as the difference in production and investment costs between cocoa production on a farm established directly after deforestation and cocoa production on a replanted old plantation or fallow land. It is therefore the opportunity cost of the forest rent. Based on survey data, Ruf and Yoddang (2004) estimated that the loss of forest rent in South Sulawesi, Indonesia in 1997 was associated with an average 30% increase in production costs. According to Ruf (2001), similar results were found by Oswald (1997) for Côte d'Ivoire.

Applying this to all regions, the price elasticity of supply translates the 30% cost increase into a left shift in the supply curve for compliant beans. Accordingly, the quantity of compliant beans decreases and the price increases. The higher input costs are passed down the supply chain, shifting the supply curves of processed products to the left. This in turn reduces the demand for inputs and shifts the demand for those inputs to the left, reducing quantities and increasing prices. Overall, quantities are reduced throughout the compliant supply chain, while the direction of the price effects remains indeterminate, except for butter and powder, for which prices increase. Consumers shift to the now relatively cheaper non-compliant products. Conversely, producers shift more resources to compliant production in order to benefit from the higher prices. Prices and quantities of non-compliant products increase.

3.3.1.5 Component: Elimination of child labour

The EUDR requires cocoa production to respect national laws on labour rights, including the elimination of all forms of child labour in cocoa farming. According to the ILO (2002), this includes hazardous, regular and light work. Light work is defined as non-hazardous work of less than 14 hours per week and is permitted above the country's minimum age (12 years or older). However, countries may make some exceptions for limited light work for children below the minimum age, for example for domestic work.

Luckstead, Tsiboe and Nalley (2019) estimate for Ghana, using a simulation model of cocoa farm households, that eliminating all three types of child labour, without any compensation, would reduce cocoa production by 6.022%. As this is the only estimate available, it is applied here to all countries. However, the characteristics of cocoa production can vary widely between countries, for example in terms of the prevalence of child labour in cocoa and production cost structures.

The reduction in production is implemented by shifting the supply curve of compliant beans to the left, and thus leads to the same theoretical effects as the previous component, the zero deforestation commitment, but to a lesser extent.

3.3.1.6 Component: Côte d'Ivoire and Ghana convert fully to EUDR compliance

Both Côte d'Ivoire and Ghana have highly regulated cocoa markets governed by marketing boards. Both countries are currently undertaking initiatives to map all their cocoa parcels and establish national traceability systems. Both are also taking steps to become EUDR-compliant at the national level, which could secure an EUDR low deforestation risk classification. If successfully implemented and effectively shared with private traders and processors, this could reduce the EUDR-compliance costs for companies in terms of operational traceability and due diligence obligations.

This scenario is simulated by introducing a 150% export tax and a 100% consumption tax on non-compliant products. It is also assumed that traceability and segregation costs are halved at all stages of the supply chain and that the production tax on EUDR-compliant products in the CG region is reduced accordingly.

The taxes are so high that they completely discourage the consumption and export of non-compliant cocoa products in CG. Instead, producers switch to compliant products, which now command relatively higher prices. Demand prices for non-compliant products, on the other hand, rise massively, motivating consumers to switch to compliant products. Therefore, the quantities of compliant products in CG clearly increase, while the direction of the price change depends on the strength of the shifts in the two curves.

3.3.1.7 Component: Ban from protected areas in Côte d'Ivoire and Ghana

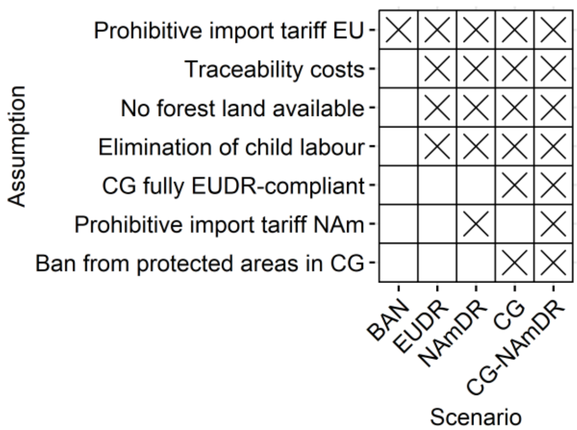
The EUDR also requires compliance with relevant national legislation on protected areas. Using satellite imagery and validated ground data, Kalischek *et al.* (2023) estimated that 30% and 7% of the total cocoa plantation area in Côte d'Ivoire and Ghana, respectively, is located in protected areas. Data are not available for other regions. Banning cocoa from protected areas still allows non-compliant cocoa production on other land, and we assume that all protected area land is included in the non-compliant share of land. The only scenario in which non-compliant cocoa production is reduced to such an extent that this assumption is immediately invalidated is the CG scenario. There, Côte d'Ivoire and Ghana apply the EUDR nationwide, implicitly banning cocoa from protected areas.

Using the data from Kalischek *et al.* (2023), this would reduce the area under cocoa in the CG region by 20.9%. This translates into a further 20.9% shift to the left of the bean supply curves in CG. Implemented in addition to the ban on non-compliant cocoa products in CG, this shock leads to a reduction in compliant cocoa production in CG and an increase in the price of compliant products.

3.3.2 Scenarios

The reference point for comparing the results is the base scenario, which represents the global cocoa bean and processed cocoa product markets in 2019. All counterfactual scenarios ask the hypothetical question of what the markets would have looked like in 2019 if the EUDR had already been in place. However, the assumptions about what the EUDR implies, i.e. how other regions and market actors react and adapt to it, differ between the five scenarios constructed, as shown in the overview in Figure 1. The scenarios are then simulated using the market model described above and evaluated in terms of the changes that occur relative to the base scenario. The five scenarios are summarised in Table 1.

Figure 1. Overview of the scenario assumptions.



Source: Own elaboration.

Table 1. Scenario descriptions.

Scenario	Description
BAN	Ban on imports of non-EUDR compliant cocoa and cocoa products into the EU. It implicitly stops all EU production and exports of cocoa products, reducing the EU market to EUDR-compliant products.
EUDR	BAN + Account for the higher cost of producing EUDR-compliant cocoa and products due to the need to ensure traceability across the supply chain, the higher input needs or lower yields required when having no virgin forest available for growing the cocoa, and the need for hiring more labour to eliminate child labour.
NAmDR	EUDR + Canada and the US also implement an EUDR-equivalent policy.
CG	EUDR + Côte d'Ivoire and Ghana both nationally convert all their cocoa production to EUDR-compliant and also account for a cocoa growing area decrease due to a ban of cocoa from protected areas.
CG-NAmDR	CG + NAmDR.

Source: Own elaboration.

4. Results and discussion

4.1 Reference scenario

Table 2 summarises our 2019 dataset on bean production, consumption in terms of bean equivalents and associated deforestation. It shows that West Africa produces 75% of the world's beans (CG 61% and RoAfr 14%) while consuming only about 1% of cocoa products in bean equivalents. The EU accounts for one third of world cocoa consumption in bean equivalents. 45% of this consumption is traceable, meaning that with the introduction of the EUDR, 55% will become illegal and will need to be replaced, either by upgrading existing supply chains for EUDR compliance or by switching sources. In addition, the EU exports cocoa liquor, butter and powder equivalent to 10% of global consumption in bean equivalents. With the introduction of the EUDR, these exports from the EU will also need to be compliant.

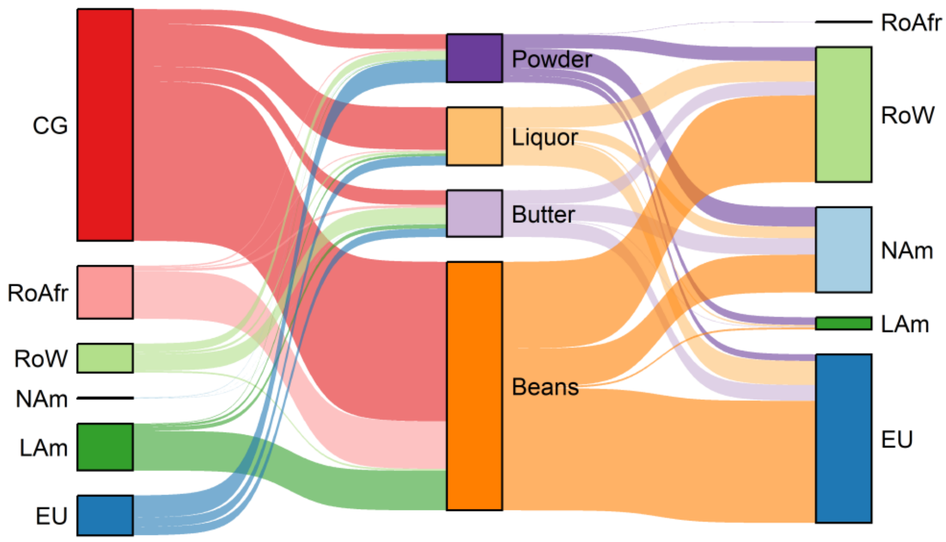
Table 2. 2019 production and consumption of beans and bean equivalents, respectively.

	Production of beans						Consumption of bean equivalents			
Region	**Production (1000 t)**	**% of global**	**% traceable**	**Farmgate price (US$/t)**	**Deforestation (1000 ha)**	**Deforestation efficiency (ha/1000 t)**	**Consumption (1000 t)**	**% of global**	**% traceable**	**Deforestation (1000 ha)**
CG	2859.1	60.8	46.8	1430.2	85.8	30.0	26.1	0.6	46.8	0.8
EU	--	--	--	--	--	--	1573.9	33.5	44.9	52.1
LAm	895.1	19.0	35.6	2213.1	27.4	30.7	468.3	10.0	38.4	14.1
NAm	--	--	--	--	--	--	1030.1	21.9	44.7	32.4
RoAfr	668.4	14.2	42.1	2159.1	30.0	44.9	26.2	0.6	42.5	1.2
RoW	281.2	6.0	44.0	1869.3	7.9	27.9	1580.3	33.6	43.8	50.6
Total	4703.7	100.0	43.9	1709.0	151.1	32.1	4705.0	100.0	43.9	151.1

Source: Own elaboration based on constructed 2019 database. Consumption represents consumption of the semi-finished products liquor, butter, and powder. Deforestation refers to annual deforestation attributed to cocoa farming. For consumption, it refers to the total deforestation implied at the origins of the beans.

The Sankey diagram in Figure 2 shows the trade flows of cocoa beans and the three processed products between the six aggregate regions, all expressed in bean equivalents. It shows that most cocoa is traded in the form of beans, with the remainder traded in roughly equal proportions as liquor, butter and powder. The CG region, which includes the two largest producers of cocoa beans, accounts for the largest share of world trade in cocoa beans, but also for liquor and significant shares of butter and powder. The rest of the cocoa bean trade originates almost entirely from RoAfr and LAm, in roughly equal proportions. The EU is the main source of traded cocoa powder and the RoW the main supplier of butter. By far the largest share of beans is destined for the EU, followed by RoW and NAm.

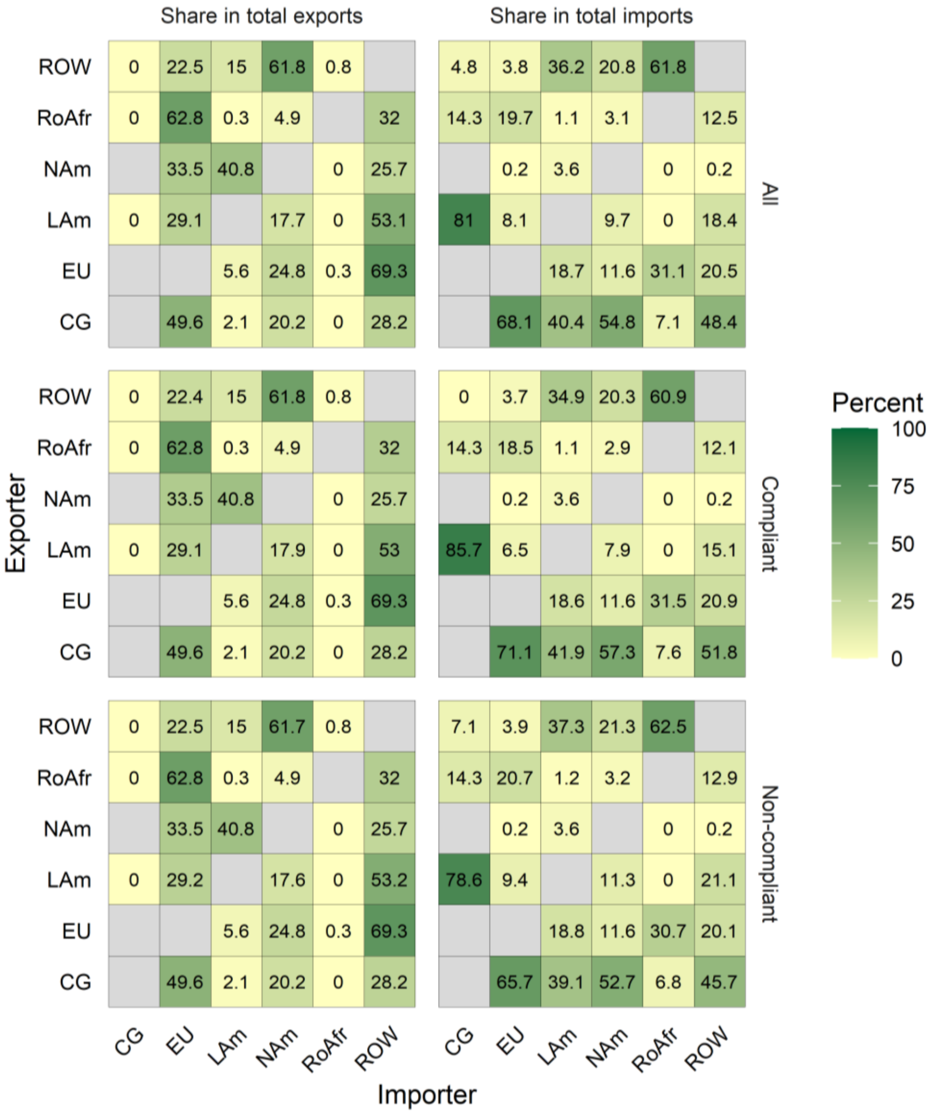
Figure 2. Trade in cocoa beans and the three processed products between regions in tonnes of bean equivalent.



Source: Own elaboration based on constructed 2019 database.

The heat maps in Figure 3 show the interdependence of the regions as sources and destinations of their trade in terms of all their cocoa products aggregated to a single bean equivalent quantity. They provide a first insight into the potential magnitude of the impact of the EUDR on each region. The left-hand panel of the top row indicates that the RoAfr (63%) and CG (50%) are particularly dependent on the EU as a destination for their cocoa exports, with all regions sending at least 20% of their exports to the EU. This suggests that the new legislation may require the most significant changes from the RoAfr and CG, either in terms of adapting to meet the EUDR, shifting production to other products, or finding new markets for their products.

Figure 3. Dependency on regions as sources and destinations for a region's cocoa trade, in bean equivalents.



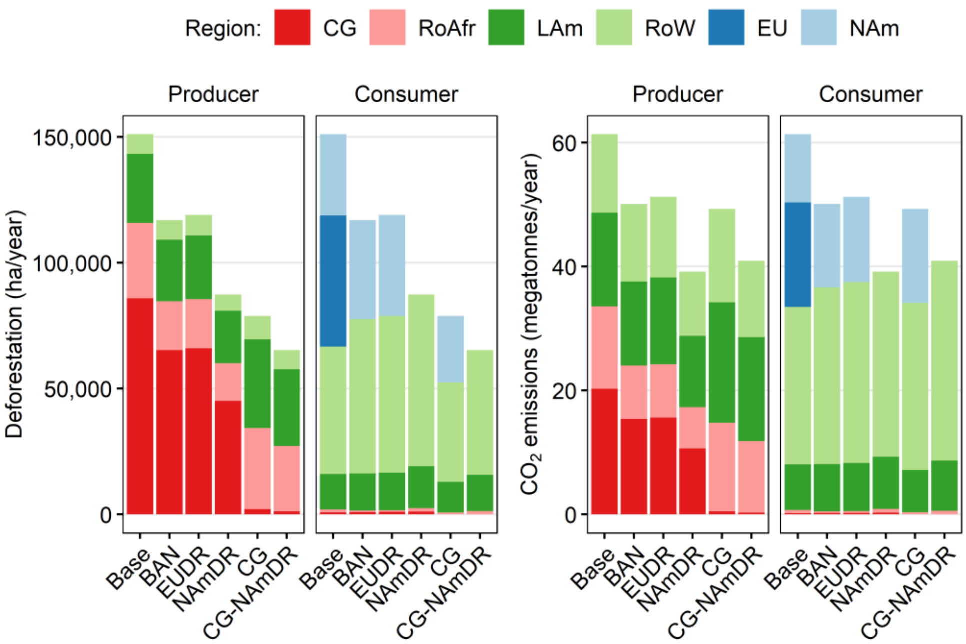
Source: Own calculation from constructed 2019 database.

The right-hand panel shows that the EU imports almost 90% of its cocoa from Africa (68% from CG and 20% from the RoAfr), highlighting the EU's extreme dependence on African cocoa. It is therefore logical that the EU should focus its efforts on supporting African cocoa producers to adapt to the EUDR.

The middle and bottom rows show these dependencies separately for EUDR-compliant and non-compliant trade. While the figures for the exporters' dependence are virtually identical to those in the top panel, there are some notable differences between them for importers' dependence. Nevertheless, the importer dependencies are all qualitatively very similar.

The annual deforestation in hectares attributed to cocoa farming is shown in the left panel and the associated CO_2 emissions in the right panel pair of Figure 4, from both the production and consumption perspective. The majority of global cocoa-related deforestation is attributed to CG (57%), while 20% and 18% are attributed to RoAfr and LAm, respectively. The relationship between deforestation and associated CO_2 emissions is not direct as each location differs in the amount of carbon stored in and above the ground. While CG is responsible for 57% of global cocoa-related deforestation, it is associated with only 33% of the corresponding CO_2 emissions. Conversely, the data shows that RoW accounts for only 5% of deforestation but 21% of the resulting emissions. From a consumption perspective, the EU and RoW each account for 34% of deforestation, followed by NAm with 21%. In terms of emissions, however, 27% are attributed to the EU 41% to RoW.

Figure 4. Annual deforested area and associated CO2 emissions attributed to cocoa farming in producer and to consumption in consumer regions, respectively.



Source: Own elaboration based on simulation results.

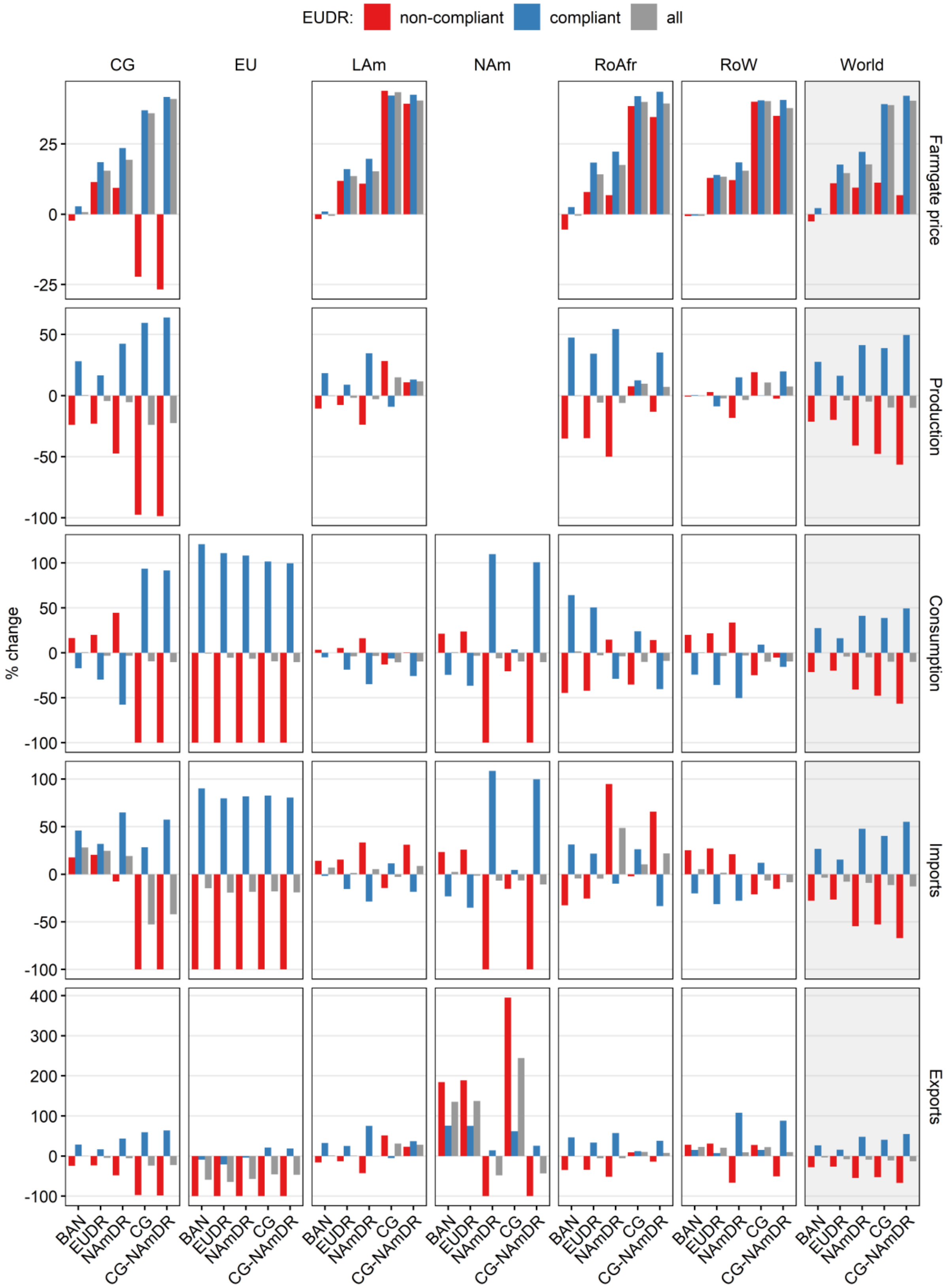
4.2 Simulation results

The simulation results are interpreted relative to the reference scenario and indicate how the economy would have looked different in 2019 if the policies of the specified scenario had already been in place for enough time for all actors to fully adjust.

4.2.1 Scenario BAN

Figure 5 summarises the simulation results for each regions separately and for the world as a whole for the production quantities of cocoa beans and the associated average farmgate prices, as well as for the bean-equivalent quantities of consumption, exports and imports. In addition to the changes in the compliant and non-compliant values, the figures show the change in the sum of the two quantities or the average in the case of the farmgate price.

Figure 5. Simulated percentage changes in cocoa bean farmgate prices and production and in bean equivalent consumption, imports and exports. All values refer to quantities except for the farmgate price which is measured in US$. The average prices for the world are calculated as Laspeyres indices.



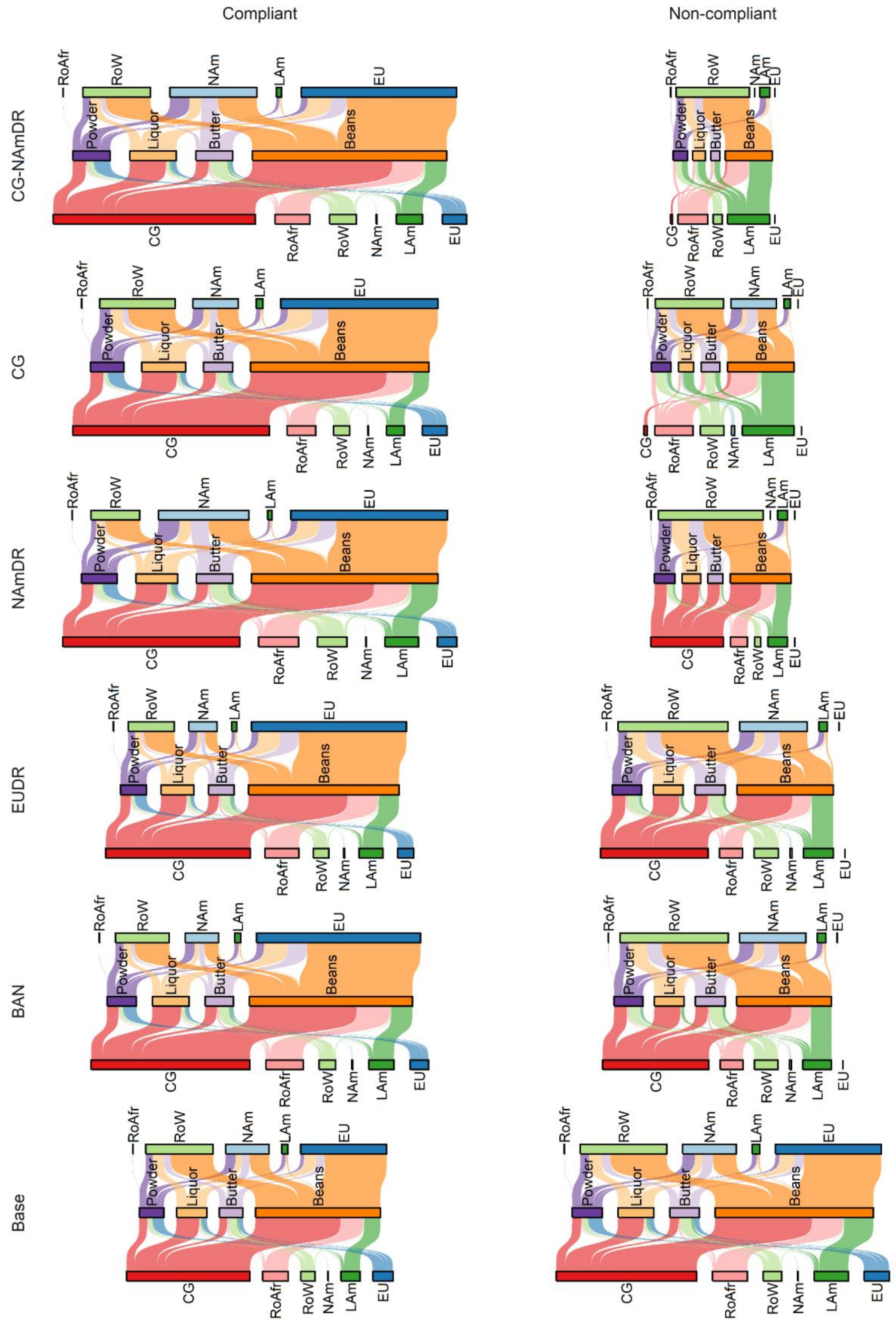
Source: Own elaboration based on simulation results.

Driven by the EU's total ban on non-compliant cocoa, consumers are switching to compliant cocoa. Ignoring market reactions, world demand for compliant cocoa in bean equivalents increases by 42%, with a correspondingly large decrease in demand for non-compliant cocoa. The model results show that EU imports of compliant cocoa increase by 90%. In addition, EU exports of compliant cocoa decrease by 9%, indicating that EU processed cocoa is now more oriented towards the internal market. EU consumption in terms of total bean equivalents falls by less than 1%.

As consumers in all regions are assumed to be rather indifferent to EUDR-compliance, they easily switch to non-compliant products when faced with higher prices. As the EU also bans exports of non-compliant cocoa products and its exports of compliant products decline (Figure 6), a gap is created in the world market for processed products, providing an opportunity for other regions to develop their cocoa processing sectors.

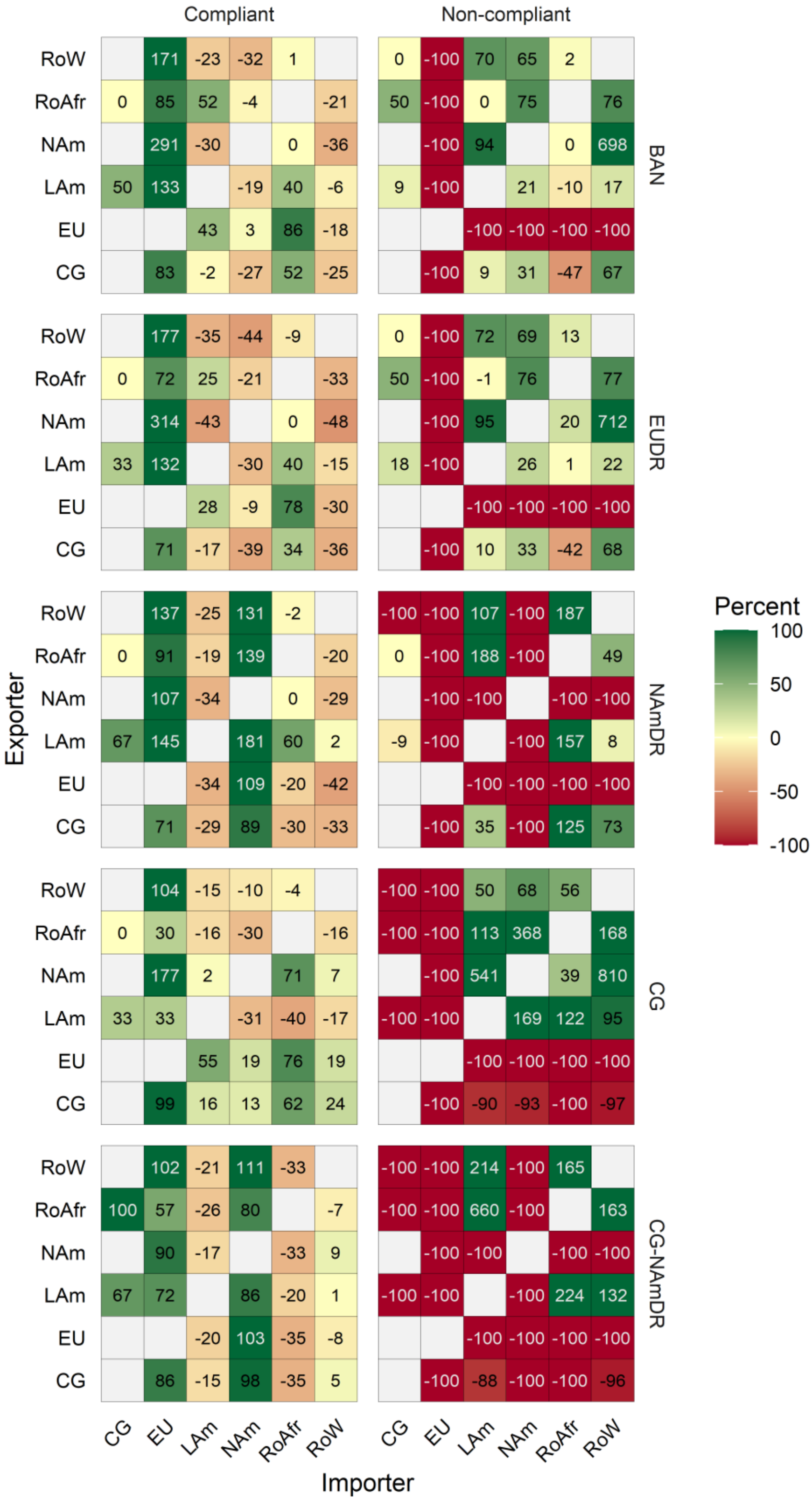
Globally, production and the average farmgate price remain virtually unchanged (both increasing by 0.1% or less). However, the BAN causes a major reshuffling of trade flows, with more compliant products going to the EU and non-compliant products going to other regions, see Figure 7, top row. The EU stops all imports and exports of non-compliant cocoa and massively increases imports of compliant cocoa from all regions. By contrast, the other regions increase their imports of non-compliant cocoa and decrease their imports of compliant cocoa.

Figure 6. Simulated trade flows in cocoa bean equivalent.



Source: Own elaboration based on simulation results.

Figure 7. Changes in trade flows in cocoa bean equivalents.

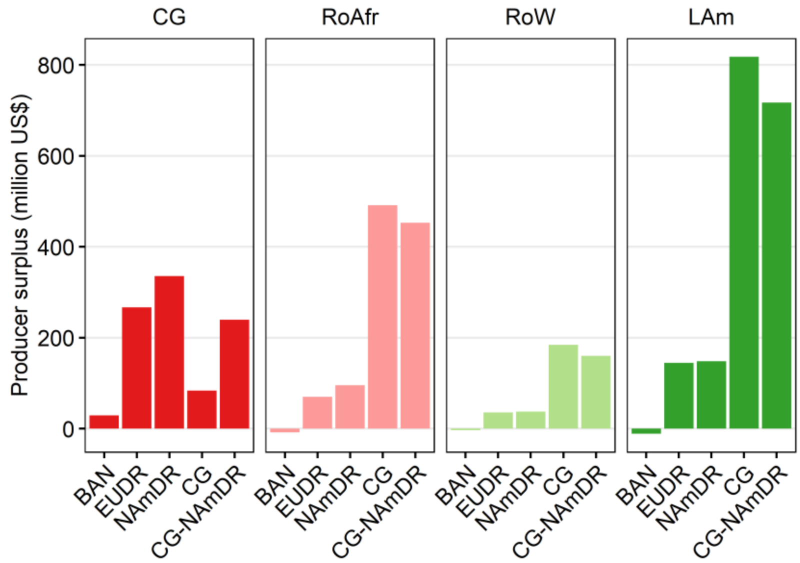


Source: Own elaboration based on simulation results.

In line with their high initial shares of exports to the EU (Figure 3), RoAfr and CG are the most affected by the EU ban. Accordingly, they shift production strongly from non-compliant (RoAfr -35 and CG -24%) to compliant (+48 and +28%). CG benefits marginally from this shift as its total production and prices increase marginally. All other regions experience a slight decrease in their bean production and farmgate prices.

The producer surplus of cocoa farmers, defined as the price received by farmers above their marginal costs, increases slightly in CG, while decreasing slightly in the other regions (Figure 8).

Figure 8. Changes in producer surplus of cocoa farmers.



Source: Own elaboration based on simulation results.

Annual global cocoa-related deforestation decreases by about 34,000 ha or 23% compared to the base. On the consumption side, the EU stops all cocoa consumption associated with deforestation. As all other regions increase this consumption, the overall reduction in deforestation is well below the EU's initial share of 35%. Each cocoa-producing country's contribution to the reduction largely reflects its initial share of total (non-compliant) EU imports and its deforestation efficiency, measured as average annual deforestation per tonne. Associated CO_2 emissions drop by 18%. The global share of compliant beans in total bean production increases to 56%.

4.2.2 Scenario EUDR

This scenario adds the cost of EUDR compliance on top of the BAN scenario, increasing the cost of bean production and adding further costs along the supply chain. As a result, global farmgate prices increase globally by around 15%, with prices for compliant and non-compliant products increasing by 18 and 11%, respectively.

As the higher prices are due to the higher cost of producing compliant products and not to higher demand compared to the BAN scenario, the shift from non-compliant to compliant bean production is muted and total bean production decreases in all regions. Globally, bean production and bean equivalent consumption decrease by 4%. In line with the reduction in global supply and given that supply is inelastic, farmgate prices increase more than production falls, so that overall farm revenues and producer surpluses increase everywhere.

The increase in compliant consumption in RoAfr is puzzling at first sight. However, it can be attributed to RoAfr's imports of cocoa powder from the EU. As demand for non-compliant products generally increases, the corresponding prices of powder from all regions increase more than those of compliant powder from the EU and thus RoAfr increases its consumption of them. Nevertheless, total cocoa consumption in RoAfr represents only 0.6% of world consumption (Table 2).

The trade flows of non-EU regions (Figure 7) show an increased shift towards non-compliant products. The policy achieves a total global share of 53% for compliant beans. In line with the muted shift towards compliant production, global cocoa-related deforestation is reduced by 21% and associated CO_2 emissions by 16%, slightly less than in the BAN scenario. Trade-induced leakage[19], defined as the share of initial deforestation attributable to policy-implementing regions, here the EU, that is not prevented by the policy, is 38.3%.

4.2.3 Scenario NAmDR

If, in addition to the EU, the USA and Canada adopt an EUDR-equivalent policy and ban all non-compliant products from their markets, a further 21.9% of world bean equivalent consumption is affected, of which 55.3% is initially non-compliant. Ignoring market responses, a 70% increase in global compliant bean production would be required to meet this additional EU and NAm demand. Demand for non-compliant cocoa would fall accordingly. The global average farmgate price increases by 18%, with the compliant price increasing by 22%, i.e. 4 percentage points more than in the EUDR scenario, while the price for non-compliant beans is 1.5 percentage points lower. Consequently, production shifts more towards compliant beans, with the production of compliant beans increasing by 41% and the production of non-compliant beans decreasing by 41%. Overall, world bean production and consumption of bean equivalents fall by 5%.

The global share of compliant beans associated with this scenario is 65%. Producer surplus increases at least as much as in the EUDR scenario in all regions, with the largest absolute increase in CG.

The addition of NAm to the bloc adopting the deforestation regulation virtually doubles the reduction in deforestation of the EUDR scenario to 42.2%, even though NAm has only a 21.4% share of initial deforestation compared to the EU's 34.5%. Trade-induced leakage shrinks to 24.6%.
The decrease in leakage is due to the fact that only RoW and LAm remain significant consumers of non-compliant cocoa. As cocoa demand is price inelastic, consumer prices fall more than proportionately to the volumes supplied to the market as they absorb additional large volumes from the market. A much smaller potential market is now facing a much larger volume. CO_2 emissions associated with cocoa-related deforestation fall by 36%.

The widening price cap between compliant and non-compliant cocoa increasingly drives producers to switch to compliant production. However, under the assumption of diminishing marginal product, the switch becomes increasingly costly. In the new equilibrium, the world average price for compliant cocoa is 11 percentage points higher than for non-compliant cocoa.

4.2.4 Scenario CG

Ignoring market adjustments, switching all of CG's cocoa production to EUDR-compliant beans would result in a 74% increase in the world supply of compliant beans and a corresponding decrease in the supply of non-compliant beans. However, the ban on cocoa from protected forests in CG would reduce the total supply of CG beans by 20.9%. In addition, compliant beans are produced at a higher cost.

Together with the EUDR, these shocks increase the CG producer price for compliant beans by 37% and production by 60%. Nevertheless, total bean production in CG falls by 24%. Although bean production increases in all other regions due to rising world prices, total world production falls by 10%,

[19] Note that other forms of leakage, particularly the leakage to other sectors within the region, are not captured by the model.

as does consumption. Average world prices for compliant and non-compliant beans increase by 39 and 11%, respectively.

Trade in non-compliant cocoa beans and products increases massively between LAm, NAm, RoAfr and RoW, while trade in compliant products gravitates strongly towards the EU and CG.

While the change in farmers' producer surplus is positive in CG, the gain is much smaller than in the EUDR and NAmDR scenarios. For the other bean-producing regions, this scenario yields the largest gains in farmers' surplus of all the scenarios. While the CG ban on cocoa from protected forests is beneficial for the surplus of all regions including CG, the marginal cost of conversion to compliant increases with the proportion of resources already converted, making forced full conversion costly, especially as it is not fully matched by the forced demand from the EUDR.

The share of compliant beans in total global beans rises to 67%. Annual global cocoa-related deforestation is reduced by 48%. This is less than the initial 57% of deforestation caused by CG, as other regions shift production to non-compliant cocoa, particularly LAm and RoAfr. Associated CO_2 emissions are reduced by 20%.

4.2.5 Scenario CG-NAmDR

The final scenario combines the NAmDR and CG scenarios. The regions EU and NAm increase their demand and CG increases its supply of compliant cocoa through a law, for which the initial shock of 70% additional global demand is still lower than that of 74% additional global supply. Again, the ban on cocoa from protected forests ins CG corresponds to a 20.9% loss in production.

Similarly, while the higher demand for compliant cocoa compared to the CG scenario results in a better outcome for CG farmers in terms of prices and production, and the additional demand for compliant cocoa from NAm significantly increases CG's producer surplus, the surplus remains slightly below the level reached in the EUDR scenario, as total CG production falls by 23%. Farmers in the remaining bean-producing regions' gain strongly surplus, but slightly less than in the CG scenario.

The global share of compliant beans increases to 73%. Trade of remaining non-compliant cocoa concentrates between LAm, RoAfr and RoW, which also reduce their imports of compliant cocoa. This scenario results in a 57% drop in global annual deforestation, the highest of all scenarios, and a 33% drop in associated CO_2 emissions.

4.3 Caveats

Caveats caused by data limitations have been discussed above, such as the opportunity cost of a forest rent that is assumed to be the same everywhere or the vague data on currently traceable cocoa. However, there are other limitations that deserve attention.

In particular, the model used neglects other EUDR products that grow under the same specific conditions as cocoa, namely coffee, oil palm and rubber, and compete for similar resources. Therefore, the corresponding input and factor markets, especially for land, interact in cocoa growing regions and may lead farmers to shift production between these crops.

The model includes cocoa and derived products, but not consumer products, as data on the cocoa content of the latter is unavailable. As a result, the model may give an incomplete picture to the extent that final chocolate products are traded across the aggregate regions analysed. We expect this to be limited.

A drawback of the Armington assumption-based bilateral trade model implemented here is that it restricts trade flows to the links where trade initially took place. However, this type of model tends to be more realistic in that it allows a region to import and export a particular product simultaneously, based on product differentiation, which is regularly observed in trade data.[20] As only a small proportion of cocoa is traded through commodity exchange markets, buyer-seller relationships are important and changing them creates frictions. In addition, transport costs increase with distance and establishing production and other facilities in countries requires significant investment. Therefore, a rapid and complete shift of the cocoa trade to other source countries is not anticipated. Most importantly, as our regions are quite aggregated, our analysis does not omit any relevant trade links.

[20] The mayor alternative is the spatial trade model by Takayama and Judge (1971), which assumes trade of a homogeneous product and explains trade across space largely by differences in transport costs. However, apart from adopting the for cocoa not applicable homogeneous products assumption, this model type can produce extreme, unrealistic swings in trade flows.

5. Discussion and conclusions

The EUDR represents a significant development in the EU's approach to taking responsibility for the negative environmental, labour and human rights impacts of its citizens' chocolate consumption in third countries throughout its supply chain. This study uses a global partial equilibrium model of cocoa beans and derived products to assess the potential impact of the EUDR on various aspects of the global cocoa market, including production, prices, trade patterns and ultimately the welfare of cocoa farmers and the issue of deforestation. The study provides the first comprehensive quantitative assessment of the impact of the EUDR on the global cocoa market and offers valuable insights into the potential impact of the EU's policy measures.

With the EU permitting the import, production, consumption and export of one cocoa product variant, while banning the other, the EUDR effectively divides the cocoa market in two. Adopting EUDR-compliant production methods increases production costs, which are offset by higher selling prices. Given the high EU demand for the compliant variants, those players in the supply chain who are able to switch at relatively low cost will adapt to the EUDR and benefit from higher prices. Initially, these will be companies that have already put in place the necessary traceability and monitoring systems, either through independent sustainability certification or manufacturers' own sustainability schemes. The remaining non-compliant cocoa will be diverted to other regions.

Indeed, redirection of trade flows is one of the major expected impacts of the EUDR, with EUDR-compliant cocoa and products being attracted to the EU and non-compliant cocoa and products diverted to other countries. The EU consumes about one third of the world's bean production, and the data used suggests that almost 44% of beans are traceable from farm to shelf in 2023. Assuming that traceability has been established as part of sustainability programmes, these beans could be made EUDR-compliant with little additional effort. If this were the case, a simple rerouteing of trade flows would be sufficient and little would be achieved in terms of reducing deforestation.

However, our model is implemented on the assumption that there is a certain persistence in trade links, due to established buyer-seller relationships and the fact that cocoa beans are not homogeneous, but vary in quality and taste. As a result, trade volumes are shifted between existing trade routes, which are never completely disrupted in the absence of an outright ban on imports or exports. In the EUDR scenario, RoAfr experiences the largest shift in production towards compliance due to its strong export dependence on the EU, followed by CG. Furthermore, cocoa processing and chocolate manufacturing typically require large investments (Oomes *et al.*, 2016) and cannot be easily relocated or duplicated. These processes may also exhibit economies of scale in production. Therefore, EU production capacity could lead to lock-in effects if it is more costly to establish new production facilities outside the EU than to upgrade the value chain for EUDR-compliance. Such upgrading has multiple benefits, such as improved ethical reputation, alignment with sustainability agendas, and reduced risk of reputational damage and incurring these costs later when other countries follow suit.

As EUDR-compliant and non-compliant products are physically identical, we assume that consumers have no preference for either, meaning that consumer prices for compliant and non-compliant variants are very similar in non-EU regions. However, as EU companies are only allowed to process and export compliant products, the higher production costs reduce the competitiveness of EU exports of cocoa product. This in turn creates an opportunity for other processing and manufacturing locations to fill the resulting gap.

A direct and positive impact of the EUDR on cocoa farm revenues is a consequence of the decline in global production caused by the higher production costs of compliant cocoa. As cocoa demand is price inelastic, the reduction in quantity demanded in response to the increase in consumer prices is less than proportional. Accordingly, farm revenues are projected to rise. The simulation results also indicate that farmer welfare, as measured by producer surplus, is expected to increase in all regions under all EUDR scenarios. Farmgate prices for compliant beans are generally higher than for non-compliant beans, but the difference varies widely between the scenarios.

In response to the EUDR, cocoa producers adapt to the new market conditions and adjust their distribution channels accordingly. Accordingly, the reduction in non-compliant cocoa, and by extension deforestation, is significantly lower than the EU's initial share of deforestation attributable to cocoa consumption. As a result of this leakage, the EU's ability to influence deforestation in third countries is less than originally assumed. However, the potential for leakage decreases as more regions adopt EUDR-like policies. In the scenarios where the NAm region also adopts an EUDR-like policy, only a small customer base remains to cause leakage, and the additional forest area saved from deforestation is actually similar in size to the deforestation area initially attributed to NAm's consumption.

It is worth to noting that the assumption about the initial proportions of cocoa being traceable is important in determining the final impact on deforestation. In our data, we assume that initially traceable cocoa is exported in roughly equal proportions to all destinations. However, it may well be that a larger proportion is already exported to the EU. This would imply that the EUDR's deforestation-reducing effect could actually be lower.

The deforestation and CO_2 emissions data utilised here suggest that forests in CG, the main source of cocoa for the EU and the focus of some scenarios, store less carbon per hectare than other regions. Accordingly, the model suggests that the EUDR and other scenarios lead to a percentage reduction in deforestation-related CO_2 emissions that is lower than the reduction in deforestation. Nevertheless, this will help producing countries meet their GHG emissions reduction commitments. Of course, forest conservation provides many other sustainability benefits, including biodiversity, soil health, and climate and water regulation. However, these benefits are not reflected in the model due to a lack of data.

The scenarios in which CG forces a full switch to EUDR-compliant cocoa show a smaller increase in producer surplus than other EUDR scenarios. The cost of conversion to EUDR-compliance is expected to increase with the proportion of production that is already compliant, for example because of the need to include farmers in increasingly remote areas where infrastructure is poorer and monitoring is more difficult. This suggests that such farmers in particular will need support to make the transition to a new livelihood.

However, as CG alone produces 61% of the world's beans, there would be a large surplus of compliant beans even if NAm also introduced an EUDR-like policy. Nevertheless, the scenario in which CG forces a full conversion to EUDR-compliance and NAm implements an EUDR-like policy results in a much better welfare outcome for CG farmers. It is therefore crucial that the supply of EUDR-compliant beans achieved through government enforcement in producer countries is matched by a corresponding (enforced) increase in demand.

The EUDR simulation results indicate positive welfare impacts for cocoa farmers, but the long-term benefits not captured in the model could be even more significant. In addition to a better and more liveable environment with conserved forests, increased biodiversity and productive soils, the EUDR's legality condition requires stronger enforcement of human rights, environmental and labour laws, which promises better future livelihoods for farmers and, in particular, better development opportunities for children, enhancing future well-being and income potential. Adult labour and land would also be better remunerated. However, these benefits depend on effective enforcement and the avoidance of leakage, which could simply shift environmental harm and child labour to other sectors.

It is important to note that the impact of the EUDR on the cocoa market cannot be directly generalised to other EUDR products, as the structure of the cocoa market is unique. The EU is the world's largest importer and consumer of cocoa, accounting for one third of global cocoa consumption, and cocoa bean production is largely concentrated in a few West African countries. At the same time, African countries' own consumption of cocoa is negligible. Therefore, the EUDR is expected to have a greater influence and impact on deforestation in the cocoa sector than in other EUDR sectors.

It remains to be seen whether the EUDR will be sufficiently disruptive to create a 'Brussels Effect' and set a quasi-standard that foreign companies and governments will generally follow to facilitate access to the EU. Other consumer countries, such as the UK and the US, are considering similar demand-side deforestation legislation, but these seek to eliminate only illegal deforestation from their supply chains, as opposed to all deforestation as in the EUDR (Weiss *et al.*, 2020). However, the overlap of these legislative initiatives could potentially increase incentives for chocolate manufacturers to comply with the most stringent requirements, as all proposals share many components of the necessary infrastructure, such as traceability and monitoring.

Companies with strong EU dependency may choose to become fully compliant rather than operate parallel, segregated value chains, depending on the cost of segregation, their economies of scale (e.g. due to fixed costs) and their expectations for the evolution of the policy environment. There likely exist tipping points for producer and consumer countries, as well as for companies, marking the boundary at which full conversion to compliance is the optimal choice. In addition, countries with significant cocoa manufacturing sectors, such as Switzerland, where exports are heavily EU-oriented, may adapt their laws to fully align with the EUDR.

EU companies importing from countries classified as "low risk" for non-compliance will benefit from simplified, less costly EUDR due diligence requirements. This could provide an additional incentive for governments to achieve national compliance, as the associated cost advantages will benefit domestic producers and may attract further companies targeting the EU, depending on the cost differences between risk classes.

As the study has shown, the unilateral demand-side approach of the EUDR risks being ineffective due to leakage. Nevertheless, the EUDR creates a level playing field for cocoa-producing countries, as competitors in the EU market will no longer be able to gain cost advantages by exploiting the environment, labourers or children. This should also make it easier for producer country governments to implement and enforce sustainability legislation.

The policy implications of this study are clear: the problems that the EUDR seeks to address through trade linkages are fundamentally due to the absence or weakness of corresponding institutions abroad. These institutions do not sufficiently enforce environmental, labour and human rights laws, or do not take into account future costs, such as environmental costs. The study highlights that the EU's own leverage to reduce its cocoa-related deforestation is limited by trade-induced leakage to other countries, and further reduced by leakage to other sectors. The EU's leverage is likely to be even smaller for other EUDR products.

This underlines the importance of intensifying diplomatic efforts to eradicate deforestation, both with consumer countries to reduce the potential for diversion of non-compliant products, and with producer countries to lobby for full compliance and prevent leakage to other sectors. The study highlighted that leakage decreases as more countries implement similar policies. However, the EUDR and similar demand-side trade regulations, such as those being considered in the UK and US, could incentivise producer countries to establish or strengthen the relevant institutions, thereby accelerating the process. This would be the optimal outcome. In the meantime, it is recommended that technical and financial assistance – for example, from the EU – be used to ensure that producer country governments and companies are prepared and that small and remote cocoa farmers are not left behind. This assistance should support them in transitioning to other livelihoods or integrating them into compliant supply chains.

Future work should extend the analysis to all EUDR commodities, taking into account the interactions between these markets. In addition, incorporating an explicit spatial representation of land, taking into account location and climatic suitability for cocoa cultivation, has the potential to provide new insights into the long-term impacts on for forests and protected areas under alternative policy scenarios.

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List of abbreviations

CES	Constant Elasticity of Substitution
CG	Côte d'Ivoire and Ghana
CGE	Computable General Equilibrium
CO_2	Carbon dioxide
EU	European Union
EUDR	EU Deforestation Regulation
GHG	Greenhouse gas
LAm	Latin America
NAm	Northern America (Canada, United States)
PE	Partial Equilibrium
RoAfr	Rest of Africa
RoW	Rest of the World

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