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Tropical forests and forest-risk commodities: an integrated framework for the assessment of deforestation risks associated with the trade of FRCs in Europe

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Abbreviations and acronyms

AFOLU	Agriculture, forestry and other land use
EU	European Union
EUDR	European Union Deforestation Regulation
EUTR	European Union Timber Regulation
FAO	Food and Agriculture Organisation
FLEGT	Forest Law Enforcement, Governance and Trade
FLA	Forest loss attributed
FRA	Forest Resources Assessment
FRCs	Forest risk commodities
GHG	Greenhouse gases
ILUC	Indirect Land-Use Change
MRIO	Multi-region input-output analysis
ppe	Primary product equivalent
PTF	Physical trade flows approach
SDGs	Sustainable Development Goals
SMEs	Small and medium enterprises
SNA	Social network analysis
UK	United Kingdom
USA	United States of America

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Summary

Despite the apparent decrease in global forest loss in the last few years, deforestation rates in tropical countries remain alarming. Deforestation drivers linked to agriculture expansion, wood extraction and infrastructure development, along with economic, political and social factors, have shaped how deforestation occurs in the tropics. They reflect the existing patterns, trends and actors involved in this matter. In this sense, the increasing demand for agricultural products that originate from tropical forest ecosystems is causing the expansion of the farming frontier in many countries by displacing forests. This is resulting in environmental and socio-economic issues that go from higher rates of biodiversity loss and the emission of greenhouse gases to increased corruption in forest-related sectors and social conflicts. More specifically, a telecoupling perspective allows seeing that the demand for forest risk commodities (FRCs) from powerful economies such as the European Union, the United Kingdom and China makes international trade a major responsible for deforestation in producing countries in the tropics.

Recently, in order to reduce deforestation attributed to forest risk commodities such as cocoa, coffee, oil palm, soy, beef and wood, the EU published a proposal for a regulation on deforestation-free products. This proposal aims to prevent products originating from deforestation sources from entering the EU market or being exported from it by establishing a due diligence procedure that would ensure a negligible risk of non-compliance. Operators would have to ensure that their products are deforestation-free and that they were produced following the relevant legislation of the country of production. In this context, this study addresses the first point of compliance from a broad perspective by proposing an integrated framework for assessing the deforestation risk embedded in FRCs exported from tropical countries into the EU market. The top 15 exporters of 12 commodities related to cocoa, coffee, soy and oil palm were chosen to carry out the deforestation risk assessment for each country and product, based on trade data from 2003 to 2020. Furthermore, a social network analysis was included to display the relationships between producing/exporting countries and importing countries in terms of the relevance and role of certain actors in the trade of FRCs.

The results show that the exports of FRCs into the EU market are causing extensive deforestation for their production due to cropland expansion, especially in Indonesia and Malaysia for palm oil, in Brazil and Paraguay for soybean, in Cotê d'Ivoire and Indonesia for cocoa, and in Tanzania and Indonesia for coffee. Other tropical countries, such as Malaysia, Colombia, Papua New Guinea, Honduras and Peru, also display concerning deforestation figures attributed to EU imports of FRCs. Furthermore, the results reveal that EU countries with prominent port and/or processing facilities and big industries, such as the Netherlands, Germany, France, Spain and Italy, are importing the largest shares of FRCs from tropical countries among other EU countries. Relationships among producing/exporting and importing countries are basically condensed into a few countries, making them the main actors in the supply chain of these FRCs and, thus, the ones that should be taking more extensive measures towards a shift to a deforestation-free supply chain.

1. Introduction

Forests have played a crucial role throughout history by providing and supporting land-based communities with ecosystem services (Reed et al., 2017; Balvanera, 2012). It has been widely studied that forests represent the most species-rich habitat in the world (Brockerhoff et al., 2017) and an important carbon sink (Tagesson et al., 2020). Beyond other functions, they also contribute to nutrient cycling (Sayer et al., 2020) and mitigate water scarcity and climate change (Ellison et al., 2017). Nevertheless, according to the last Forest Resources Assessment (FRA) published by the Food and Agriculture Organisation (FAO) of the United Nations (FAO, 2020), approximately 420 million ha of forest have been lost worldwide in the past 20 years. Although the annual rate of deforestation in 2015-2020 decreased compared with the previous period (2010-2015), moving from 11.8 million ha to 10.2 million ha, tropical countries still show alarming deforestation figures, accounting for more than 90 % of global deforestation since 1990.

Land-use changes have triggered many environmental and social concerns, from biodiversity loss (Chaudhary and Mooers, 2018) to a decrease in ecosystem services provision (Hasan et al., 2020). Through land-use changes, land can act as both a source and a sink of CO_2. Activities such as agriculture, forestry and other land use (AFOLU) represented around 23 % of the total net anthropogenic emissions of greenhouse gases (GHGs) (i.e., CO_2, CH_4 and NH_2) during 2007-2016 (IPCC, 2019). Among these, deforestation has been proven to be the primary source of emissions worldwide, whereas agriculture-driven deforestation is predominant in developing countries (Leblois et al., 2017; Doggart et al., 2020; Ngwira et al., 2019). Still, emissions from the agricultural sector are expected to keep increasing in the following years, mainly due to population and income growth and changes in consumption patterns (IPCC, 2019).

More specifically, deforestation and land clearing in tropical countries are being consistently linked with the production of agricultural commodities traded in foreign markets (Henders et al., 2015). These forest-risk commodities (FRCs), i.e., cocoa, coffee, oil palm, soy, beef and wood, embody severe consequences for ecosystems and human communities (Partiti, 2020), despite their contribution to local livelihoods and development (zu Ermgasssen et al., 2020a) and food security throughout the world (Medina and Thomé, 2021). At the same time, many developed countries are increasing their imports of products with embodied deforestation (Hoang and Kanemoto, 2021) while also increasing their forest cover (Pendrill et al., 2019a).

In this context, the role of global markets and institutions in halting or triggering deforestation is of particular concern, though joint effort with producing countries is also needed (dos Reis et al., 2021). The European Union (EU), acknowledging its responsibility and role with reference to deforestation and forest degradation embodied within global supply chains, is proposing a regulation regarding the previously mentioned FRCs and their associated products (e.g., chocolate, furniture, leather) associated with deforestation and forest degradation (European Comission, 2021). The proposal targets due diligence as the core for guaranteeing compliance with EU rules that prevent the placing of FRCs on the EU market. In this way, the EU would limit their contribution to deforestation and GHG emissions (Wardell et al., 2021).

Nevertheless, it is unclear how to assess deforestation risks in tropical forests embedded in the EU's demand for FRCs. A framework that captures the dynamics behind deforestation risks associated with FRCs is needed so that decision-makers and agents across supply chains can have appropriate tools to prevent forest loss in the tropics. In this sense, this study aims to develop and evaluate an integrated framework for assessing deforestation risks associated with the Production and trade of FRCs in Europe. In order to do that, the study intends to quantify the production and trade flows of four FRCs over time, highlighting key players among producers, exporters and importers, as well as relevant changes in their patterns, to then analyse the role of the EU within the international trade in FRCs. All this, by using socioeconomic and environmental indicators identified in the literature, linked with FRCs production and trade patterns that would explain deforestation risks.

1.1 Background

1.1.1 Globalisation, trade liberalisation and forest risk commodities

Globalisation has increased the interdependence of countries around the world, promoting growth and reducing income inequality and poverty in developing countries (Yameogo and Omojolaibi, 2021). At the same time, trade liberalisation has contributed to placing goods from distant places in various markets while also promoting the development of large, multinational companies (Garret and Rueda, 2019). A global economy scatters consumer goods, consumerism, consumption patterns, and uniform market rules and structures (Sideri, 2000), and ultimately it is the consumer's choice and demand that drives production (Lenzen et al., 2012).

Nevertheless, the growing global demand for commodities, the increased market integration, changes in the number, diversity and specialisation of actors involved in international trade, and the increased importance of the private sector show an increasing influence on land use (Godar and Gardner, 2019). Globalisation has triggered new land demand, new land-use agents and land redistribution, causing land use to be embodied in remote flows and processes (Friis, 2019). Supply chains, currently extended worldwide, are transferring environmental and social impacts associated with consumption to remote locations (Moran et al., 2020). Still, complex trade relationships make tracking back land-use changes attributed to commercial croplands a challenging task (Franco-Solís and Montanía, 2021).

A study conducted by Pendrill et al. (2019b) showed that Latin America exports products embodying 22-34 % of its CO_2 emissions due to deforestation processes, while the Asia-Pacific region exports 40-49 % and Africa 8-32 %. The Production of FRCs to meet global demand for food, fibre and energy has become a significant driver of land-use change (Godar and Gardner, 2019). Moreover, the current bioeconomy trend has raised concerns regarding the need for land for biomass production, and the pressure this could have (and that is already having) on forests (Bastos-Lima, 2021; Fristche et al., 2020; Rulli et al., 2019). Since demand increases cause the offer to increase, FRC-importing countries are somehow financing forest loss (Marín Durán and Scott, 2022). For instance, the EU is the second largest importer of tropical deforestation and associated emissions after China, as its imports of commodities between 2005 and 2017 have caused 3.5 million hectares of deforestation and the emission of 1,807 million tonnes of CO_2 (WWF, 2021).

1.1.2 The new EU Regulation on deforestation-free products

Technological solutions referred to transport and communication came into place to answer natural barriers to the international trade in commodities. In contrast, governmental barriers are less anticipated on some occasions and are likely to be enacted or removed anytime (Anderson, 2014). The EU, given the current context of international trade, intends to take responsibility for its share in deforestation in other parts of the world by developing a new regulation to tackle this issue from their role as importers (Marín Durán and Scott, 2022). The EU has acknowledged its role in deforestation and forest degradation as a consumer of FRCs and the urgency to promote measures to reduce its contribution to this global issue (European Commission, 2021a). The policy debate recognises deforestation in tropical countries as an externality generated by EU imports (Weatherley-Singh and Gupta, 2018).

The new Regulation to minimise EU-driven deforestation and forest degradation (in short EU Deforestation Regulation, hereinafter EUDR) seeks to promote the consumption of relevant commodities (i.e., cocoa, coffee, oil palm, soy, beef and wood) and relevant products (those fed or made using relevant commodities) from deforestation-free sources (European Commission, 2021a). Due diligence obligation is planned as the alternative to check on EU and non-EU companies' compliance with legal requirements that would prove that supply chains are not causing deforestation in producing countries. This way, the EU would prevent products associated with forest loss to be placed on the European market. Eventually, effective actions derived from the new Regulation are expected to reduce the EU's contribution to GHG emissions and biodiversity loss and minimise its share in deforestation and forest degradation (European Commission, 2021a).

This initiative prohibits that relevant commodities and products are placed and made available on and exported from the EU market if they do not demonstrate compliance with the EUDR, considering that due diligence is mandatory for carrying out commercial activities within the EU market. The EUDR establishes that relevant commodities and products can be placed on the EU market or exported from it only if "*a) they are deforestation-free; b) they have been produced in accordance with the relevant legislation of the country of production; and c) they are covered by a due diligence statement as laid down in Article 4(2)"* (European Commission, 2021a; p.37).

The mentioned article establishes that operators are obliged to perform due diligence procedures for all commodities and products, making reference to deforestation and legality. In this sense, the operators shall state that no or only negligible risk is associated with the relevant commodities and products they want to place on the EU market or export. As for the traders, the EUDR differentiates those who are and are not small and medium enterprises (SMEs). Traders who are SMEs shall provide information about the supply chain (operators or traders who have supplied them with relevant commodities or products). Traders who are not SMEs are considered operators and shall comply with the exact requirements that are mandatory for those.

In this sense, responsibility is mainly transferred to the operators and traders, who must keep records of the due diligence statements made available via an information system. These statements shall include documents and evidence regarding the relevant commodities and products, including information on, e.g., quantity, geo-localisation coordinates of the place of Production, and verifiable proof that the relevant commodities and products comply with the requirements to be placed on the EU market or exported from it. Moreover, operators shall maintain due diligence systems and records and perform a risk assessment to determine if there is a risk that the relevant commodities and products do not meet the Regulation's requirements.

1.1.3 Other policies addressing deforestation and forest-risk commodities

The EUDR is not the first attempt of the EU to address deforestation and forest degradation in other countries. Some policies, mainly aimed at reducing illegal timber, have somewhat considered these issues (Bager et al., 2021). For example, the EU Action Plan on Forest Law Enforcement, Governance and Trade

(FLEGT), launched in 2003, aims to develop and implement measures to guarantee that only legally harvested timber is imported into the EU. The FLEGT includes specific supply-side measures aiming to ensure legal forest management and supply chains in extra-EU producing countries. Voluntary Partnership Agreements (VPAs) were established between EU and non-EU countries to ensure timber legality, including commitments and actions from both parties under a licensing scheme.

Developed within the framework of the FLEGT Programme, the EU Timber Regulation (EUTR), which entered into force in 2013, operates on the demand side by setting obligations for operators who place timber and timber products on the EU market. It prohibits the placing of illegally harvested timber and derived products and establishes due diligence procedures that include information on the product, risk assessment and risk mitigation. Based on an analysis made by the European Commission (2021b), the EUTR has evidenced a number of difficulties regarding due diligence systems and implementation. Smaller operators face challenges when applying due diligence systems in part due to limited understanding of the Regulation and limited capacities to demonstrate the legality of the products. Additionally, the FLEGT Regulation has shown slow progress in its implementation and no clear evidence of a positive impact even though more than 15 years have passed.

In 2019, the EU Communication on stepping up EU Action to Protect and Restore the World's Forests was adopted, which aimed to protect and improve the health of forests and increase sustainable and biodiverse forest cover around the globe (European Commission, 2019). Unlike the EUTR and the FLEGT, this EU Communication draws more direct attention to FRCs and the EU's responsibility. For instance, among the priorities set, it was included reducing the EU's footprint related to consumption and promoting the consumption of deforestation-free products. The EU Communication has set the ground for developing and reviewing policies regarding deforestation, agriculture, consumption, trade, international cooperation for development, research, and finance (Bager et al., 2021). Hence, the EUDR is part of the plan of action to curb deforestation and forest degradation described in the EU Communication and intends to tackle some of the priorities set on it.

Besides the EU, other initiatives aiming to curb deforestation are currently being developed in the United Kingdom (UK) and the United States of America (USA). The UK intends to halt deforestation through a due diligence law that would require large companies to demonstrate that the FRCs they use do fulfil producing countries' laws on forest protection (UK Government, 2020). Some scholars and NGOs have argued that the initiative leaves a gap for legal deforestation (Paim, 2021); however, the final document is still under revision after a public consultation process (UK Government, 2021). As for the USA, with the Forest Act of 2021, the Congress seeks to prohibit imports of certain commodities embodying deforestation, requiring declarations stating there has been proper caution to assess and mitigate illegal deforestation risks.

1.2 Problem statement

Agriculture expansion and livestock rearing are the major drivers of deforestation in tropical countries (Armenteras and Rodríguez Eraso, 2014; Ngwira and Watanabe, 2019; Oljirra, 2019). The loss of forest cover has significant consequences on biodiversity and GHG emissions (Vijay et al., 2016), soil erosion, water availability (Veldkamp et al., 2020), ecosystem resilience (Zemp et al., 2017) and people's well-being (Carrasco et al., 2017). However, the discussion on the role of the global demand for commodities in triggering deforestation is very recent, though it has been gathering the efforts of several researchers in the past few years (Henders et al., 2015; Mammadova et al., 2020; Pendrill et al., 2019a; Hoang and Kanemoto, 2021).

Globalisation has intensified the interactions among geographically distant systems and across different scales (Liu et al., 2007). Remote interactions between telecoupled systems are increasingly impacting global-scale issues, such as biodiversity, climate change, food security, land use, water availability (Liu et al., 2013). These systems, often complex and not well understood, portray crucial drivers of deforestation (Johansson et al., 2020), and current market trends and trade policies may be enhancing forest loss within supply chains (Mammadova et al., 2020). Nevertheless, tracing some products' origin and impact remain a challenge (zu Ermgassen et al., 2020a).

In this sense, and considering the urgency of the current issues associated with the international trade of commodities, the EU has launched a proposal for a Regulation to minimise EU-driven deforestation and forest degradation (European Commission, 2021a). The EUDR establishes that due diligence systems and risk analysis that take into account deforestation risks are mandatory for all operators and traders. However, it does not mention how to do it, what to include or which criteria should be followed.

Since previous regulations have not and are not showing the expected results from their implementation due to a number of challenges (European Commission, 2021b), it is evident that it is more than necessary to build a framework in order to assess deforestation risks in tropical forests embedded in the EU's demand for FRCs. An integrated framework should help all the involved actors deal with this proposal and comply with its requirements in the most accurate way.

1.3 Objectives and research questions

1.3.1 General objective

To develop and assess an integrated framework for evaluating deforestation risks associated with the Production and trade of FRCs within the EU.

1.3.2 Research questions

- What are the main environmental and socioeconomic indicators that can be used to detect/assess deforestation risks associated with those flows?

- What are the main trade flows of FRCs toward EU countries?

1.3.3 Specific objectives

- To identify a socioeconomic and environmental indicators and test their link with FRCs production and trade patterns in order to assess risks associated with them.

- To quantify the production and trade flows of FRCs over time, highlighting key players (producers/exporters/importers) and relevant changes in their patterns.

- To analyse the role of the EU and EU member states within the international trade in FRCs.

1.4 Structure of the thesis

Chapter 1 sets out the research questions and objectives based on the identified problem's background information.

Chapter 2 introduces the relevant theories in the study, including the definition of the terminology utilised within the research and the main concepts that will help understand the flow of information presented here. Special attention is paid to theories such as telecoupling and the trends that explain the research problem.

Chapter 3 describes the research methodology. Likewise, the techniques used in the data analysis are explained in detail.

Chapter 4 presents the main findings derived from the data analysis.

Chapter 5 presents the discussions of the results, the limitations of this study and the suggestions for future research.

Finally, the conclusions that have been drawn from the results are found in Chapter 6.

2. Theoretical background

This chapter presents the theoretical background for the research. It is organised into two parts: literature review (2.1) and theoretical approach (2.2).

2.1 Literature review

The results of an extensive literature review on the topics addressed by the research are presented within this section.

2.1.1 Tropical deforestation and land-use change

Deforestation is the land-use change from forest to other purposes, such as agriculture or infrastructure (FAO, 2020), involving the change of the biophysical attributes (cover) of the land's surface (Hu et al., 2019). Besides playing an important role in increasing the Earth's temperature and threatening biodiversity, tropical deforestation is responsible for 8 % of global CO_2 emissions (Global Witness, 2021). According to data from the FAO FRA (FAO, 2020), deforestation averaged 9.28 million ha per year in the tropical domain in 2015-2020. Africa accounted for the highest deforestation rate during that period, with 4.41 million ha per year, followed by South America and Asia, with 2.96 million ha per year and 2.24 million ha per year, respectively. Even though deforestation rates in the tropics have reduced compared with previous FRAs, Africa's rates are decreasing slower than those of South America and Asia, which have reduced their rates to almost half during this century.

Overall, deforestation brings up issues related to public health, climate change and agricultural Production (Vargas Zeppetello et al., 2020), but also about biodiversity and the rights and livelihoods of local communities (Seymour and Harris, 2019). However, the magnitude of the subsequent changes derived from tropical deforestation will be related to the land use assigned after forest clearing (Silvério et al., 2015). In the case of agricultural Production, the environmental impacts will vary also depending on the geographical location (Kastner et al., 2011).

Different social and economic factors can influence decision making that could lead to forest clearing (Murtazashvili et al., 2019). The integration of global markets and cropland displacement are increasing deforestation in tropical counties, mainly encouraged by the Production of commodities with great demand in developed countries (Ordway et al., 2017). Deforestation for agricultural expansion is influenced by the costs and benefits of a pool of options. In this sense, forest clearing occurs when it is more profitable to convert a forest into agricultural land than to convert an already existing land that would require extra inputs and further investment (Meyfroidt et al., 2014). In other words, deforestation results from intricate socioeconomic processes where human activities induce land-use change and land-cover change (Geist and Lambin, 2001). Hence, it should be tackled from an integrated environmental, social and economic perspective since its causes and consequences do not merely correspond to one sector or affect one system (Liu et al., 2017).

2.1.2 Deforestation drivers and deforestation risk

Deforestation drivers go from insecure tenure and swidden agriculture to population growth and international markets (Rudel et al., 2009). A straightforward way to look at tropical deforestation drivers is by splitting them into proximate and underlying causes. Geist and Lambin (2001) elaborated on the conceptual framework of what causes deforestation. They defined proximate causes as the near-final or final activities that have a direct impact on the environment (e.g., cattle ranching, fuelwood extraction, oil exploration), while underlying causes were described as the processes or forces that trigger these proximate causes (e.g., market growth, corruption, technological development) and create deforestation loops since they concentrate most of the pressure on forests (Mammadova et al., 2022). Overall, drivers appear differently in each case and are very context-specific, depending on the geographical and socioeconomic characteristics of the area (Rodrigues Trigueiro et al., 2020). Nevertheless, deforestation drivers are often hard to identify thoroughly because of their complex and changing nature (Hoang and Kanemoto, 2021).

Of all the drivers, which also include infrastructure, mining and urban expansion, agriculture is the most important one, explained by shifting agriculture for subsistence at a small scale and forest clearing at a large to medium scale for cropland, pastures and tree plantations for commercial purposes (Hosonuma et al., 2012). More specifically, forest conversion to shifting agriculture shows to be more prominent in Latin America, followed by Asia and Africa, whereas forest conversion to croplands is more substantial in Africa, followed by Latin America and Asia (Houghton, 2012). Likewise, since globalisation and urbanisation increased during the 1980s, distant consumers became agents driving deforestation in the tropics (Rudel et al., 2009).

The increased production of food, feed and fibre is basically being supported by land-use change. Agricultural expansion is the main driver of deforestation, and it is associated with impacts on biodiversity and a reduced capacity of systems to cope with climate change (FAO and UNEP, 2020). According to the Intergovernmental Panel on Climate Change (IPCC, 2019), the total food production increased by 240 % from 1961 until 2017 because of agricultural expansion and increasing yields. Moreover, this expansion is expected to significantly increase in tropical countries in the upcoming years, having considerable impacts on tropical forests and semi-arid environments, especially in South America and Sub-Saharan Africa (Laurance et al., 2014). While the impacts of agricultural expansion portray challenges to biodiversity conservation and carbon sequestration (Dinerstein et al., 2014), the causes go back to export shares, increasing economic value added to agricultural products and rural population growth (Barbier, 2004).

It is important to note that not all agricultural expansion involves forest clearing. On some occasions, when forests are not suitable for agriculture or policies in force prevent people from clearing them, agriculture expansion for producing certain commodities can happen by converting already existing agricultural lands, whether in the same place or a distant location (Meyfroidt et al., 2014). Agricultural expansion might occur even in other natural ecosystems, such as wetlands and shrublands (Ballut-Dajud et al., 2022; Hu et al., 2020). Nevertheless, it is a fact that agricultural expansion, followed by poor management practices, puts pressure on remaining forests (Acheampong et al., 2019).

2.1.3 Embodied deforestation

Embodied deforestation is defined as the deforestation caused by the Production, trade or consumption of a good, commodity or service (Weatherley-Singh and

Gupta, 2018). Ritchie and Roser (2021) speak of commodity-driven deforestation in terms of long-term, permanent land-use change from forests to other purposes. This entails social and environmental issues strictly connected to supply chains (Carodenuto and Buluran, 2020). Furthermore, all economic sectors embody deforestation risks, though they cannot be traced beyond supply chains (Mammadova et al., 2022). Trade between tropical countries and powerful economies in the world, such as the UK and the EU, shows the dynamic behind embodied deforestation and the role that consumer countries play from the demand side. For instance, during 2005-2013, Brazil and Indonesia represented almost half of the deforestation embodied in land-use change for agriculture, pastures and tree plantations (Pendrill et al., 2019a).

A study conducted by Hoang and Kanemoto (2021) identified that international trade embodies deforestation in biodiversity hotspots in areas such as Southeast Asia and the Amazonian rainforest, which represents a serious threat to biodiversity conservation. Moreover, since embodied deforestation is associated with land-use change, it is vital to assess the issues that come along with it and that compromise sustainability, such as water, energy, material and carbon footprints, to allow the elaboration of sound proposals in the policy arena (Hoekstra and Wiedmann, 2014). In this sense, consumption footprints attributed to trade flows can be allocated to the production of commodities on already cleared land and the relative contribution to forest clearing for agricultural expansion (Henders et al., 2015). At the same time, special attention should be paid to the production practices carried out for each product since deforestation can occur in different manners and moments. For instance, deforestation embodied in the export of a given commodity might be visible years before the export or the production occurred, as in the case of soybeans, which go through a land conversion process that often involves the production of pastures or other temporary crops during three years before sown (Escobar et al., 2020).

In this line of thought, talking about deforestation risk comes in an easier way to understand and analyse, as it can be linked with future or past deforestation dynamics. From a future perspective, data availability on deforestation drivers is necessary to identify possible risks precisely (Di Lallo et al., 2017). Furthermore, modelling plays an important role in predicting deforestation risk since identifying areas with a high risk of deforestation can encourage actions to prevent deforestation events from taking place (Rojas et al., 2021). On the other hand, dynamics from the past allow the allocation of risks to supply chain actors involved in the trade of certain commodities, explaining deforestation risk in hectares per year (zu Ermgassen et al., 2020a), but also to supply chains of sectors that are not proximate deforestation drivers (Mammadova et al., 2020). Trase (2020) described that deforestation risk could be analysed in terms of hectares of deforestation per tonne of export when looking back in time to estimate deforestation attributed to a commodity. For this, allocation periods are used to reflect the time required to convert the land up to when the crop is finally planted. Overall, supply chain traceability and geographical analyses can help grasp deforestation risks across the production and trade of a given product, also identifying the level (e.g., national, regional) at which it exists (Mammadova et al., 2022).

2.1.4 Forest-risk commodities

For this study, forest-risk commodities (FRCs) are those considered in the EUDR as "relevant commodities" and "relevant products" (European Commission, 2021a), so a past perspective is used. The proposal to minimise EU-driven deforestation and forest degradation associated with these commodities (i.e., cocoa, coffee, oil palm, soy, beef and wood) and products (e.g., chocolate, leather, plywood) aims to stop the trading in FRCs on the EU market to deforestation-free commodities and products. In this regard, the EU proposal has defined "deforestation-free" as the relevant commodities and relevant products that were grown, harvested, raised or fed with no link to deforestation or forest degradation after December 31st, 2020.

2.1.5 Trade models

A distant-consumer perspective to analyse deforestation using trade models helps study the location of the possible impacts, associating consumption patterns with production (Kastner et al., 2011). More specifically, trade models allow identifying the risk that a country represents (from a demand-based perspective) to another one (from a production-induced perspective) in terms of deforestation (Pendrill et al., 2019b). The multi-region input-output analysis

(MRIO) and the physical trade flows approach (PTF) are the most commonly used methods to account for land and environmental impacts embedded in the trade of commodities (Brulein, 2021; Pendrill et al., 2019b; Ye et al., 2022; Hamilton et al., 2018). The main difference between both models is that they work with different data (PTF is based on physical quantities and the MRIO in monetary units) and different end-users (Pendrill et al., 2019b). For instance, one approach might identify a country as a net exporter and the other one as a net importer, as in the case of China's trade of agricultural products (Kastner et al., 2014).

The PTF method uses international trade data to display direct trade between producing and importing countries. It accounts for land embodied in trade by finding equivalents for primary crops in order to express trade flows (Kastner et al., 2014). Then, it allocates land requirements for each ton of agricultural commodity, based on country-specific parameters, such as crop yield (Hubacek and Feng, 2016). On the other hand, the MRIO incorporates both direct and indirect linkages, connecting different sectors and industries along supply chains (Wen and Wang, 2019) and displaying monetary flows within and between them (Hubacek and Feng, 2016). This approach traces biomass product flows up to the trade of non-biomass products (Kastner et al., 2014).

2.2 Theoretical approach

2.2.1 A telecoupling perspective

Many fundamental global sustainability challenges, such as distant interactions between coupled human and natural systems, are strongly associated across organisational levels, space and time (Liu et al., 2015). These coupled systems are integrated systems where people interact with natural components (Liu et al., 2007) through flows of capital, labour, information and symbolic elements (e.g., values, norms) that tie together coupled systems over distances (Garret and Rueda, 2019). In this line of thought, what happens in a particular system might affect that system and other systems that could be either distant or proximate (Liu, 2017). Hence, the demand and consumption of some commodities in developed countries can be linked to deforestation, biodiversity loss, GHG emissions, changes in hydrological cycles and soil erosion in tropical forests (Hoang and Kanemoto, 2021).

The telecoupling concept, as described by Liu et al. (2013), is an umbrella concept that refers to socioeconomic and environmental interactions between distant coupled human and natural systems, which could be, e.g., trade, flows of ecosystem services, spread of invasive species, migration. These coupled systems are integrated systems that address the interactions and feedbacks between human and natural systems, following an interdisciplinary approach (Liu et al., 2007). Each system consists of flows (of materials, energy and information), agents (who facilitate or prevent those flows), causes and effects, and they can be referred to as spillover, sending or receiving systems, depending on the direction of the flows between them (Liu et al., 2017).

Figure 1 shows the application of the telecoupling framework of the trade in FRCs produced in tropical countries and exported to/imported by EU countries, as based on a literature review. Since this study addresses deforestation risk in tropical countries from an international trade perspective, the flows were defined as the provision (production and export) and demand for FRCs (import). The sending system consists of tropical countries and the different actors that are part of it, namely producers, companies and institutions involved in the production and trade in FRCs. On the other hand, the receiving system is composed of EU countries and their consumers, institutions and importing companies. Spillover systems are not included because of the complexity of the analysis. It is assumed that each tropical country could represent a spillover system for another tropical country. At the same time, non-EU countries importing FRCs (e.g., China, India) could also be spillover systems, as they can be affected or affect the interactions between tropical countries and EU countries.

As for the causes, they are market-driven in both systems. For instance, part of the increased production of soybeans in Brazil in the last few years could be associated with drought events in the USA and the subsequent decrease in their yields, which created a market opportunity for Brazil to produce and export more soybeans to fill that shortfall (Song et al., 2021). So, even if the cause behind the observable cause is not market-driven, what pushes producing countries to produce is always the market. On the other side, what drives this production is basically consumers' choice and the trade context surrounding it. Regarding the effects, they go from socioeconomic to primarily environmental, given the nature of the interactions between systems. The telecoupling framework is relevant for this study to understand the dynamics rooted in FRCs trading systems and their further consequences in terms of deforestation risks derived from the trade flows of such commodities in tropical countries.

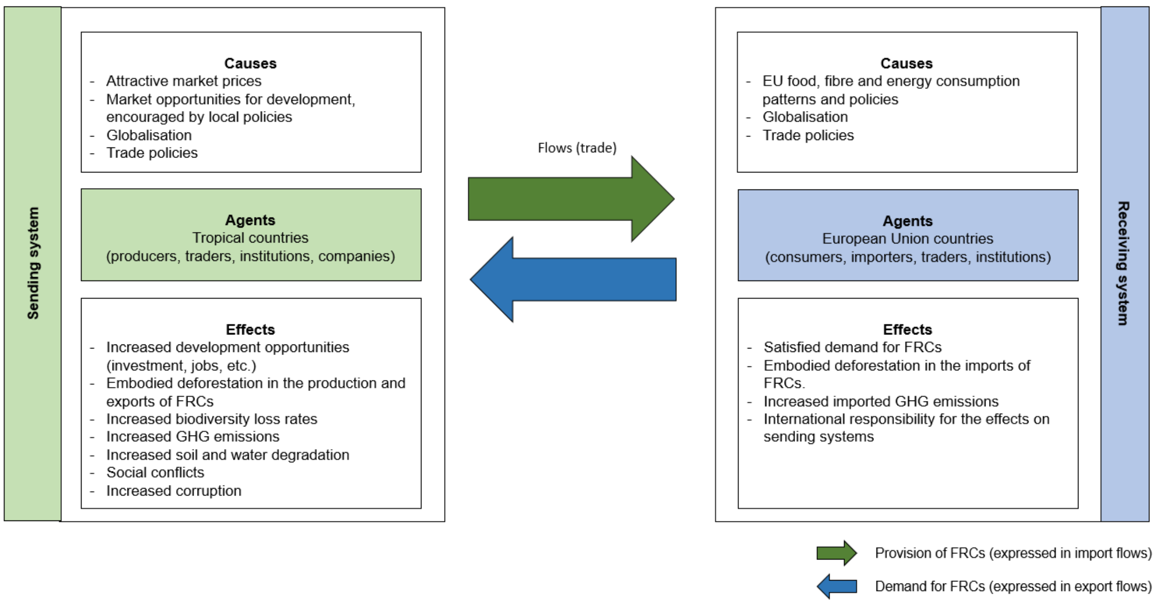


Figure 1. Components of the telecoupling framework applied to the trade in FRCs produced in tropical countries and exported to/imported by EU countries. Own elaboration.

3. Research methodology

This section presents the methodology that was followed in order to answer the research questions and address objectives set as part of this study. It includes the research approach, the scope, and the data collection methods used, with a detailed description of the steps taken and the sources of information used.

3.1 Research approach

The integrated environmental and socioeconomic framework for assessing deforestation risks associated with the production and trade of FRCs in Europe was built based on a literature review and gathers all the relevant information surrounding the topic, including the variables and indicators associated with deforestation risks attributed to commercial agriculture in tropical countries and a social network approach. Moreover, the proposed framework intends to be helpful to operators, traders, researchers and competent authorities who work with FRCs.

In order to apply the framework, it is necessary to follow some steps that would allow a comprehensive approach to the research problem. First, information on the production and trade of FRCs was collected from FAOSTAT and analysed based on physical trade amounts. The dataset covers 18 years (2003-2020), and considers trade flows to and from the EU in terms of EU imports from tropical countries (i.e., EU countries as reporter countries and tropical countries as partner countries). Trade between tropical countries was also analysed in the case of non-producing countries exporting FRCs to the EU. Likewise, in the case of producing countries whose production is lower than the exports in specific years. With the detailed trade matrix, it was possible to rank the main exporting countries based on import amounts from the EU to assess the dynamics further and allocate deforestation risk to each FRC. The study uses publicly available remote sensing data on deforestation in tropical countries to analyse tree cover loss over the assessed period, considering lag and allocation periods for the products. Information on land use and land cover is also used to analyse deforestation risk. This point is further explained in section 3.4.2.

Furthermore, key actors (i.e., countries) identified from trade databases (producers, exporters and importers) and the trade patterns they exhibit are assessed through a social network analysis (SNA). This way, it is possible to understand the role of the EU in the trade of FRCs and then link it to forest loss in tropical countries. The information is presented in figures displaying trade flows (i.e., imports from the EU) over the assessed period (2003-2020).

3.2 Scope

The study focuses the assessment phase on four agricultural commodities: cocoa, coffee, oil palm and soy. These commodities were chosen based on the list of relevant commodities and relevant products provided in the EUDR (see Annex 1 for the full list), and were analysed based on production and trade data from 2003 to 2020 (18 years). The research targets agricultural crops, excluding livestock and forestry products, as they follow different production and trade patterns. Likewise, it was decided to exclude chocolate and coffee extracts from the analysis. The nature of these products (and, therefore, their impact associated with deforestation) varies depending on the proportion of primary product used to produce them, which is not specified in the EUDR, nor distinguished in the databases that were consulted.

Furthermore, some decisions were made based on data availability in order to get the final list of FRCs for this study. This, since FAOSTAT does not provide information for all the products and by-products considered in the EUDR, and some products could not be linked with those that were available. For instance, coffee husks are not included in the study, even though trade data are available. This is because coffee husks derive from coffee cherries, and the first production item available for coffee was green coffee, which is already a product derived from coffee cherries, making it inaccurate to go backwards in the processing flow. The final list of FRCs assessed in this research is presented in Table 1.

The countries considered in the analysis are: i) EU countries and ii) tropical countries. The latter are those that lie within the tropical domain, which, based on the latest FAO FRA (FAO, 2020), accounts for 45 % of the world's forests. In this sense, and in order to keep consistency with other studies and publications, the list of tropical countries is based on the countries table presented in the FAO FRA 1990 (FAO, 1990). Besides the original list, China, Mauritius and South Sudan were added since they also have a considerable share of tropical forests in their territories, yet were not included in the FAO FRA 1990 scope. This accounted for a total of 93 countries: 41 in Africa, 19 in Asia and the Pacific and 33 in Latin America and the Caribbean. After a first data screening, only the top 15 exporting countries (based on import amounts from the EU) for each FRC were considered in the further steps of the study, reducing the list to a total of 45 countries (Annex 2).

Table 1. List of the 12 FRCs assessed in the study.

	FRCs	FAO Code
Cocoa	Cocoa, beans	661
	Cocoa, paste	662
	Cocoa, butter	664
	Cocoa, powder and cake	665
Coffee	Coffee, green	656
	Coffee, roasted	657
Oil palm	Oil, palm	257
	Oil, palm kernel	258
	Cake, palm kernel	259
Soybean	Soybeans	236
	Oil, soybean	237
	Cake, soybeans	238

3.3 Data collection

Since this research aims to provide the most up-to-date information available as part of an analysis of the last two decades, data were gathered directly from publicly available sources, such as FAOSTAT, the FRA 2020 and Hansen et al. (2013). The data were condensed into two final datasets: one for production and trade (3.3.1) and another one for deforestation and land use (3.3.2). All the information was verified considering the metadata description available for each data source.

3.3.1 Production and trade

In order to build a dataset on production and trade, information was collected from the FAOSTAT website, as presented in Table 2. All the data is presented in tonnes to keep consistency using the same measurement unit. It was deemed to be necessary to collect information on trade between tropical countries after preliminary screening of the data showed that non-raw-material-producing countries (e.g., Burkina Faso) were exporting processed products (e.g., soybean oil), which can be explained by sourcing dynamics taking place in some countries. Considering the trade of FRCs within the tropics allows allocating deforestation where it actually corresponds and not over-counting it in countries that only process raw material and do not entail forest loss in their territories but somewhere else.

Additionally, the data requirements presented in Kastner et al. (2011) were considered for the input data in the assessment. In this sense, technical conversion factors for agricultural commodities were gathered to convert secondary products into primary product equivalents (more details on this are available in Annex 3). This way, it was necessary to convert processed products in order to quantify raw material inputs needed to produce them and thus identify possible links to deforestation dynamics associated to them. Moreover, FAOSTAT provides data on area harvested, yield and production of each relevant commodity, but not of each relevant product. The purpose of this conversion was to allow the allocation of tonnes of a commodity produced per hectare, despite of their level of industrialisation. This way, all the FRCs presented in Table 1 were assessed in terms of primary product equivalents (ppe).

For instance, using conversion factors provided by UTZ (2017), 100 kilogrammes of cocoa beans (100 % cocoa beans) are used to produce 82 kilogrammes of cocoa paste; hence, the conversion factor to calculate the area needed to produce 82 kilogrammes of cocoa paste, in terms of cocoa bean equivalent (the primary product), would be 0.82. Knowing this, the area needed to produce them is calculated using yield data (section 3.4.4 for further details). Kastner et al. (2011) followed a different methodology, which was based on caloric contents, but for this study it was found appropriate to focus on mass balances, as they can be adapted worldwide to each specific context. These mass balances work with input and output ratios, considering primary products as input quantities (100%), and linking them with pruduct-specific output quantities (%). Even though double-counting cannot be avoided using these conversion factors, it is essential to state that the final deforestation matrix reflects the deforestation risk associated with the overall production of every product in each trading relationship.

Concerning the datasets retrieved from FAOSTAT, some information gaps regarding products and countries were observed. For instance, some countries have not reported official data, thus, only FAO estimations are available. In other cases, data is not available for certain years. All the issues were found to generate data inconsistencies when trying to compare production amongst countries. Hence, it was decided to cover the data gaps whenever sound estimations were possible based on data available in other years. For example, i) whenever there was a gap between years reporting the same quantity, that same quantity was considered also for the gap, or ii) whenever there was a gap between years that were growing/decreasing in the same ratio (e,g., 200, 250, *gap*, 350, 400), the same ratio was used for the gap (e.g., gap is 300). Cases where it was not possible to find a logic were left as they were found.

Table 2. Datasets utilised to build the production and trade dataset for the analysis.

Source dataset name	Contains information on	Region	Years covered
Crops and products, FAOSTAT	Area harvested, yield and production per commodity and per all primary crops	TC*	2001 - 2020
Trade matrix, FAOSTAT	Total import and export quantities per commodity per reporter and partner country	EU-TC and TC-TC	2001 - 2020

*TC: Tropical countries.

3.3.2 Deforestation and land use

The data set by Hansen et al. (2013) on deforestation was used on the Google Earth Engine platform to access and explore remote sensing information on tree cover loss between 2001 and 2021 (20 years), based on tree cover from 2000. With that, it was possible to observe deforestation patterns among tropical countries. Hansen et al. (2013) define “tree cover” as all vegetation higher than 5 meters that take the form of natural forests or plantations under a given canopy cover, while “tree cover loss” is defined as the replacement disturbance or the complete removal of tree cover at a given canopy cover. In this study, the chosen canopy cover was ≥ 30%, and the data on tree cover loss was used to represent deforestation. The data derived from the script (Version 1.9) was collected from the Global Forest Watch (2022), which was readily available. According to them, tree cover loss could result from human activities and natural causes, such as wood extraction, land clearing for other land uses, storms and fires.

Data on land use and land cover were collected from FAOSTAT, as described in Table 3. Rates based on the following and previous three years were used to estimate the data for the years 2000 and 2020, respectively. This step was necessary to cover the entire assessment period showing the transitions between one year and the following (e.g., 2000-2001) since these are linked to land-use changes and to the equations used to allocate deforestation risk to the production of FRCs (further explained in section 3.4.2).

Table 3. Datasets used to build the deforestation and land use dataset for the analysis.

Source dataset name	Contains information on	Years covered
Land use, FAOSTAT	Cropland, land area under permanent meadows and pastures, planted forest	2001 - 2019
Land cover, FAOSTAT	Grassland	2001-2019
Deforestation, Hansen et al. (2013); Global Forest Watch (2021)	Deforestation per year	2001 - 2020

3.4 Data analysis

Data were processed using different methodologies and tools, which are described below. Data analysis was done using Excel matrices, Google Earth Engine and Gephi 0.9.2, a specific SNA software.

3.4.1 Initial data screening

A preliminary data screening was carried out to identify the top 15 exporting countries for the FRCs considered in the study during the period 2003-2020. The

FAO trade matrix based on EU countries as reporting countries and tropical countries as partner countries provided essential information on the import amounts per each year and product for every importer and exporting country. The total EU imports were added up to get the total amounts (tonnes) imported from each tropical country and product to the overall EU market. This way, it was possible to identify the countries that exported the largest amounts of FRCs into the EU for each of the 12 products considered. The top 15 exporting countries for each FRC were selected and used in the subsequent analysis (the complete list of selected countries and their exported quantities per FRC is available in Annex 4).

The reasoning behind doing an initial screening using the FAO trade matrix and not the data on the FAO crops and products spreadsheet is based on the following assumptions: i) not all tropical countries necessarily export what they produce to the EU, ii) not all tropical countries export as much as they produce, but some of them export more than they produce, given that iii) some countries source themselves with FRCs from other tropical countries and then re-export them (after having processed them or not) into the EU market.

Considering the last point, a second screening was carried out based on the top 15 countries for each FRC. For this purpose, production (production values and area harvested) and trade (imports and exports) values of each tropical country whithin the top 15 exporters for each FRC were used. This screening sought to identify indicators of sourcing between tropical countries, based on the following: i) raw material production values (in tonnes) minus overall export values (in tonnes) should be greater or equal to zero, and ii) should the previous result be a negative value, then sourcing from other tropical countrie(s) is expected and, thus, it is necessary to analyse and cross-check the data in the FAO trade matrix based on tropical countries as both reporter and partner countries. This last step allowed identifying where deforestation is occurring and ti allocate it properly to the top exporters.

3.4.2 Trade model and trade flows

Regarding the existing approaches to analysing land use embedded in trade flows, Kastner et al. (2014) found that the multi-region input-output analysis

(MRIO) and the physical trade flows approach (PTF) show very different results from one another. This led them to question the accuracy of MRIO in delivering credible results. Nevertheless, Hubacek and Feng (2016) stated that researchers should decide on which method to use based on their research purposes. They determined that MRIO is more fitting for tracking global supply chains and linking them to embodied land in trade when performing the analysis of land-use drivers, while PTF is more limited to agricultural and forestry products, computing for land-use for each commodity but not accounting for highly processed products. For this study, an approach based on (but not equal to) PTF was used since the relevant products in the EUDR still conserve the characteristics of the primary commodities, and re-exports within the EU are not applicable given the aim of the research: the new regulation would ban direct trade of FRCs. Hence, direct exporters (tropical countries) and importers (EU countries) are considered the central agents in the scenario being assessed here, even though re-exports might occur later on in the supply chain. In any case, if a EU country imports an FRC directly from a tropical country, it is held accountable for the deforestation risk embedded in its production, even if this importing country is not the final consumer. Furthermore, the approach used in this research considers that FRCs are not causing deforestation anywhere but in tropical countries. It uses the detailed trade matrix from FAOSTAT as the starting point to allocate deforestation risk to each commodity traded during the assessed period.

Collected data were analysed both in terms of production and trade, focusing on the producing/exporting countries identified in the preliminary screenings, as they were expected to evidence more extensive deforestation in their territories. In the case of the assessment of trade between tropical countries, only those who exhibited negative balances in terms of production (i.e., exports to the EU overpassing production amounts) were analysed. In this sense, a matrix containing information on production, area harvested, yield and exports to the EU (in ppe) was built. This matrix included information on every commodity per year and per country and was the point of departure for attributing forest loss to EU exports. It is essential to mention that, since data were handled in terms of ppe (due to reasons already reported in 3.3.1), some under and over-estimating could have taken place in the calculations, so, even though it did not happen in all cases, the countries' imports from other tropical countries were expected to fill the gap between their domestic production and their exports to the EU.

For instance, country A shows a deficit of cocoa (in ppe) in its balance, but only for cocoa beans and cocoa powder and cake (not in ppe). So it imports cocoa (in ppe) from country B and covers its deficit with those imports, but they actually correspond to cocoa butter (not in ppe). In this case, there is a mismatch. However, since there was no other way to decide which imports would correspond to which product and which country (in case the imports were larger than the deficit), all exporting countries were capped among all their exports to the EU (in ppe) to cover the deficit. This even distribution was also applicable to cases where the imports were insufficient to cover the deficit.

3.4.3 Deforestation risk

Commodity deforestation risk is expressed in terms of deforested hectares attributed to a country (in this case, an EU country) that imports an FRC from a tropical country in a given year. It estimates the exposure to deforestation that an importing country could have taken part in along its supply chain, comparing the production area to the deforestation that happened during the allocation period of a given FRC, and that is directly linked with its production (Trase, 2020).

It is important to note that deforestation and production do not happen simultaneously and that allocation and lag periods should be part of the analysis (Goldman et al., 2020). Trase (2020) defines the allocation period as the time between initial deforestation and the production of the commodity for which the area was deforested, while the lag period corresponds to the minimum time required to harvest a given FRC after forest clearance. This is done under the assumption that i) sometimes, first plantings of commodities for production may be delayed after forest clearance, ii) remote sensing could fail at detecting immediate changes, and iii) some forests could be cleared for mere speculation, but no actual production is taking place during the initial years (zu Ermgassen et al., 2020a). Moreover, some legal procedures could also be required before planting, and that might require time.

Researchers investigated allocation and lag periods in the last few years, however, results are currently only available for soybeans (Fehlenberg et al., 2017; Song et al., 2021; zu Ermgassen et al., 2020b). This crop's production is usually preceded by a cattle ranching period; hence, for this study, a 3-year interval will be used as the allocation period, based on Song et al. (2021). Regarding cocoa, coffee and oil palm, these commodities evidence different production patterns since harvest could occur years after they were first planted because they have to reach maturity to start producing fruits (Goldman et al., 2020). These crops are assumed to be planted right after the deforestation event; therefore, lag periods are attributed to each of them, as shown in Table 4 and illustrated in Figure 2.

These allocation and lag periods were taken into account for the analysis of deforestation, considering that, if land clearing and planting of cocoa, coffee or oil palm happened in. e.g., 2001, which is the first year considered in the deforestation analysis in this study, harvest actually happened in 2003. The same criteria is applicable in the case of soybean, for which the allocation period is three years as well, though planting occurs later in time and corresponds to a lag period of one year. It is also assumed in the study that these initial periods are followed by yearly production. In any case, production in a given year is related to deforestation events three years before (e.g., production in 2006 is related to deforestation in 2004).

Table 4. Allocation and lag periods considered for each FRC.

FRC	Allocation period (years)	Lag period (years)	Sources
Cocoa	3	3	Kuwornu et al., 2011; Lopes and Pires, 2014
Coffee	3	3	Krishnan, 2017; Amarasinghe et al., 2015
Oil palm	3	3	Uning et al., 2020; Maluin et al., 2020
Soybean	3	1	Song et al. 2021

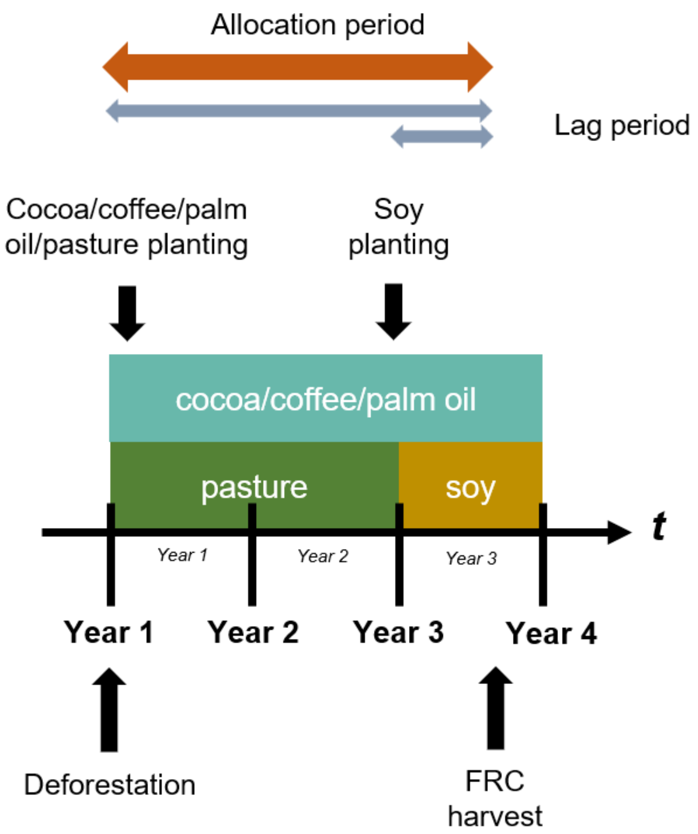


Figure 2. Allocation and lag periods for the production of FRCs considered in the study. Own elaboration, adapted from Trase (2020).

In order to attribute deforestation to the production of FRCs, the land balance model presented in Pendrill et al. (2019b) was used to calculate forest loss Δ*F* in a given year (t) in proportion to their relative area expansion, namely expanding cropland (Δ*FCL,t)*, expanding permanent pasture (Δ*FPP,t)*, and expanding forest plantations (Δ*FFP,t)*, following equations (1), (2) and (3). In this sense, *GPLt* stands for gross pasture loss, and *CLEt, PPEt, and FPEt* stand for the expansion of cropland, permanent pastures (land under permanent meadows and pastures) and forest plantations, respectively. If these areas are shrinking instead of expanding, the values are zero, whereas *GPLt* takes only negative values as positive and does not consider any area expansion. All the variables are presented in hectares. The expanding areas and the loss (in the case of *GPLt*) were computed by simply calculating the difference between values for a certain year and values referred to the previous one (e.g., 2002-2001). These calculations were done for the whole period 2000-2020 to cover all the tree cover loss data from Hansen et al. (2013).

This way, forest loss is attributed to the expansion of cropland, pastures and forest plantations. At the same time, if forest loss exceeds the expansion of those land uses, then forest loss could be attributed to other causes (e.g., infrastructure, mining), as shown in Figure 3. Equation (4) was used to further attribute forest loss due to cropland expansion to the expansion of specific crops (i.e., cocoa, coffee, oil palm and soybean) per year (*ΔFCL,i,t)*. For this purpose, the area harvested expansion of all 156 primary crops included on FAOSTAT (e.g., maize, paddy rice, strawberries) and the area harvested expansion (*AHE,t)* of the specific commodity (*i*) were used. In this case, the calculations contemplated the three-year allocation period for all primary crops and FRCs. This way, the deforestation and land use matrix was built starting from 2001 (2000-2001) for all variables associated with land use and forest loss, from 2003 (2002-2003) for area harvested expansion of all crops.

$$\Delta FCL,t = MIN[MAX[CLEt - GPLt; 0];\ \Delta Ft * \frac{MAX[CLEt - GPLt; 0]}{MAX[CLEt - GPLt; 0] + PPEt + PPEt} \quad ,(1)$$

$$\Delta FPP,t = MIN[PPEt;\ \Delta Ft * \frac{PPEt}{MAX[CLEt - GPLt; 0] + PPEt + PPEt} \quad ,(2)$$

$$\Delta FFP,t = MIN[FPEt;\ \Delta Ft * \frac{FPEt}{MAX[CLEt - GPLt; 0] + PPEt + PPEt} \quad ,(3)$$

$$\Delta FCL,i,t = \ \Delta FCL,t * \frac{AHE,i,t}{\sum_i AHE,i,t} \quad ,(4)$$

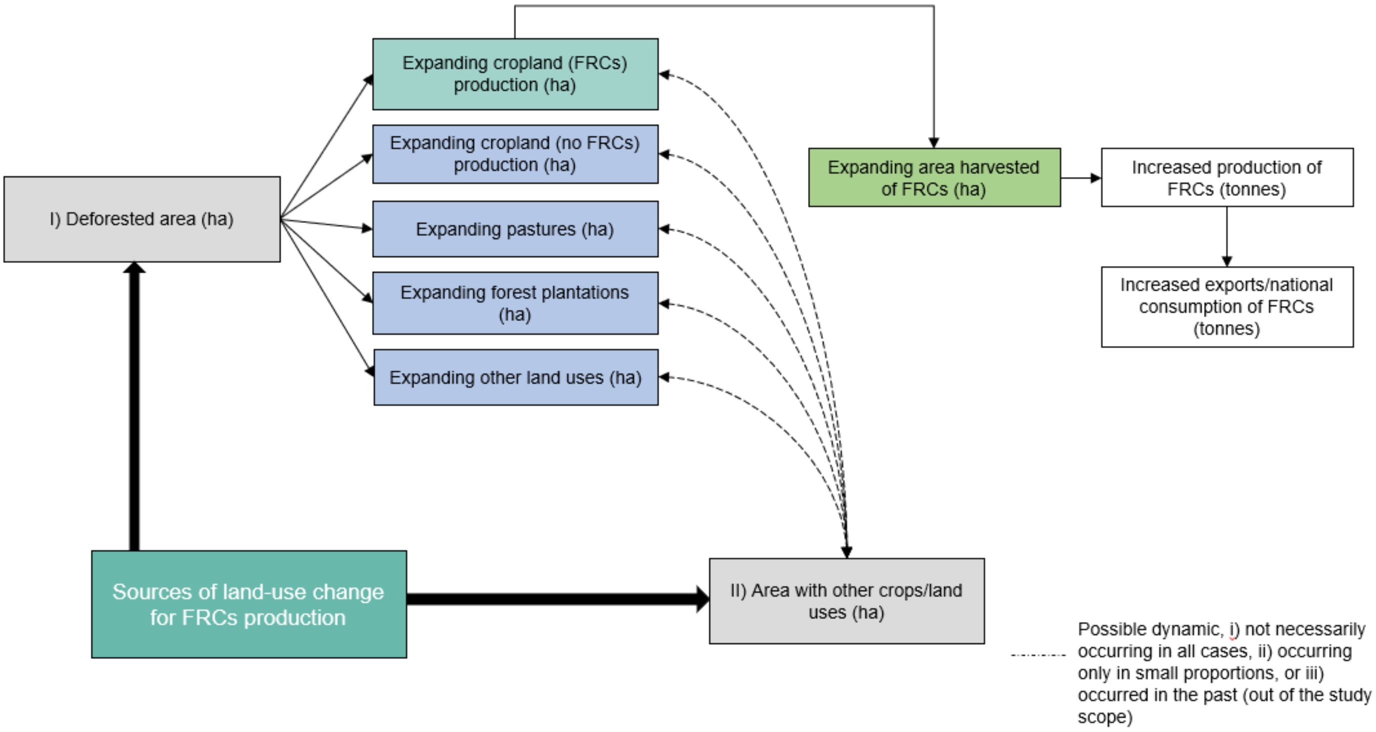


Figure 3. Sources of land-use change and its association with deforestation and production of FRCs.

3.4.4 Attribution of deforestation risk in the trade matrix

Once forest loss attributed to the expansion of cocoa, coffee, oil palm and soybean was calculated, it was possible to allocate it to EU exports. For this purpose, data on imports from the EU ($EU_{,i,t}$) in tonnes and yield ($Y_{,i,t}$) in tonnes/ha of each FRC and country were used to account for the area harvested required to produce them ($AHEU_{,i,t}$), as shown in Equation (5). After this, forest loss attributed to exports to the EU for each FRC ($\Delta FEU_{,i,t}$) was calculated using data on the area harvested to produce the exported amounts ($AHEU_{,i,t}$), the area harvested for each commodity ($AH_{,i,t}$) and the forest loss area attributed to each crop expansion ($\Delta FCL_{,i,t}$), as presented in Equation (6).

A three-year allocation period was also taken into account for this step, so these results matched the previous results on the deforestation and land use matrix starting in 2003, as shown in the example in Table 5.

$$AHEU,i,t = \frac{EU,i,t}{Y,i,t} \quad , (5)$$

$$\Delta FEU,i,t = \Delta FCL,i,t * \frac{AHEU,i,t}{AH,i,t} \quad , (6)$$

Table 5. Representation of the input data over time for calculating the different variables.

		Year		
Country	**Item**	**2003**	**…**	**2020**
Country A	ΔF	2001		2018
Country A	$\Delta FCL,t$	2000-2001		2017-2018
Country A	AH,i,t	2003		2020
Country A	AHE,i,t	2002-2003		2019-2020
Country A	Σ_i AHE,i,t	2002-2003		2019-2020
Country A	EU,i,t	2003		2020
Country A	Y,i,t	2003		2020

After getting the overall results regarding deforestation attributable to each country's exports to the EU, the data was proportionally distributed amongst EU imports in the detailed trade matrix from FAOSTAT. All the data were managed in terms of primary product equivalent; thus, the distribution of deforestation risk hectares was done following the same logic. The abovementioned could have led to underestimating or overestimating deforestation risks attributable to third parties (tropical countries sourcing other tropical countries). This is since data on single commodities (e.g., cocoa butter, palm oil, soybean cake) were not considered for these calculations but data on the overall category (e.g., cocoa, oil palm, soybean). Despite this, managing the data in terms of primary product equivalents was believed to be the most efficient and effective way to reach the results.

3.4.5 Social network analysis

Social network analysis (SNA) is a methodology widely applied in social sciences. It allows studying social networks to grasp how agents interact and the implications of these complex interactions (Durland and Fredericks, 2006). SNA helps identify contents and patterns within agents (e.g., who are the most influential actors, which of them are not well-connected) by using statistics and algorithms (Tabassum et al., 2018). The graphical illustration of SNA are sociograms, where nodes represent agents and these agents' interactions or ties are represented by lines. Besides its vast use in social sciences, environmental and socioeconomic sciences have also begun to use SNA to study phenomena such as the spatial interactions of CO_2 emissions and urban agglomeration (Song et al., 2019), metacoupled systems and global soybean trade (Schaffer-Smith et al., 2018), market trends in pistachio trade (Bui-Klimke et al., 2014), the responses of community structures of herbivores species to environmental change (Meise et al., 2019). Furthermore, SNA is being increasingly used in the natural resources management arena, for it allows the identification of stakeholders in decision-making processes (Prell et al., 2016).

The software Gephi 0.9.2 was used to create a visual network to represent the relationships and interactions between tropical countries (producers/exporters) and EU countries (importers), highlighting key players (producers/exporters and importers) and relevant changes in their patterns. For this purpose, nodes and edges spreadsheets were prepared based on the trade data compiled for the previous analyses from the FAOSTAT databases. The edges spreadsheets included traded amounts as the feature “weight”, besides exporting and importing countries as features “source” and “target”. After running some statistic functions for each network, centrality measures were gathered to show how the actors behave in the FRCs trade structure and identify their importance within the network. The analysis was focused on: i) closeness centrality and ii) eigenvector centrality.

Closeness centrality is referred to the influence a node has on reaching others (Saqr et al., 2020) and its efficiency in exchanging information (i.e., imports/exports of FRCs) with them (Lü et al., 2016). This measure assesses a node's importance based on its position with respect to other nodes in the network, suggesting that the more central a node is, the easier it is to spread information (Wehmuth and Ziviani, 2013). On the other hand, the eigenvector centrality especially focuses on the centrality scores of the node's connections, reflecting how selective the node is and the quality of its collaborations in terms of influence, engagement and associations (Saqr et al., 2020). In other words, this measure intends to grasp a node's importance by also looking at its neighbour's importance (Das and Pal, 2018).

4. Results

In this chapter, the results of the data analysis are presented. Section 4.1 provides a summary of the integrated framework for assessing deforestation risks associated with the production and trade of FRCs in Europe, while Section 4.2 presents the results of data analysis based on the final datasets – i.e., production and trade, and deforestation and land use–, and Section 4.3 shows the results from the SNA. More detail on Section 4.2 is included in annexes 4 and 5.

4.1 The integrated framework

The theoretical background section of this research (Section 2) presented a compilation of the topics surrounding deforestation risks attributed to trading FRCs in the EU market, establishing the framework for the subsequent analysis that was carried out, as presented in the research methodology (Section 3). In this sense, Figure 4 shows the skeleton behind the assessment of FRCs and the issue of unsustainable supply chains that embody the deforestation of tropical forests. Table 6, on the other hand, provides a summary of the main concepts.

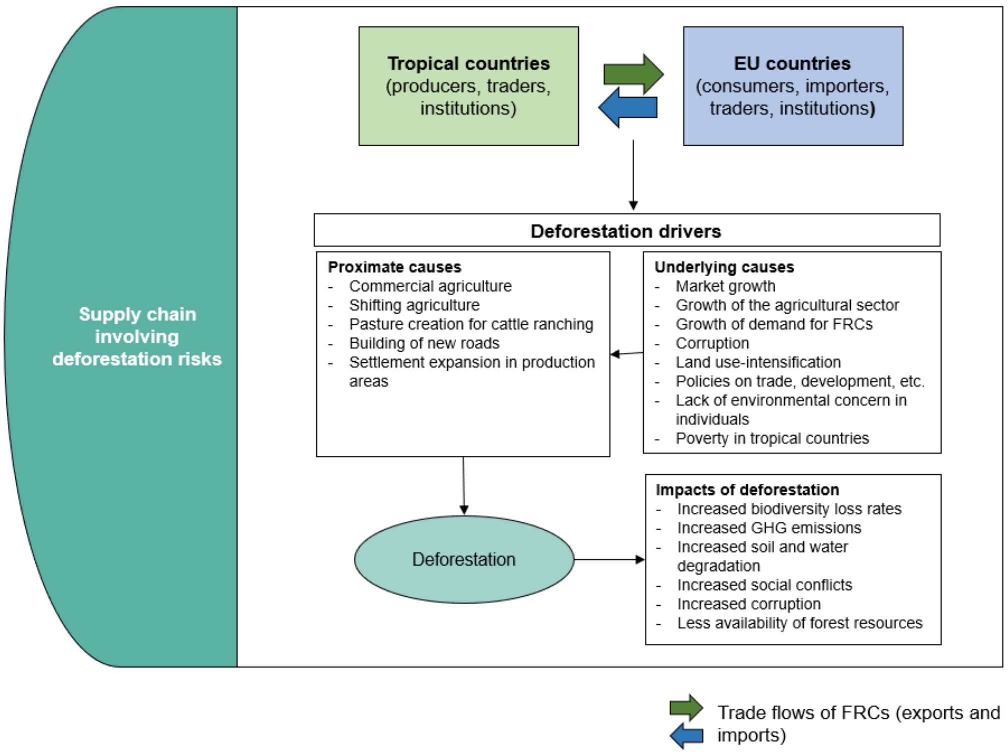


Figure 4. An integrated framework for assessing deforestation risks associated with the production and trade of FRCs in Europe. Own elaboration.

Table 6. Concepts used for the integrated framework for assessing deforestation risks associated with the production and trade of FRCs in the EU.

Concept	Description
Deforestation	Loss of forest area in tropical countries
Supply chain involving deforestation risks	The sequence of processes to produce and trade a commodity that potentially causes deforestation in tropical forests at the beginning of the FRC's allocation period
Tropical countries	Countries that lie within the tropics
EU countries	Countries that are part of the European Union
Producers	Producing countries where deforestation takes place for the production of FRCs
Traders	Intermediary (country) buying and selling FRCs, whether from tropical countries to EU countries or from EU countries to other EU countries
Importers	Countries directly purchasing FRCs from tropical countries
Consumers	Final consumers of FRCs
Institutions	Public and private institutions involved in economic and political matters concerning FRCs
Deforestation drivers	Economic, institutional, political and other influential factors that cause deforestation (Geist and Lambin, 2001)
Proximate causes	Human activities (i.e., agricultural expansion, wood extraction and infrastructure expansion) that directly cause deforestation (Geist and Lambin, 2001) in tropical countries
Underlying causes	Variables (e.g., social, cultural, technological) that support the conditions for proximate causes to exist (Geist and Lambin, 2001), both from the supply-side and the demand-side (tropical countries and EU countries, respectively)
Impacts of deforestation	The economic, social and environmental consequences of forest loss in tropical countries

4.2 Deforestation risk embodied in the trade of forest risk commodities in the EU

As it can be observed in Figure 5, deforestation is attributed to three main categories: expanding cropland, expanding forest plantation and expanding permanent pasture, which represent 21.3, 14.5 and 7.6% of the total forest loss in 2001-2020, respectively. The sum of those values is below the total value of forest loss for each year, which implies forest loss is also due to other drivers. The total forest loss in those 45 countries considered for this study reached 171,495,456 ha in the 2001-2020 period. Forest loss attributed (FLA) to expanding cropland represented 36,595,022 ha of forest loss, an area between the size of Germany and Japan, while FLA to expanding forest plantations and expanding pastures accounted for 24,798,531 ha and 13,076,670 ha, respectively. Over that period, the countries that evidenced more FLA to expanding cropland were Indonesia (12,458,095 ha), Brazil (6,212,938 ha), Tanzania (2,578,678 ha), Venezuela (1,842,462 ha) and Bolivia (1,813,462 ha). Detailed results are presented in Annex 6.

It is interesting to note that cropland expansion has occurred not only in deforested areas but in areas converted from other land uses. Nevertheless, some expansion peaks coincide with forest cover loss peaks; FLA to expanding cropland appears to be reasonably related to those events. Among the peaks, 2017 represented the highest forest loss of the assessed period, accounting for 14,348,296 ha. On the other hand, 2016 and 2017 showed the highest forest loss due to cropland expansion, with 2,714,473 and 2,535,696 ha, respectively.

Concerning the FRCs assessed, based on the production of primary products in the top 15 exporting countries (i.e., green coffee, cocoa beans, oil palm fruits and soybeans), Figure 6 shows the forest loss attributed to their area harvested expansion during 2003-2020, corresponding to deforestation in 2001-2018, which adds up to 34,431,958 ha. From this, 5,128,711 ha are attributable to EU imports of the 12 FRCs considered in this study (for more details, see Annex 7). The data showed that the tropical countries that embedded the most significant deforestation numbers in their FRCs exports to the EU during 2003-2020 were Indonesia (2,884,110 ha), Brazil (762,291 ha), Malaysia (440,282 ha), Paraguay

(175,929 ha) and Colombia (131,903 ha). Based on the guide to interpret correlation coefficients presented in Akoglu (2018), the FLA to oil palm expansion and FLA to soybeans expansion are strongly correlated with the overall FLA to expanding cropland, whereas FLA to cocoa expansion and FLA to coffee expansion are moderately and weakly positively correlated, respectively (Table 7).

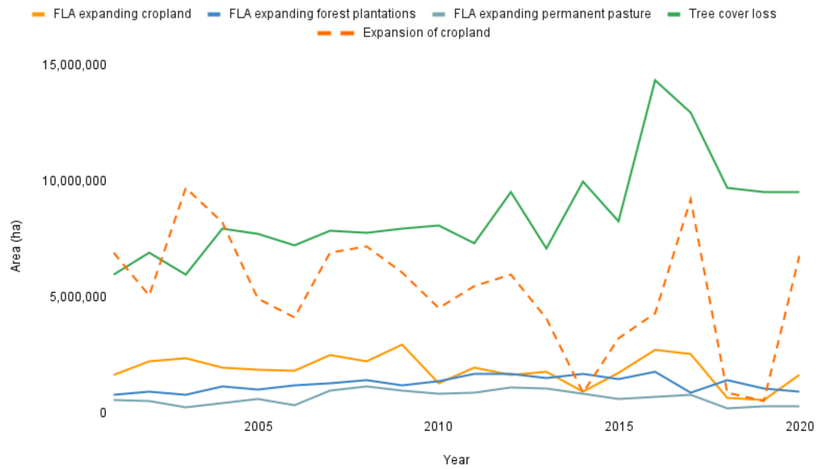


Figure 5. Forest loss attributed (FLA) to expanding cropland, expanding forest plantation and expanding permanent pasture, tree cover loss and expansion of cropland during 2001-2020.

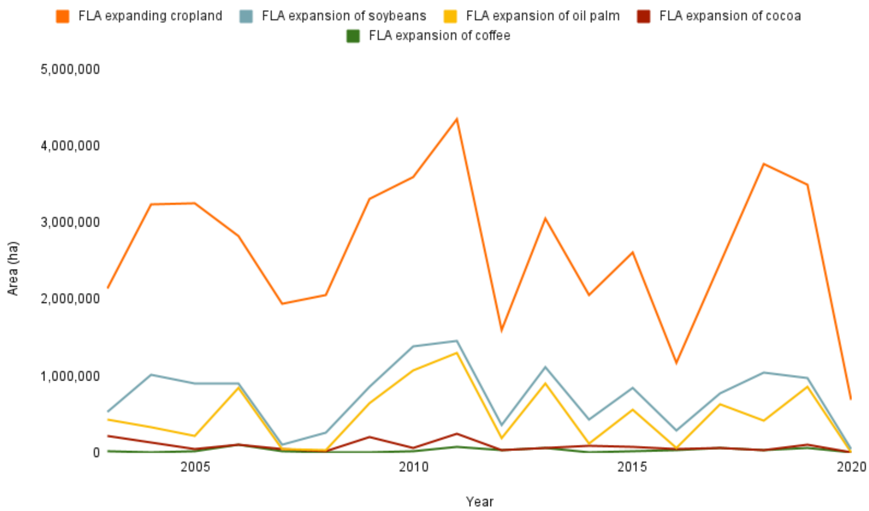


Figure 6. Forest loss attributed (FLA) to the area harvested expansion of soybeans, oil palm fruit, cocoa beans and green coffee from 2003 to 2020.

Table 7. Pearson correlation analysis of forest loss attributed (FLA) to cropland expansion and the area harvested expansion of FRCs (2003-2020).

	FLA expansion of coffee	FLA expansion of cocoa	FLA expansion of oil palm	FLA expansion of soybeans
Expanding cropland	0.26	0.37	0.59	0.40

The following sections (4.2.1, 4.2.2, 4.2.3 and 4.2.4) present the results separately for each FRC assessed in this study and are focused on showing the deforestation risk associated with EU imports. This, since grouping them would overcount the actual deforestation risk. For instance, when considering soybeans, soybean cake and soybean oil, according to the conversion factors utilised here, if an EU country imported "soybeans", the deforestation risk attributed to this FRC actually corresponds to the area required to produce those beans. On the other hand, if an EU country "A" and an EU country "B" import, separately, "soybean cake" and "soybean oil", deforestation has to be attributed to both of them, even though the primary product to produce those commodities might have come from the same land.

Section 4.2.2 presents the deforestation risk dynamic (from 2003 to 2020) attributed to the whole EU's imports from tropical countries according to the methodology used in this study (focusing on the top 15 exporters of each FRC). Likewise, the SNA results for each FRC are presented in section 4.2.3.

4.2.1 Cocoa

4.2.1.1 Cocoa beans

Over the assessed period (2003-2020), of the top 15 tropical countries that exported cocoa beans into the EU market, Côte d'Ivoire is the country that exported the highest amounts, with a total of 10,839,741 tonnes, followed by Ghana (5,058,285 tonnes), Nigeria (3,319,374 tonnes), Cameroon (2,733,710 tonnes) and Ecuador (828,491 tonnes). Figure 7 shows the share of exports among those tropical countries. In terms of EU imports, the Netherlands is the country that imported the most (12,918,189 tonnes), followed by Belgium (3,767,268 tonnes), Germany (3,423,696 tonnes), France (1,817,419 tonnes) and Spain (1,322,293 tonnes). All EU exports of cocoa beans from tropical countries add up to 25,124,515 tonnes, and the shares are shown in Figure 8.

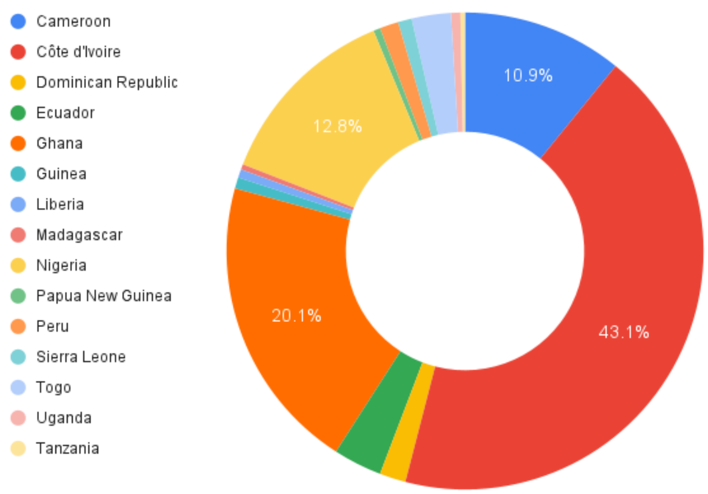


Figure 7. Share of cocoa beans exports into the EU from tropical countries (2003-2020).

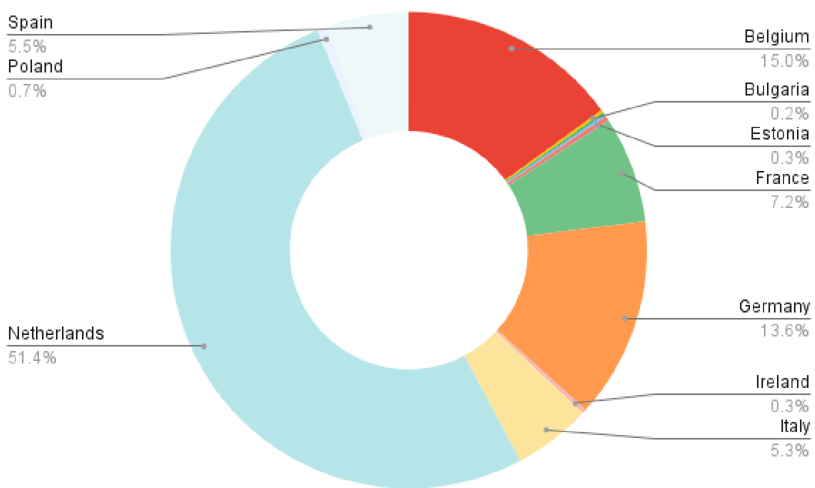


Figure 8. Share of cocoa beans imports into the EU from tropical countries (2003-2020).

As for the deforestation risk associated with the imports of cocoa beans into the EU market, the production of this commodity accounted for approximately 150,035 ha of forest loss in tropical countries, almost entirely (149,994 ha) occurring in the exporting countries (producers and exporters at the same time). The shares of tropical deforestation due to cocoa within countries EU are presented in Figure 9, which shows that the Netherlands is responsible for 37.6% of the total deforestation risk attributed to the EU for its cocoa beans imports, followed by Germany (22%) and Belgium (16.5%). These results are strictly related to the amounts imported and the countries these imports came from, since not all of them involved deforestation in producing their commodities.

On the other hand, Figure 10 presents the evolution of deforestation risk per year attributable to each EU country. Deforestation risk does not follow a single pattern across the years. Some years, namely 2003, 2004, 2011, 2014 and 2015, show peaks, implying that deforestation took place at the beginning of the allocation period of new cropland (2001, 2002, 2009, 2012 and 2013, respectively). For almost all the years, the Netherlands played a major role in importing deforestation risk embodied in cocoa beans; however, Germany overpassed the Netherlands' share with 14,864 ha of deforestation risk in 2011. According to the data, the deforestation embodied in cocoa beans exports decreased in 2016 and has maintained lower levels since then. In 2020, the forest loss was barely 8.3 ha, which could be attributed to under-reporting or under-monitoring during the Sars-Cov-2 pandemic.

Regarding the geographical distribution of deforestation risk amongst the involved countries, Figure 11 shows where deforestation risk is attributed in the EU (in terms of its exports embodying deforestation) and where it happened (or is attributed to, in the case of re-exporting countries) in the tropics. Of the 15 exporting countries, the Dominican Republic, Madagascar and Papua New Guinea were the only ones that did not generate deforestation for the domestic production of their exports to the EU. Likewise, it is interesting to highlight that Togo, Cameroon, Guinea, Uganda, Madagascar and Sierra Leone imported 1,040, 479, 236, 80, 24 and 7 tonnes, respectively, during the assessed period. This caused an estimated of about 40.1 hectares of deforestation risk in other tropical countries from which they sourced themselves with cocoa beans to export them afterwards. Still, the imported amounts do not cover all these countries' exports into the EU market in all the years. These differences could be due to underreporting, sourcing from other countries not included in the scope of this research under the category of "tropical countries", and due to the methodology used to distribute all imports amongst other cocoa-beans-related commodities (i.e., cocoa butter, cocoa powder and cake, cocoa paste).

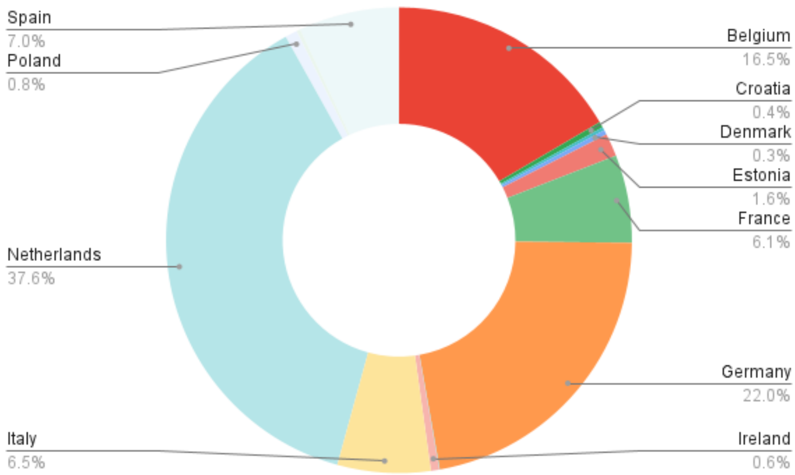


Figure 9. Share of deforestation risk attributed to cocoa beans exports to the EU (2003-2020).

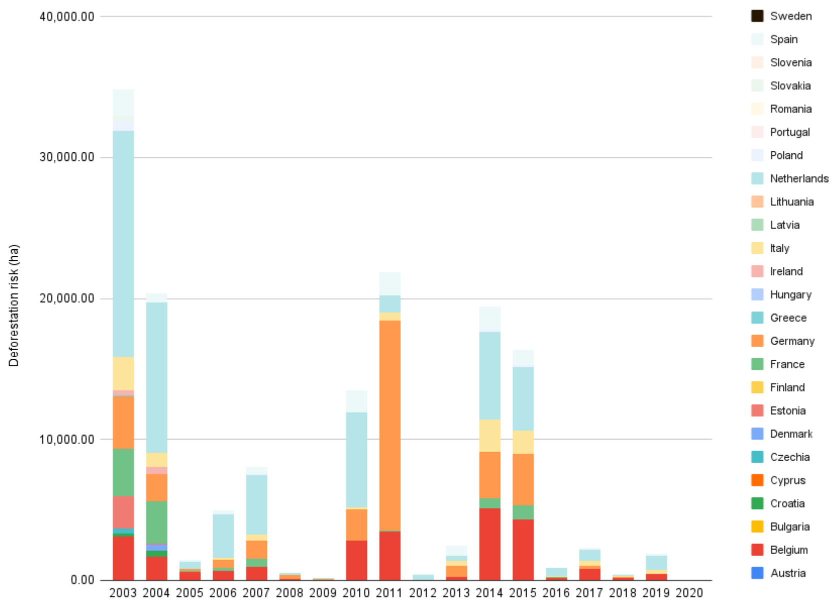


Figure 10. Deforestation risk attributed to EU countries during the period 2003-2020, based on their cocoa beans imports from tropical countries.

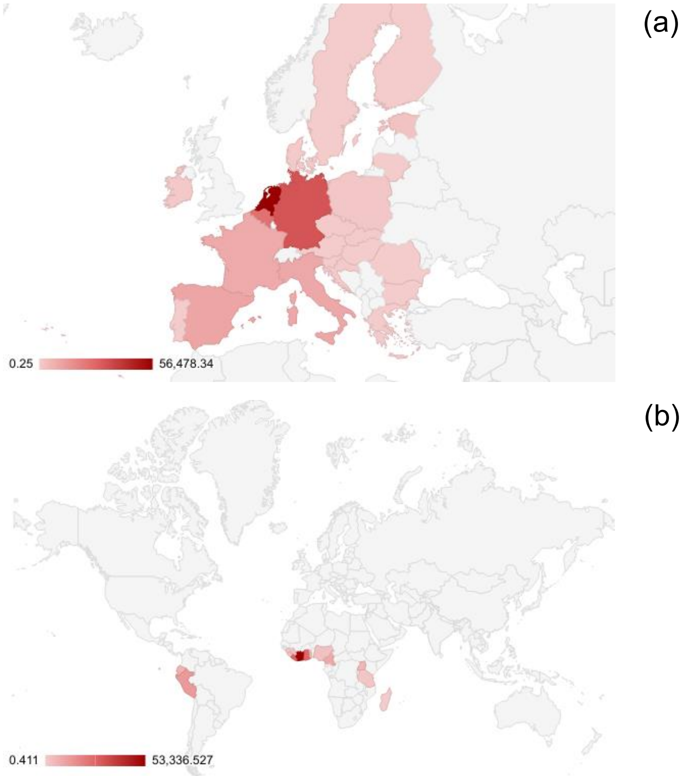


Figure 11. Geographical distribution of deforestation risk (ha) associated with trading cocoa beans in the EU among importing (a) and producing/exporting countries (b).

4.2.1.2 Cocoa butter

Figures 12 and 13 show the shares of exports and imports of cocoa butter amongst tropical countries and EU countries, respectively. The top 15 countries exported 2,780,918 tonnes of cocoa butter from 2003 to 2020. Like in the case of cocoa beans exports, Côte d'Ivoire is the country leading the list of exporters, with a total of 994,227 tonnes (35.8%), followed by Ghana with 459,503 tonnes (16.5%) and Indonesia with 338,719 tonnes (12.2%). Regarding EU imports, the Netherlands imported 1,181,316 tonnes from the top 15 tropical countries, followed by France and Germany with 925,616 and 363,437 tonnes, respectively. Together, they imported 88.9% of the total amount imported from the EU.

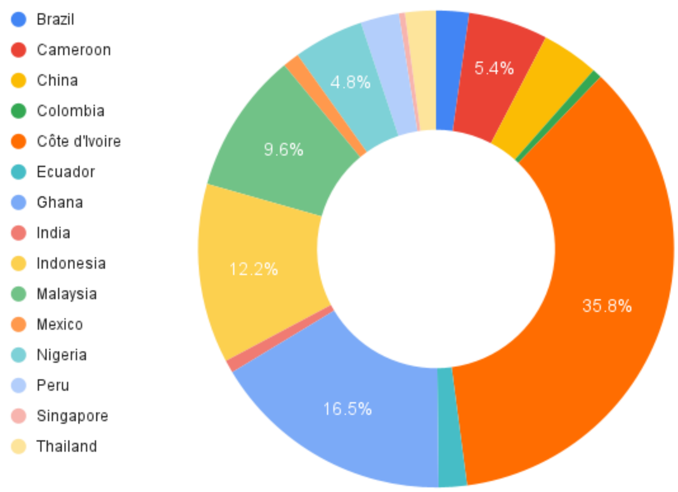


Figure 12. Share of cocoa butter exports into the EU from tropical countries (2003-2020).

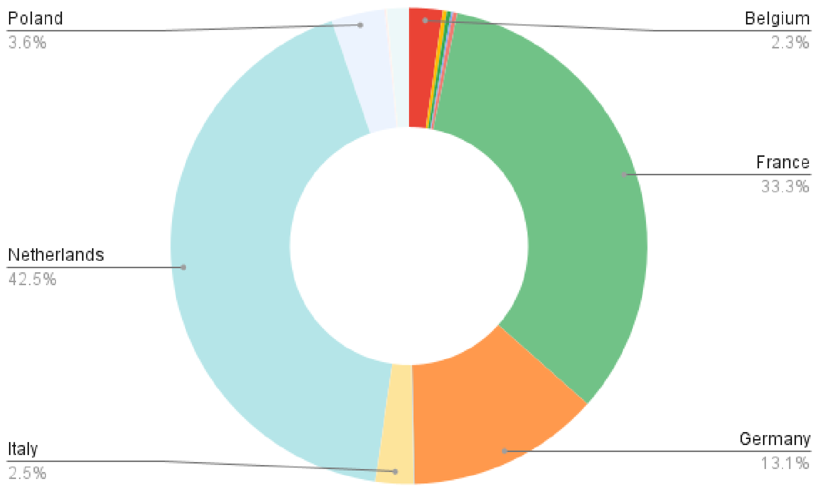


Figure 13. Share of cocoa butter imports into the EU from tropical countries (2003-2020).

During this period, EU imports embodied 95,257 ha of deforestation risk, from which 2014 imports embodied the highest deforestation risk, with significant imports from France, Germany, the Netherlands and Belgium (Figure 14). The year 2014 especially outstands with a peak that corresponds to 24,906 ha, where Germany had more important participation when compared with other years. Overall, exports to France accounted for 44.7% (42,478 ha) of the deforestation caused in tropical countries from 2003 to 2020 (Figure 15), followed by the Netherlands with 29.5% (28,101 ha) and Germany with 16.5% (15,730 ha). Out of the total area, about 21,600 ha corresponded to deforestation attributed to producing countries in the tropical domain that sourced the exporting countries to cover their demand. This estimation, based on how the negative balances (production-exports) were managed in this study, draws attention especially to Malaysia, which purchased 473,151 tonnes of cocoa beans (in ppe) from other tropical countries to then export cocoa butter to the EU, embodying 10,894 ha of deforestation risk. The same case applies to China, Thailand, Singapore and Cameroon, whose imports embodied the remaining deforestation in other countries. Of these countries, China and Malaysia are the only ones that do not produce cocoa in their territories; thus, they depend on producing countries to satisfy their national and international demand for cocoa butter. Figure 16 shows the geographical deforestation of the deforestation risk embodied in producing countries in the top 15 exporters and EU countries importing cocoa butter.

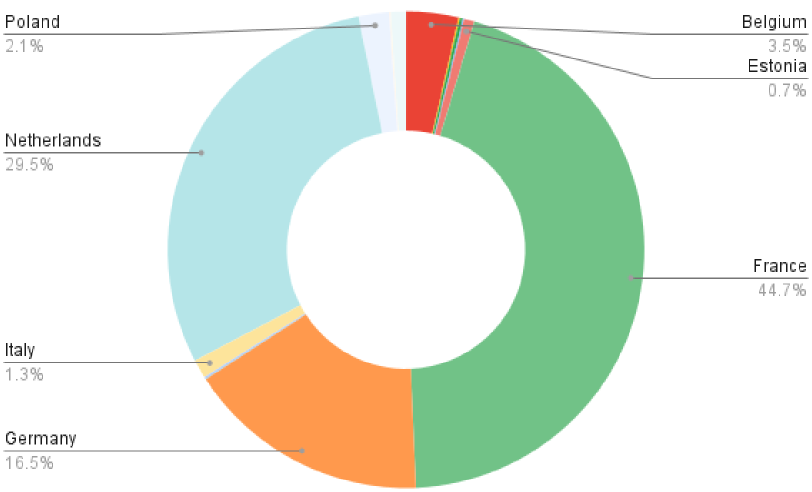


Figure 14. Share of deforestation risk attributed to cocoa butter exports to the EU (2003-2020).

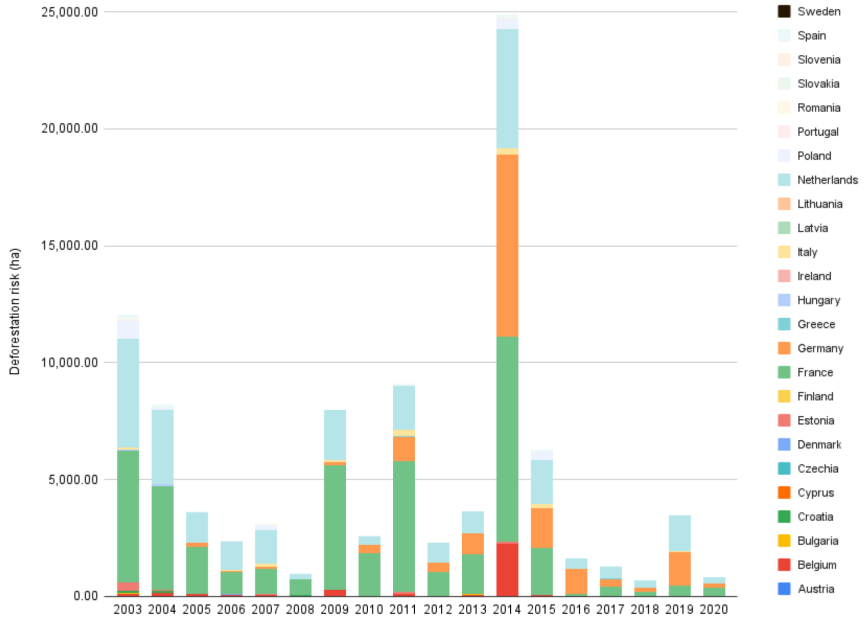


Figure 15. Deforestation risk attributed to EU countries during the period 2003-2020, based on their cocoa butter imports from tropical countries.

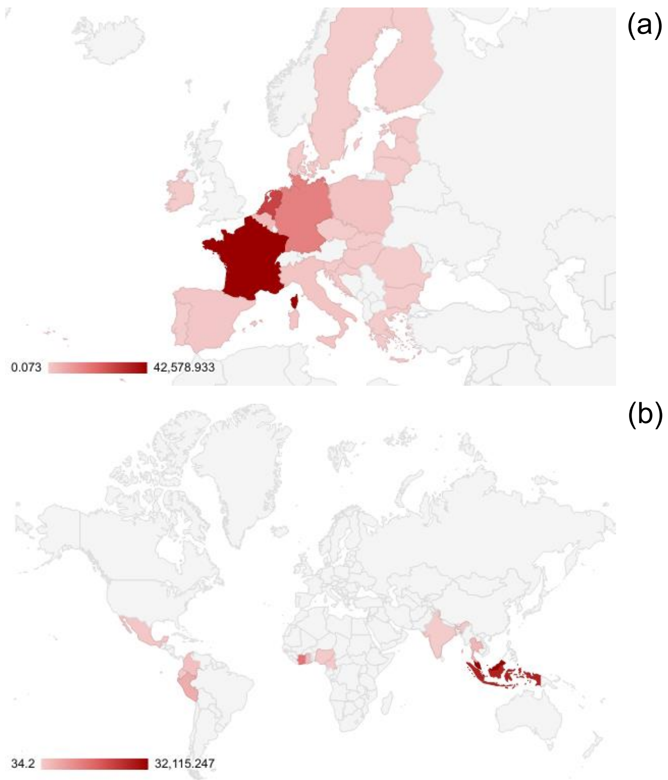


Figure 16. Geographical distribution of deforestation risk (ha) associated with trading cocoa butter in the EU among importing (a) and producing/exporting countries (b).

4.2.1.3 Cocoa paste

The shares of exports and imports of cocoa butter amongst tropical countries and EU countries are shown in Figures 17 and 18, respectively. Of them, Côte d'Ivoire has the largest share (69.7%), trading a total of 2,054,537 tonnes of cocoa paste into the EU. On the other hand, the Netherlands is the country that imports the most (1,244,601 tonnes), with 42.2%, followed France and Germany with 29.3% (863,533 tonnes) and 11.5% (338,581 tonnes), respectively. As stated in the case of cocoa butter, Malaysia is the only country in the top 15 that does not produce cocoa beans in its territory, depending entirely on imports from other tropical countries. During the assessed period, the EU market imported a total of 2,949,285 tonnes of cocoa paste, which embodied 18,067 ha of forest loss in the exporting countries and 103 ha of forest loss in other tropical countries that sourced Malaysia and Cameroon with cocoa beans (in ppe) to cover the demand from the EU. France imported 33.8% of the total deforestation risk embodied in EU imports, which added up to 6,137 ha, closely followed by the Netherlands, with 5,486 ha (Figure 19). Figure 20, on the other hand, shows that the highest deforestation risk embodied in EU imports occurred in 2003, 2014 and 2015, with 4,279, 4,032 and 3,216 ha, respectively. Likewise, there were some years with very low values, from which 2008 was the lowest (2 ha). Figure 21 shows the geographical distribution of deforestation risk amongst producer and exporting countries and EU countries.

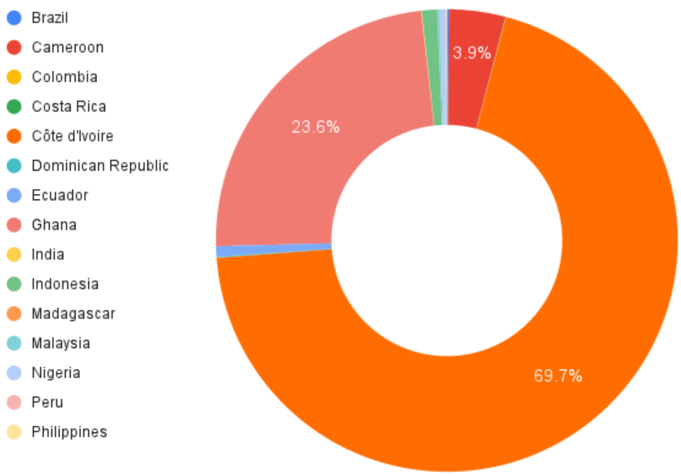


Figure 17. Share of cocoa butter exports into the EU from tropical countries (2003-2020).

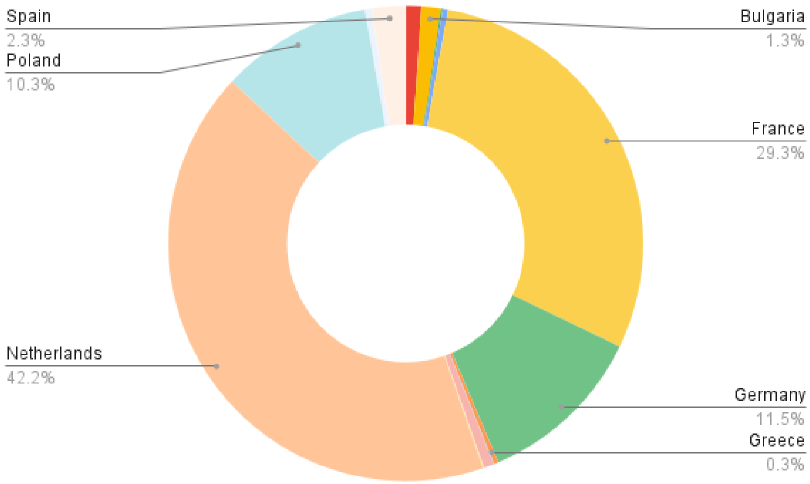


Figure 18. Share of cocoa butter imports by the EU from the top 15-exporting tropical countries (2003-2020).

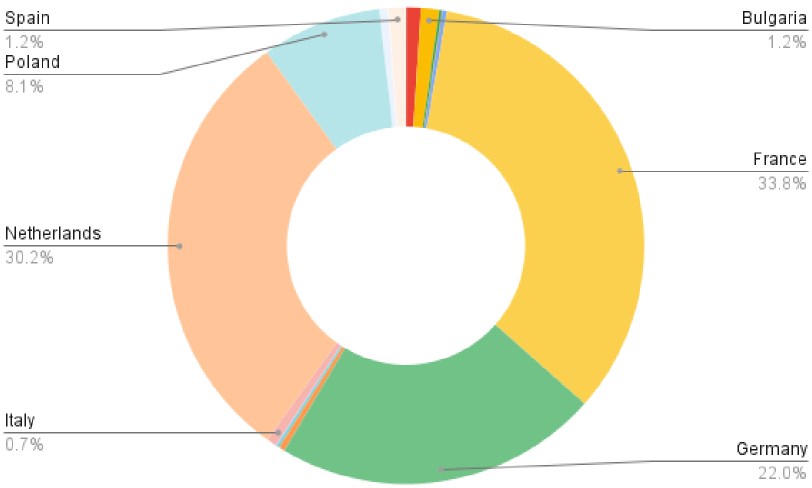


Figure 19. Share of deforestation risk attributed to cocoa paste exports to the EU (2003-2020).

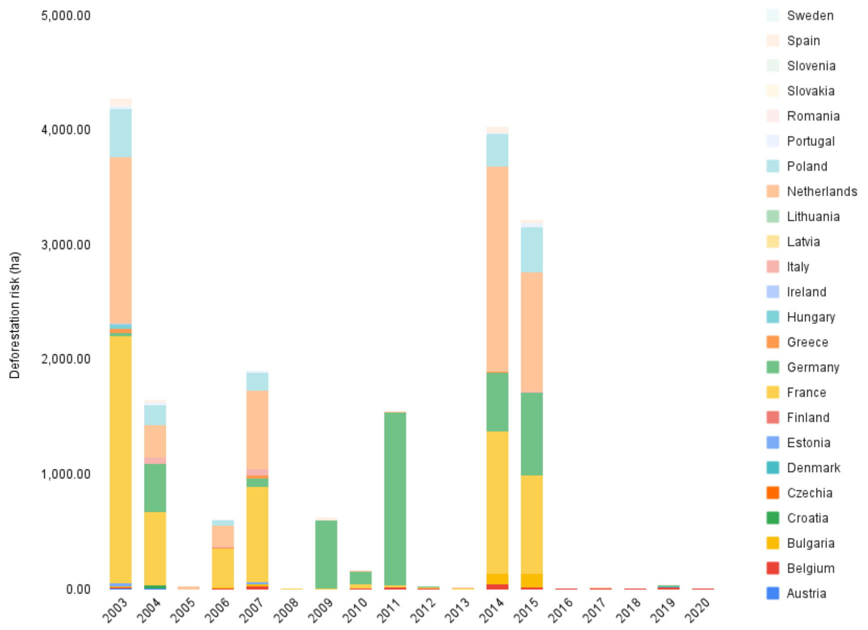


Figure 20. Deforestation risk attributed to EU countries during the period 2003-2020, based on their cocoa paste imports from tropical countries.

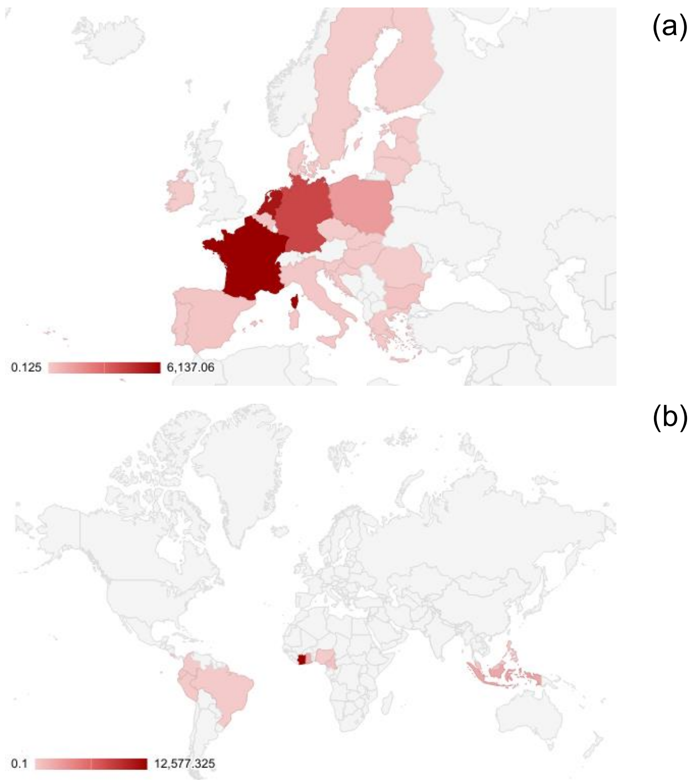


Figure 21. Geographical distribution of deforestation risk (ha) associated with trading cocoa paste in the EU among importing (a) and producing/exporting countries (b).

4.2.1.4 Cocoa powder and cake

Over the assessed period (2003-2020), the EU imported 2,164,840 tonnes of cocoa powder and cake, of which Spain imported almost half (928,138 tonnes), followed by the Netherlands (638,707 tonnes), as can be observed in Figure 22. Figure 23 shows the shares of exports from the top 15 tropical countries, from which Côte d'Ivoire still takes the lead with 47.5% of the total exports, followed by Ghana (20.6%) and Indonesia (14%). China and Singapore are part of the top 15 exporting countries, even though they do not have domestic production, hence, they are net importers and are causing deforestation in other countries (2,612 ha and 430 ha, respectively). At the same time, Thailand, Malaysia and Cameroon depended on other countries to cover the EU demand for some years. Together, these five countries imported 274,211 tonnes from producing countries. Despite that, Cameroon still needed to import from other countries not considered within the scope of this research as tropical countries to cover the EU demand. It is interesting to notice how China has positioned itself as the second top exporter, which sheds light on the role and impact that intermediary countries have in commodities trading.

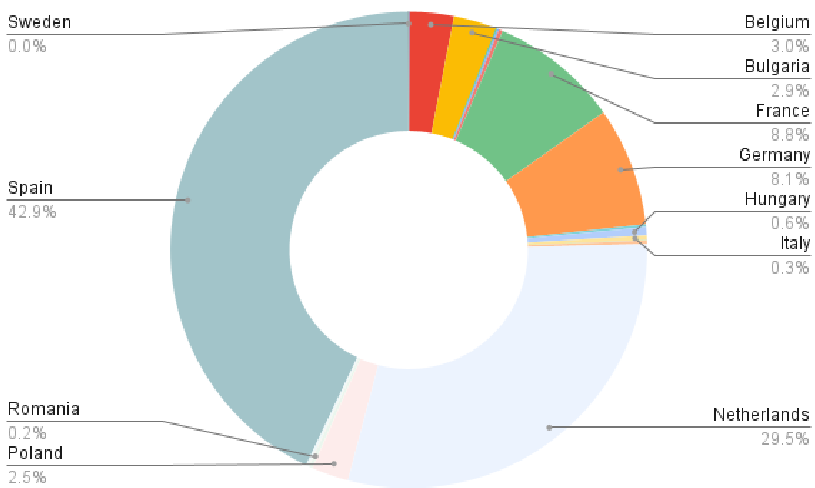


Figure 22. Share of cocoa powder and cake imports into the EU from tropical countries (2003-2020).

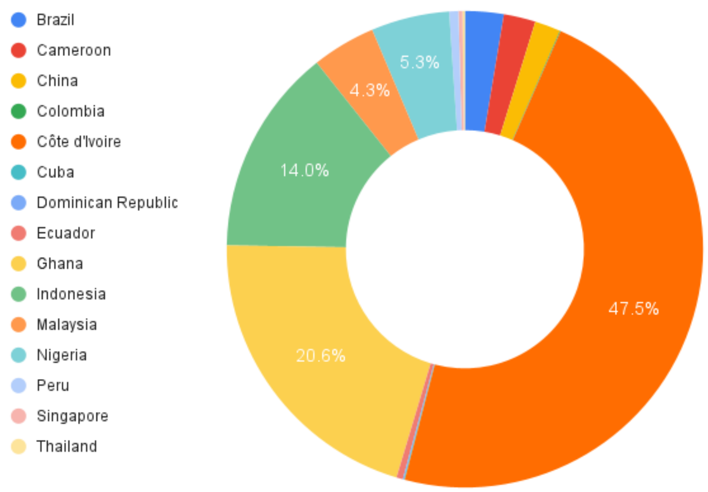


Figure 23. Share of cocoa powder and cake exports to the EU from tropical countries (2003-2020).

With respect to embodied deforestation, EU imports of cocoa powder and cake embodied 60,518.3 ha of deforestation risk, of which Spain's imports were responsible for 52.8%, followed by the Netherlands', with 14.4% (Figure 24). Furthermore, 6,851 ha of deforestation risk are attributed to other countries, but not to the exporters. Over the assessed period, 2003, 2011 and 2014 were the years with more embodied deforestation being imported into the EU, with a total of 14,817 ha in 2003, 9,577 ha in 2011 and 9,686 ha in 2014 (Figure 25). Figure 26 shows the geographical distribution of deforestation risk amongst producer and exporting countries and EU countries. Cuba and the Dominican Republic did not produce tropical deforestation, while Cameroon, China, Malaysia, Singapore and Thailand caused deforestation in other countries for a total of 0.7 ha, 2,612 ha, 3,650 ha, 430 ha and 158 ha, respectively.

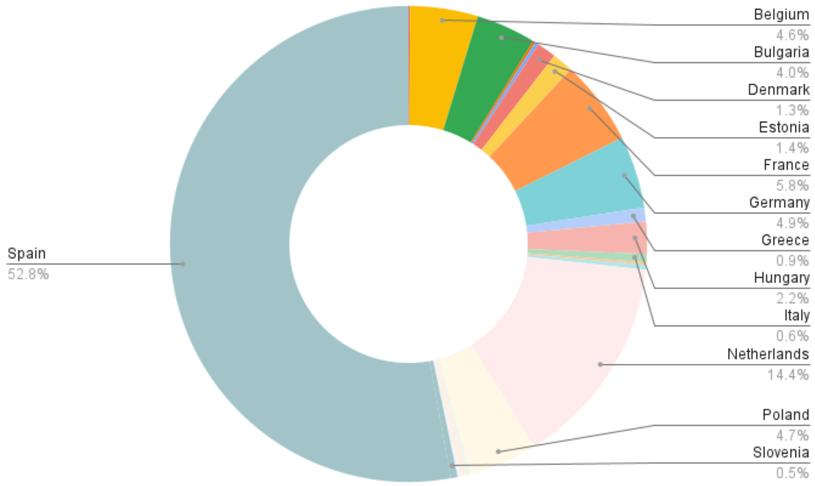


Figure 24. Share of deforestation risk attributed to cocoa powder and cake exports to the EU (2003-2020).

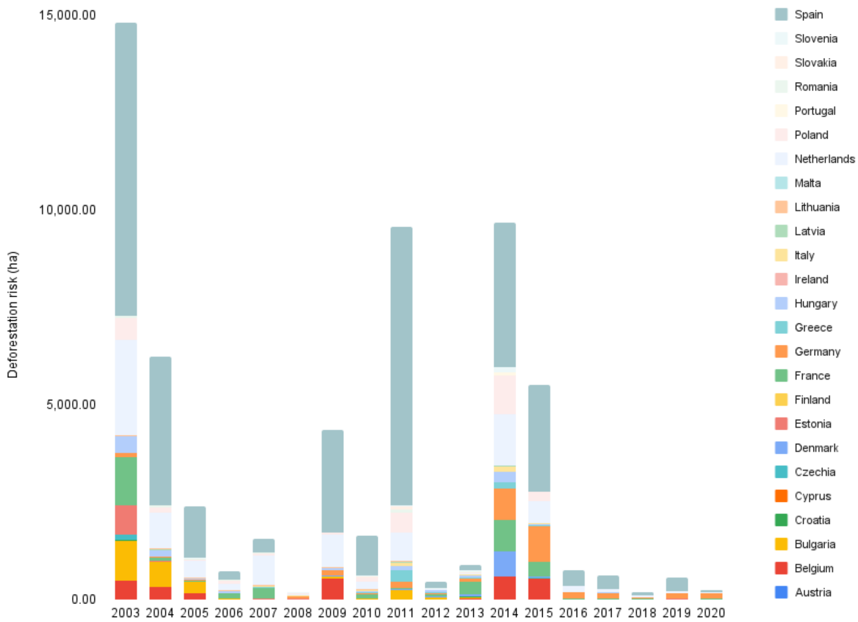
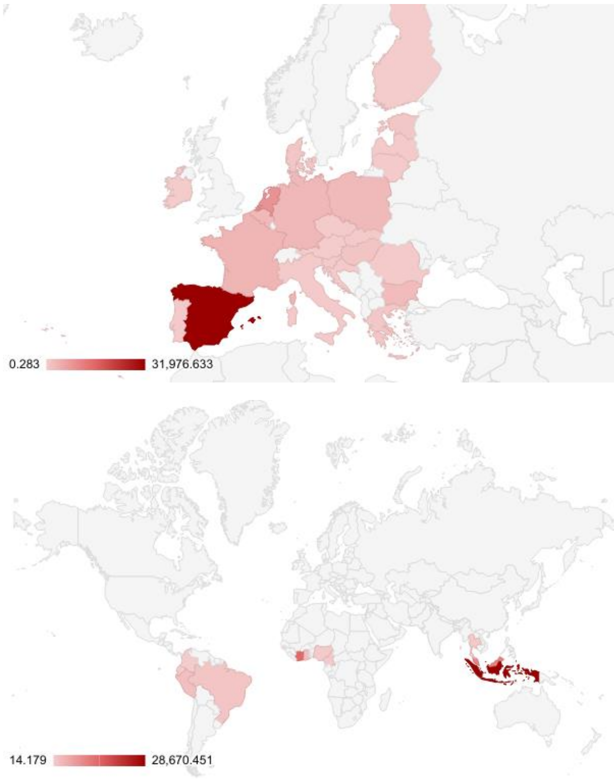


Figure 25. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of cocoa powder and cake from tropical countries.



(a)

(b)

Figure 26. Geographical distribution of deforestation risk (ha) associated with trading cocoa powder and cake in the EU among importing (a) and producing/exporting countries (b).

4.2.2 Coffee

4.2.2.1 Green coffee

Regarding the trade of green coffee into the EU, 44,133,038 tonnes were exported from the top 15 tropical countries to EU countries during the period 2003-2020. Figures 27 and 28 show that the major exporter was Brazil, with a share of 33.5% of the total exports, followed by Vietnam (23.4%) and Colombia (6.5%). The major importers were Germany (38.8%), Italy (18.7%), Belgium (9.3%) and Spain (8.9%). Among the exporters, Cameroon is the only country supplying with imports from other countries to cover the EU demand, purchasing 66 tonnes of green coffee (in ppe), though it was not sufficient to cover the negative balance of its exports. This suggests that Cameroon purchased from other countries that were not included in the list of tropical countries in this study.

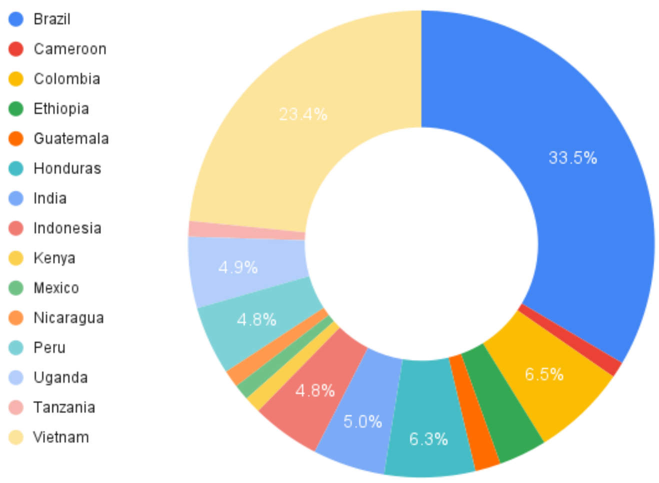


Figure 27. Share of green coffee exported to the EU from tropical countries (2003-2020).

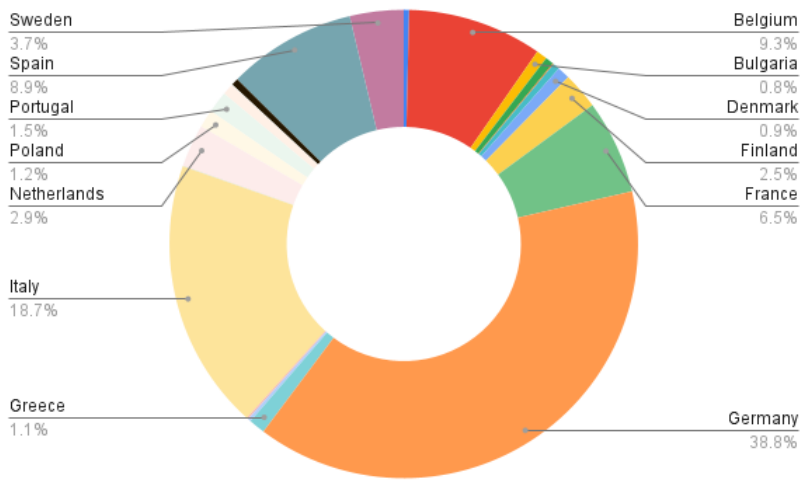


Figure 28. Share of green coffee imports into the EU from tropical countries (2003-2020).

The imports of green coffee embodied 163,061 ha of forest loss in tropical countries, of which Germany, Italy and Belgium account for the most part with 39.3%, 20.9% and 12.4%, respectively (Figure 29). The producing countries that involved more deforestation risk in the production of this FRC were Tanzania (46,561 tonnes), Indonesia (28,841) and Uganda (20,257 tonnes), even though other countries, such as Brazil and Vietnam, export considerably more than them. For this FRC, the deforestation risk in non-exporting countries, attributed to

Cameroon, was 2 ha. On the other hand, Figure 30 shows peaks in 2006, 2011, 2013 and 2019 in terms of imports with embodied deforestation, particularly linked to Germany and Italy. The geographical distribution of the deforestation risk amongst producer and exporting countries and EU countries is shown in Figure 31.

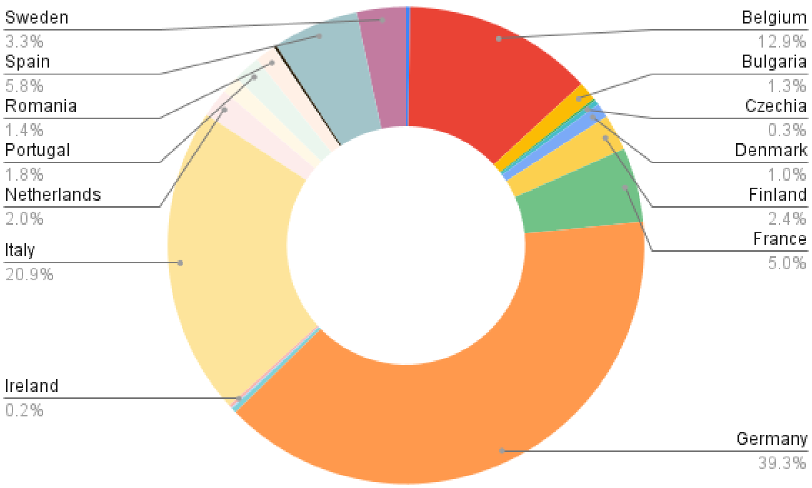


Figure 29. Share of deforestation risk attributed to green coffee exports to the EU (2003-2020).

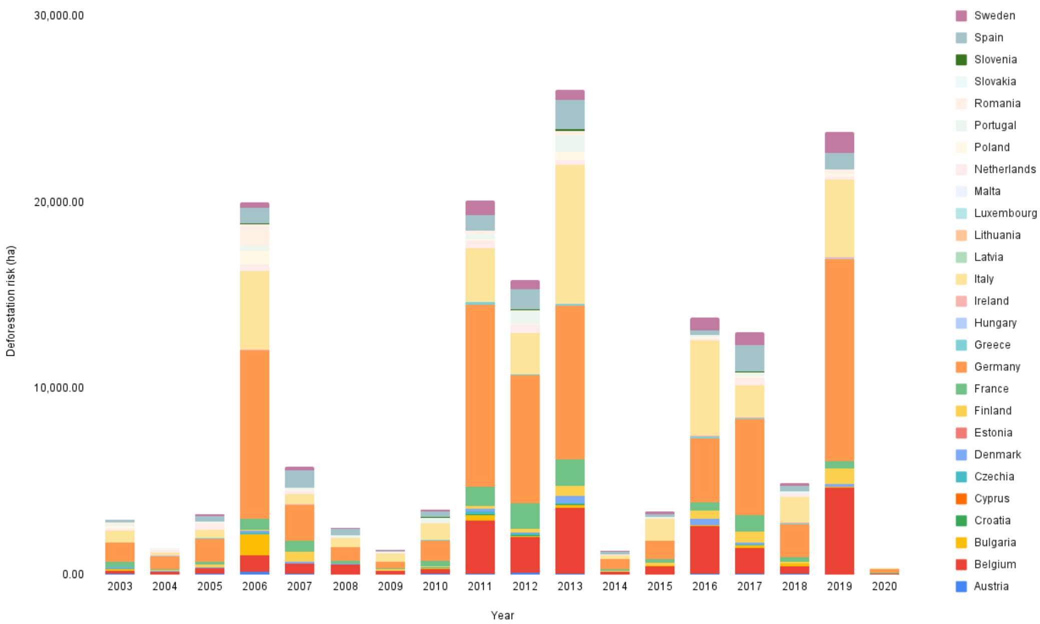


Figure 30. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of green coffee from tropical countries.

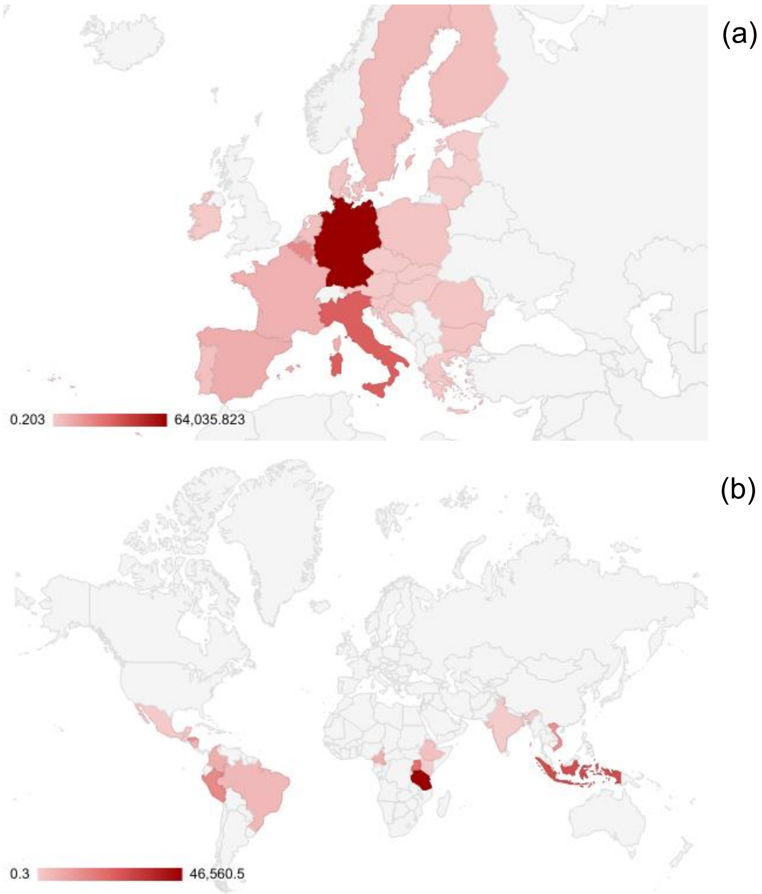


Figure 31. Geographical distribution of deforestation risk (ha) associated with trading green coffee in the EU among importing (a) and producing/exporting countries (b).

4.2.2.2 Roasted coffee

Regarding roasted coffee, Brazil was the top exporter, covering 50.4% of the total amount exported to the EU from 2003 to 2020, totalling 12,738 tonnes, followed by Colombia with 3,692 tonnes (Figure 32). The top 15 tropical countries exported 27,263 tonnes in total, and Italy, Germany, France and the Netherlands were the top importers, with 41.2%, 13.4%, 9.0% and 8.7%, respectively (Figure 33). These imports caused 47.7 ha of deforestation risk in exporting countries, being the Netherlands (23.3%) once again at the top of the list of imports with embodied forest loss, followed by Italy, Spain and Germany, with 18.2%, 14.5% and 13.2%, respectively (Figure 34). The results suggest that, even though Italy, Germany and France imported more significant amounts of roasted coffee than the

Netherlands, they have more sustainable supply chains of roasted coffee in terms of deforestation risk in tropical countries. On the contrary, Spain's roasted coffee supply chain is linked to more deforestation than supply chains associated to larger importers like Germany and France.

Furthermore, roasted coffee imports to the EU generated more deforestation risk in 2017, especially those exports to Spain, Sweden and the Netherlands (Figure 35). Figure 36 shows the geographical distribution of the deforestation risk from 2003 to 2020. Of the 15 tropical countries, China and Senegal do not produce coffee in their territories; therefore, they imported from other countries to fulfil the EU demand for the FRC, accounting for 6.6 ha and 9.7 ha of deforestation elsewhere, respectively. Likewise, the Dominican Republic and Thailand did not cause deforestation, nor in their own territories or in other countries'.

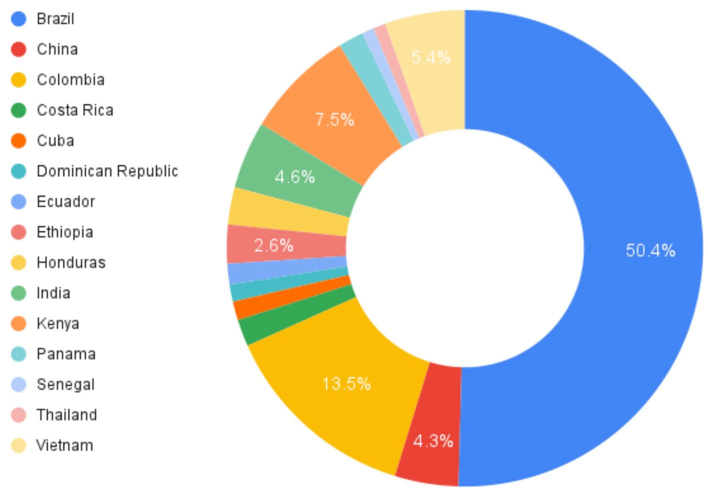


Figure 32. Share of roasted coffee exports into the EU from tropical countries (2003-2020).

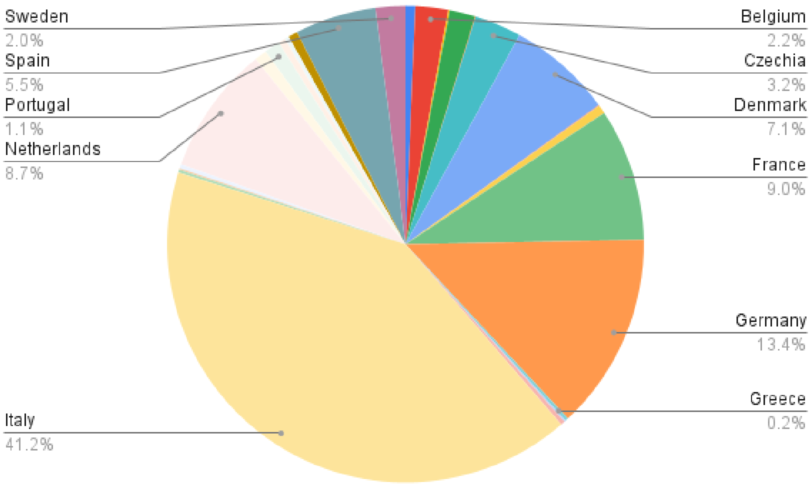


Figure 33. Share of roasted coffee imports into the EU from tropical countries (2003-2020).

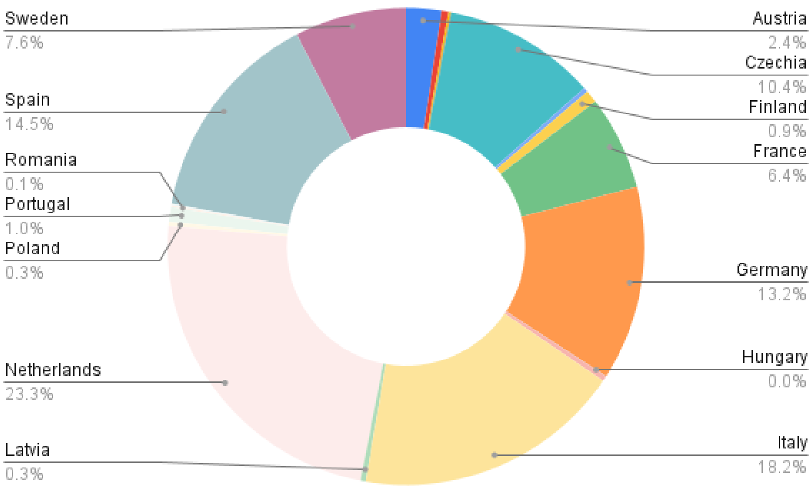


Figure 34. Share of deforestation risk attributed to roasted coffee exports to the EU (2003-2020).

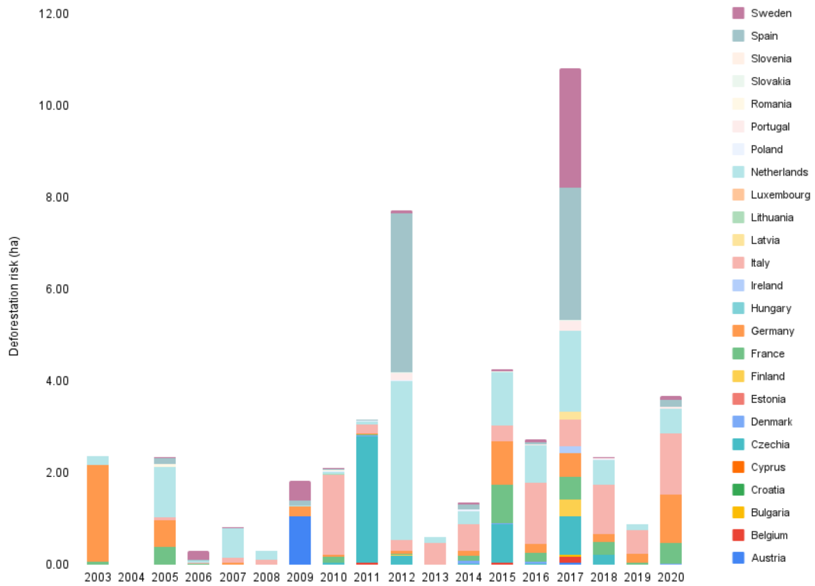


Figure 35. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of roasted coffee from tropical countries.

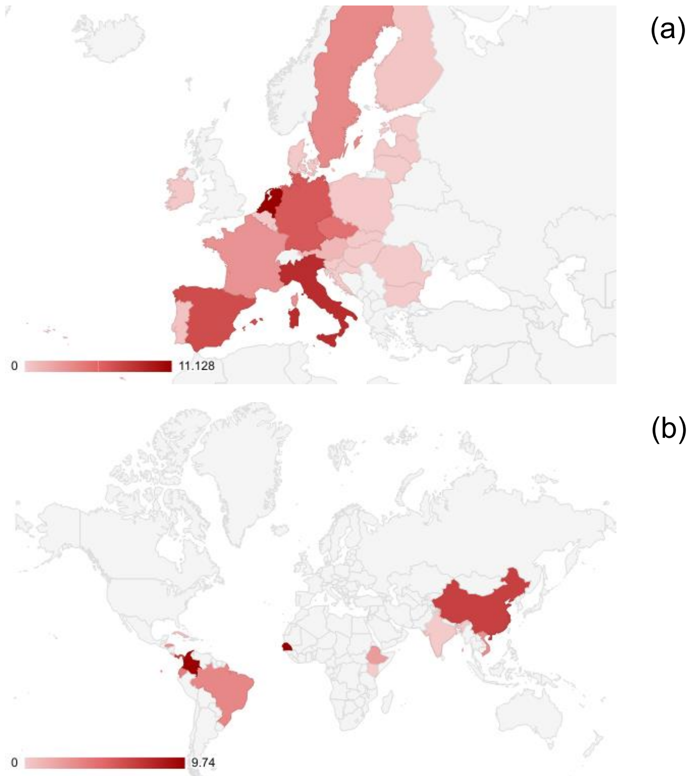


Figure 36. Geographical distribution of deforestation risk (ha) associated with trading roasted coffee in the EU among importing (a) and producing/exporting countries (b).

4.2.3 Oil palm

4.2.3.1 Palm oil

Indonesia is the top exporter of palm oil to the EU, with 46,559,633 tonnes (49.6%), followed by Malaysia (32.4%) and Papua New Guinea (6.9%) with 30,437,805 and 6,438,359 tonnes, respectively (Figure 37). The top importing country is the Netherlands, with 36,615,536 tonnes (39%), followed by Italy (19%) and Spain (17.2%), with 17,843,966 and 16,148,300 tonnes, respectively (Figure 38). The total amount of palm oil exports into the EU adds up to 93,883,704 tonnes, of which the top 15 tropical countries purchased 2,090,444 tonnes from other countries to fulfil the EU's demand. During 2003-2020, especially the trade between tropical countries accounted for an estimated of about 59,504 ha of deforestation risk elsewhere. Of these imports, Honduras is the one importing more deforestation risk to fulfil the EU's demand, with a total of 30,138 ha, followed by Singapore (11,944 ha), Papua New Guinea (11,461 ha), Guatemala (5,070 ha), Côte d'Ivoire (575 ha) and Panama (316 ha). Figure 39 shows the share of deforestation risk attributed to EU countries, based on their imported amounts and the countries from which they imported palm oil. Based on the results, the Netherlands imported a total of 284,234 ha of embodied deforestation, followed by Italy (124,486 ha), Spain (116,372 ha) and Germany (104,449 ha).

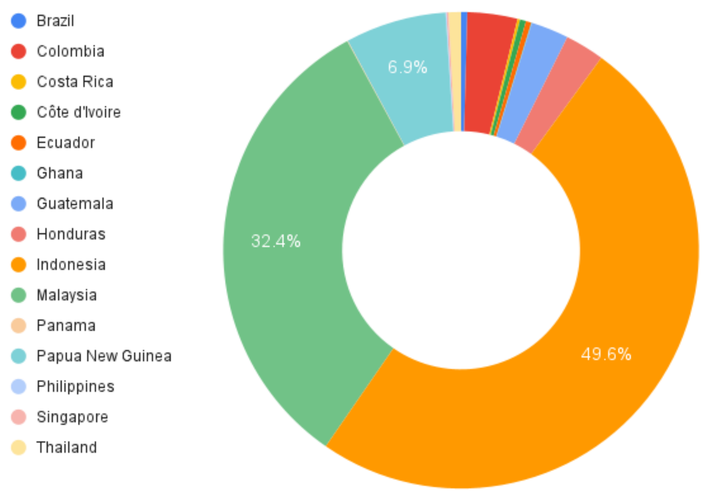


Figure 37. Share of palm oil exports into the EU from tropical countries (2003-2020).

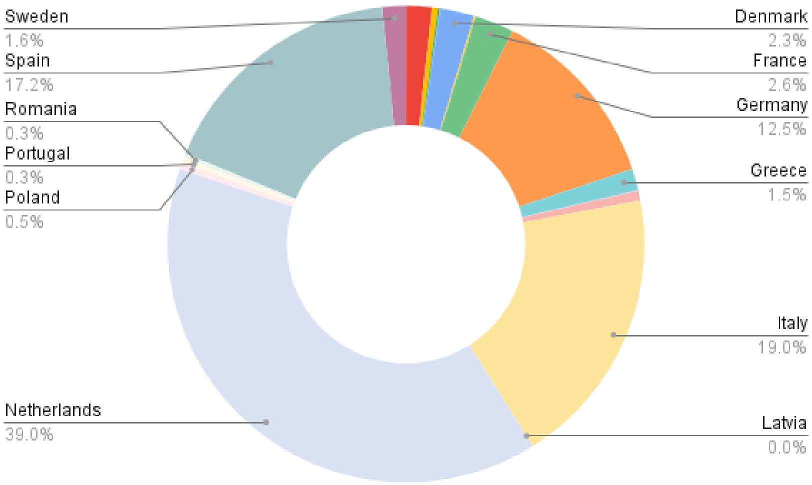


Figure 38. Share of palm oil imports into the EU from tropical countries (2003-2020).

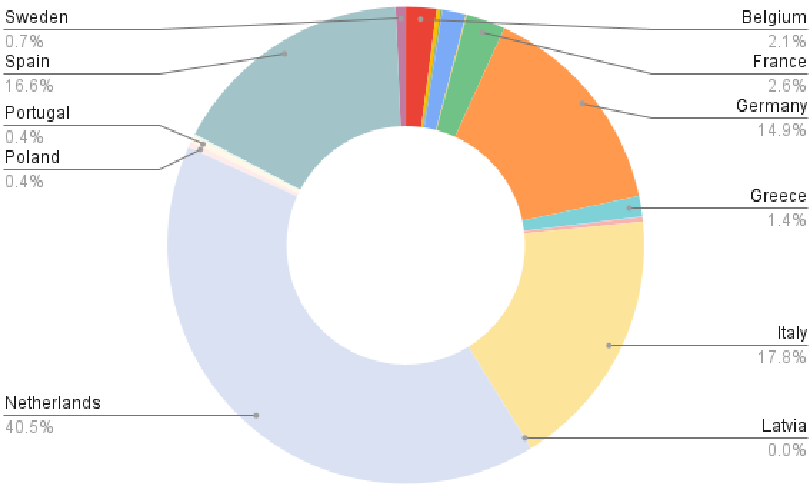


Figure 39. Share of deforestation risk attributed to palm oil exports to the EU (2003-2020).

Furthermore, Figure 40 shows that 2010 was the year where EU imports embedded the most significant amounts of deforestation risk, and that some years, such as 2007 and 2008, showed very low values of deforestation risk associated with the production of those EU imports in tropical countries. It is important to highlight that Indonesia was the country that showed the largest deforestation values attributable to their exports to the EU, with 440,914 ha, followed by Malaysia (76,231 ha), Colombia (73,334 ha) and Papua New Guinea (32,290 ha). Figure 41 shows the spatial distribution of the deforestation risk amongst producer and exporting countries and EU countries, where Indonesia's values stand out.

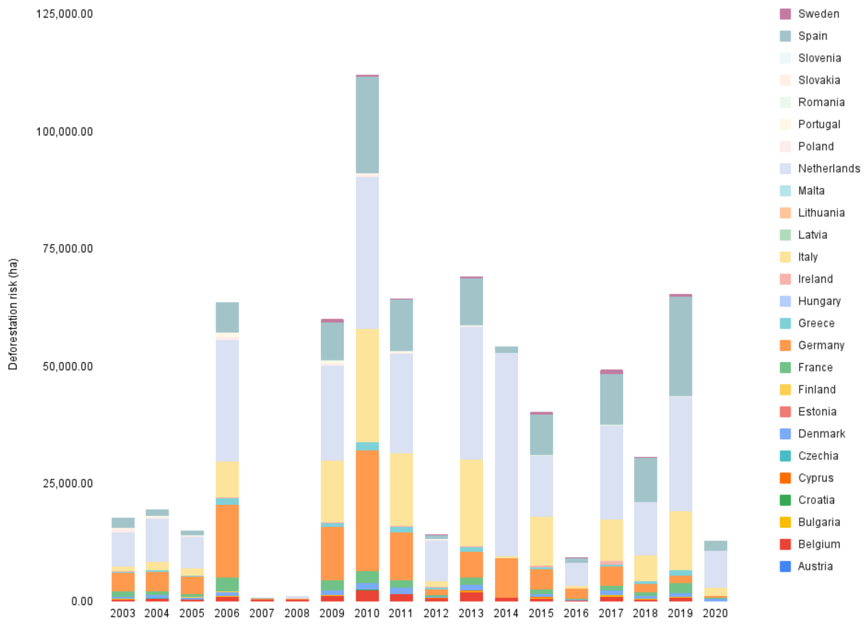


Figure 40. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of palm oil from tropical countries.

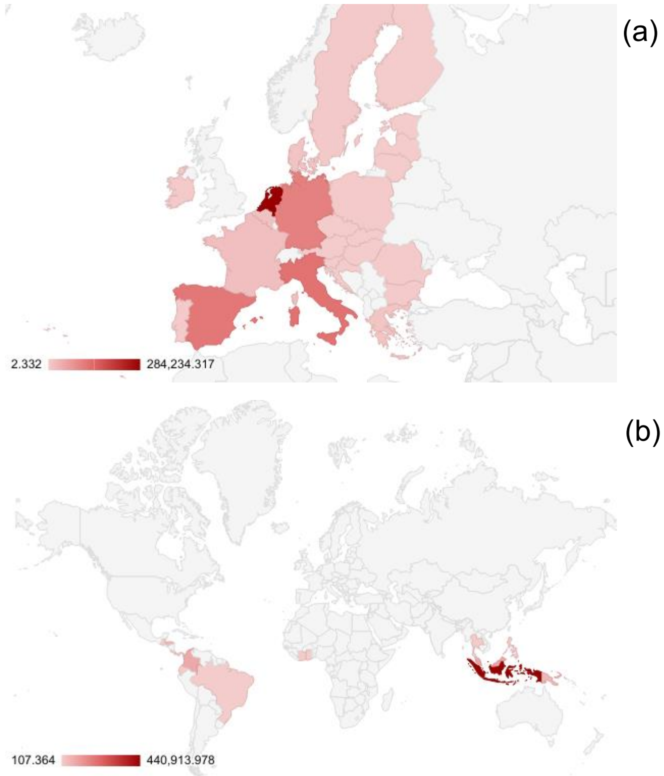


Figure 41. Geographical distribution of deforestation risk (ha) associated with trading palm oil in the EU among importing (a) and producing/exporting countries (b).

4.2.3.2 Palm kernel oil

As in the case of palm oil, Indonesia is the tropical country that exports more palm kernel oil to the EU, with a total of 6,002,125 tonnes over the period 2003-2020, followed by Malaysia with 2,791,653 tonnes, and Papua New Guinea with 713,903 tonnes, accounting respectively for 55.8%, 26% and 6.6% of a total 10,750,460 tonnes exported from the top 15 countries into the EU market (Figure 42). In the case of the EU countries, Germany imported 5,136,963 tonnes, followed by the Netherlands with 3,003,617 tonnes, accounting for approximately 75% of the EU imports from 2003 to 2020 (Figure 43). The imports of palm kernel oil embody a deforestation risk of 1,030,606 ha, of which 882,058 ha (86%) were deforested in the exporting countries, and 148,548 ha (14%) were deforested in tropical countries sourcing some of them. In this sense, Cote d'Ivoire, Guatemala, Honduras, India, Papua New Guinea and Singapore were responsible for the deforestation of 4,034 ha, 3,728 ha, 31,739 ha, 22,399 ha, 15,409 ha and 71,238 ha, respectively. It is relevant to note that Singapore and India source themselves entirely from other countries since they do not produce oil palm. Figure 44 shows that Germany is the country with more embedded deforestation due to palm kernel oil imports, with 550,527 ha (53.4%), followed by the Netherlands (25.4%) and Spain (5.8%).

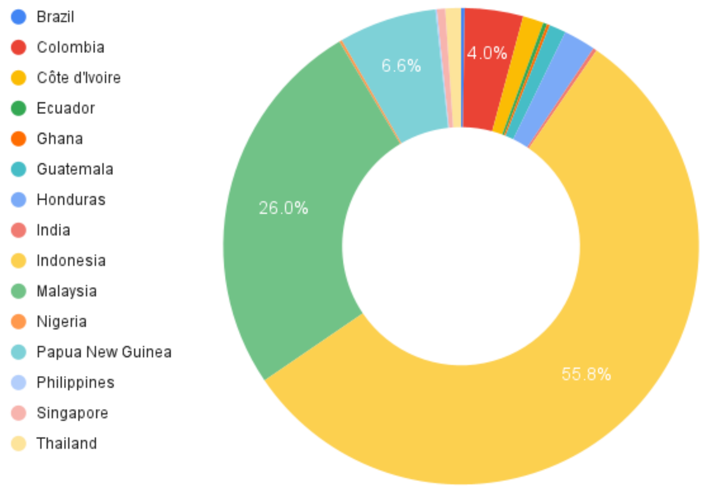


Figure 42. Share of palm kernel oil exports into the EU from tropical countries (2003-2020).

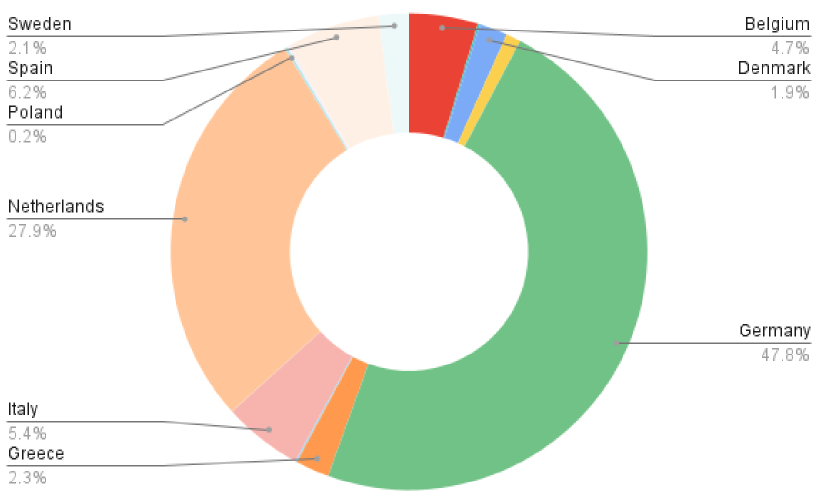


Figure 43. Share of palm kernel oil imports into the EU from tropical countries (2003-2020).

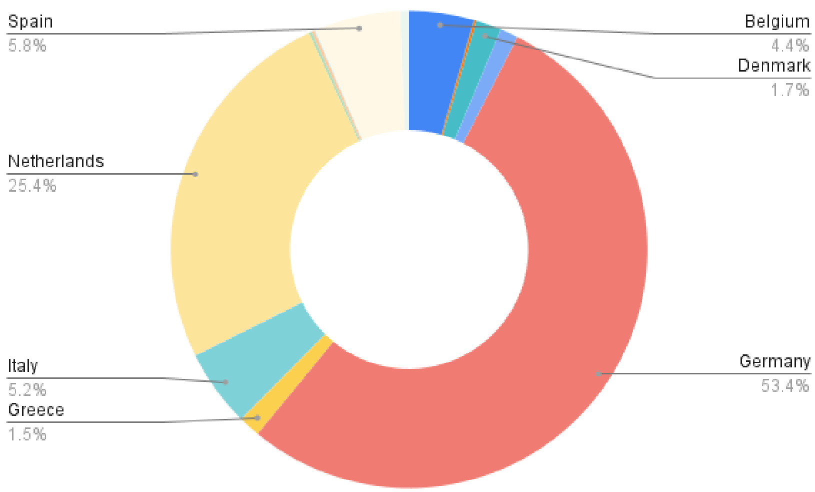


Figure 44. Share of deforestation risk attributed to palm kernel oil exports to the EU (2003-2020).

Figure 45 shows that deforestation risk was especially high in 2006, with 166,111 ha of forest loss in the tropical domain. On the other hand, the lowest values (1,845 ha and 1520 ha, respectively) are reported for 2007 and 2008. The geographical distribution of the deforestation risk associated to trading palm kernel oil in the EU is presented in Figure 46.

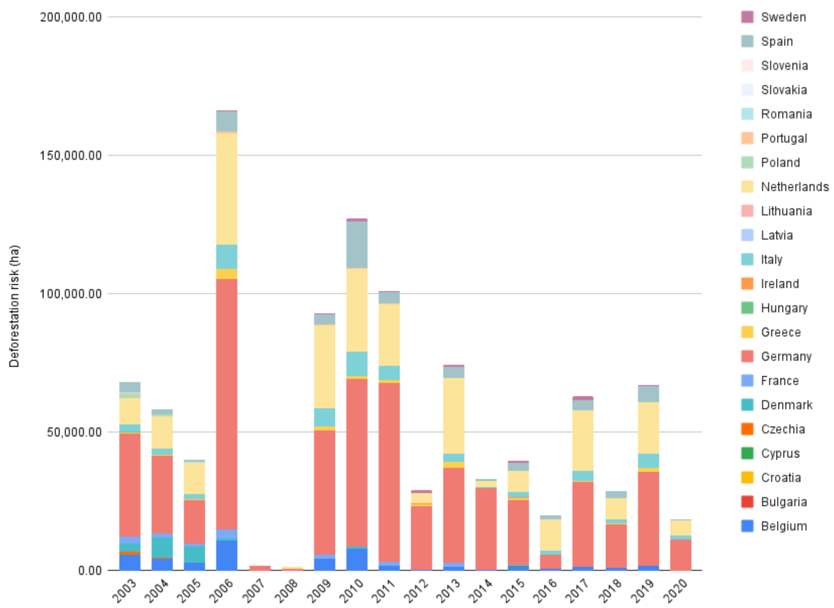
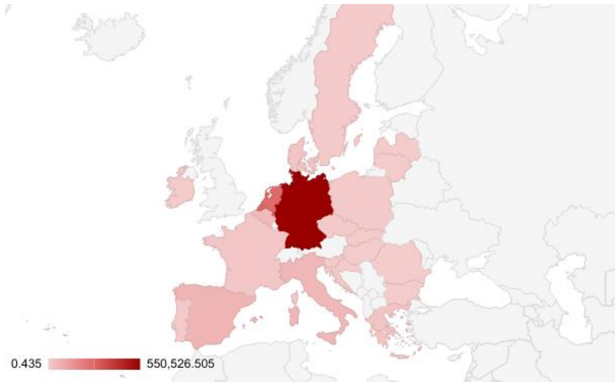


Figure 45. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of palm kernel oil from tropical countries.



(a)

(b)

Figure 46. Geographical distribution of deforestation risk (ha) associated with trading palm kernel oil in the EU among importing (a) and producing/exporting countries (b).

4.2.3.3 Palm kernel cake

In the case of palm kernel cake exports to the EU, Indonesia and Malaysia are the countries that export the largest amounts among the top 15 tropical countries, with 20,028,546 tonnes (61.0%) and 11,946,440 tonnes (36.4%), respectively (Figure 47). As for the EU, it imported a total of 32,821,722 tonnes from 2003 to 2020 from those tropical countries, from which the Netherlands imported 62.1%, followed by Germany (13.4%) and Spain (6.2%), as can be observed in Figure 48. Of the importers, Côte d'Ivoire, India, Madagascar, Niger, Singapore and Togo rely on imports from other countries to fulfil the EU's demand for palm kernel cake. These countries import a total of 2,463,834 tonnes from other tropical countries, which accounts for about 63,858 ha of deforestation risk in the producing countries. It is important to note that India, Niger and Singapore do not produce palm oil in their territories. Overall, EU imports embody 1,968,132 ha of deforestation risk, of which 1,904,273 occurred in the exporting countries. As it can be observed in Figure 49, the Netherlands imports more embodied deforestation, with a total of 1,108,424 ha (56.3%), followed by Germany (16.2%), Ireland (7.3%) and Spain (6%).

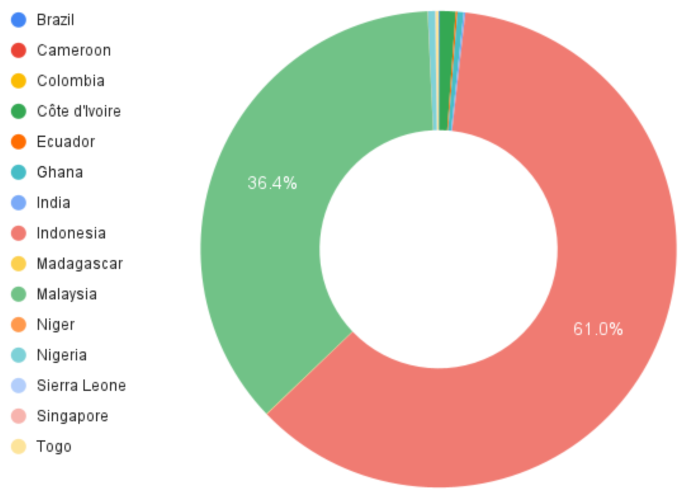


Figure 47. Share of palm kernel cake exports into the EU from tropical countries (2003-2020).

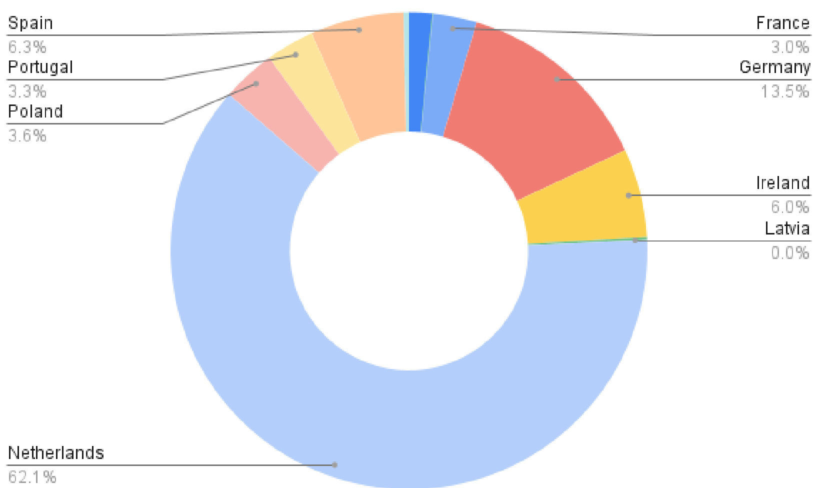


Figure 48. Share of palm kernel cake imports into the EU from tropical countries (2003-2020).

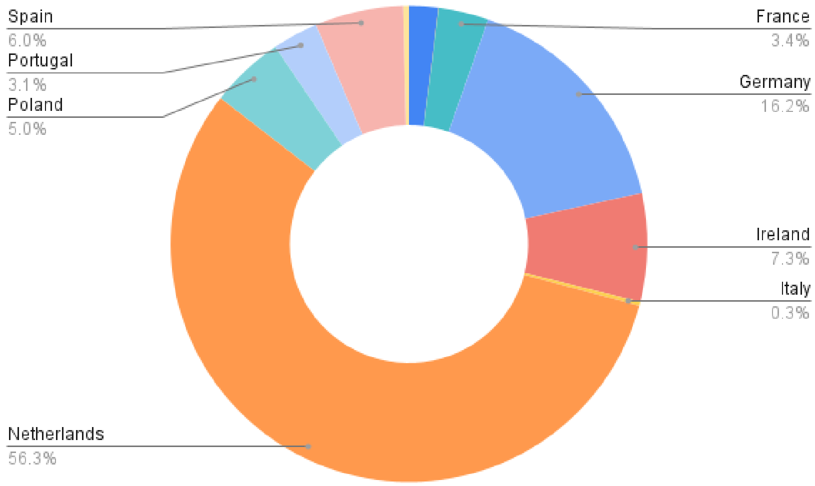


Figure 49. Share of deforestation risk attributed to palm kernel cake exports to the EU (2003-2020).

With respect to the deforestation risk associated with each year's imports, 2006, 2011 and 2013 are the years where more embodied deforestation was exported to the EU from tropical countries. Year 2007, on the contrary, did not involve any deforestation risk (Figure 50). Futhermore, Figure 51 shows that Indonesia is the country where more deforestation is associated with the production of palm kernel oil, accounting for a total forest loss of 1,652,821 ha. Among the producer and exporting countries, only Ecuador and Madagascar showed no deforestation risk in their own territories. In the case of Ecuador, this suggests a sustainable supply chain for this commodity in terms of forest loss, while Madagascar imported all the deforestation risk associated to its exports to the EU from other countries, which accounts for a total of 179 ha. Similarly, Cote d'Ivoire, India, Niger, Singapore and Togo embodied deforestation associated with trade between tropical countries for 5,867 ha, 39,229 ha, 4,217 ha, 5,066 ha and 9,300 ha, respectively.

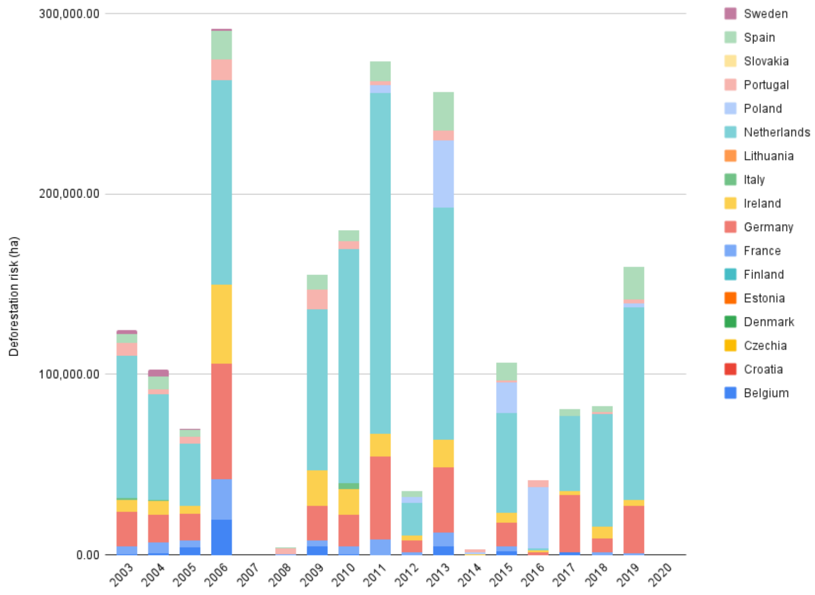


Figure 50. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of palm kernel cake from tropical countries.

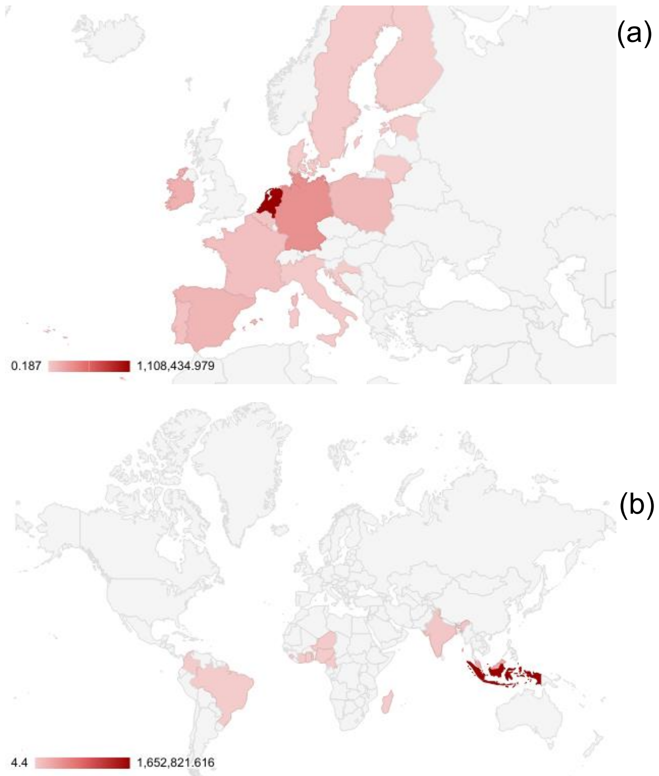


Figure 51. Geographical distribution of deforestation risk (ha) associated with trading palm kernel cake in the EU among importing (a) and producing/exporting countries (b).

4.2.4 Soybean

4.2.4.1 Soybeans

Regarding soybeans trade, Brazil is the country that exports the most significant amount to the EU, covering 84.2% of the total exports from the top 15 exporters with 115,975,269 tonnes of soybeans exported from 2003 to 2020 (Figure 52). During this period, Paraguay exported 20,606,227 tonnes, equivalent to 15% of total exports from the top 15 exporters to the EU. Amongst the importing countries, which together import a total of 137,732,073 tonnes, Spain is on top of the list with 28.4% of the total imports, followed closely by the Netherlands with 27.7% (Figure 53). Soybean imports from the EU embodied 417,764 ha of deforestation risk in tropical countries, of which the Netherlands is responsible for 30%, Spain for 23.6% and Germany for 16.3% (Figure 54).

Moreover, among the top exporters, Brazil is the country that evidenced more forest loss due to soybean production, with a deforestation risk of 286,855 ha, followed by Paraguay (123,809 ha). In contrast, countries such as Uganda, Panama, Ghana, Burkina Faso and Benin, did not show deforestation associated with soybeans production in their own territories. Antigua and Barbuda, is a special case, since it does not produce soybeans in its territory and relies on imports from other countries to fulfil EU’s demand. Côte d'Ivoire, Ghana, Panama and Togo also rely, though only in part and for some years, on imports from other countries as well. These imports, specifically those from other tropical countries, add up to a total of 61,389 tonnes, which are estimated to have generated around 1,279 ha of forest loss. From them, Panama is responsible for 922 ha, and Togo for 342 ha.

Concerning the evolution of the deforestation risk, Figure 55 shows two important peaks in 2004 and 2005, where deforestation attributed to soybeans reached 90,387 ha and 105,956 ha, respectively. Since 2017, deforestation embodied in the EU’s imports from the top exporting countries seems to be consistently decreasing. Figure 56 shows the geographical distribution of deforestation risk associated with the international trade of soybean between tropical countries and the EU.

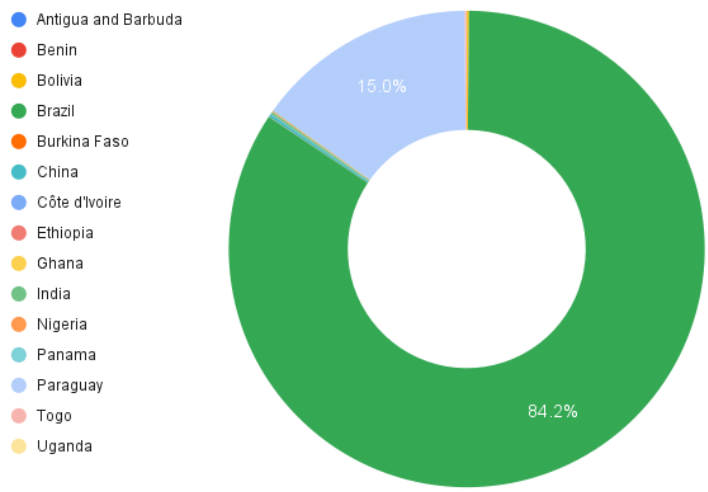


Figure 52. Share of soybeans exports into the EU from tropical countries (2003-2020).

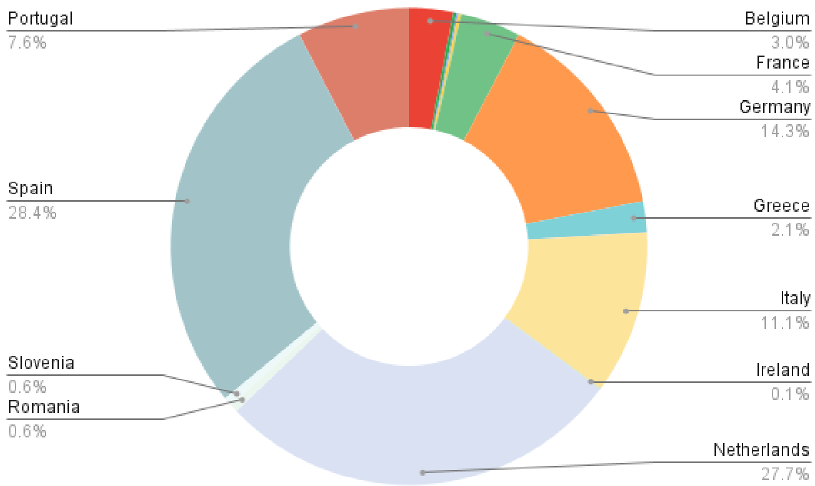


Figure 53. Share of soybeans imports into the EU from tropical countries (2003-2020).

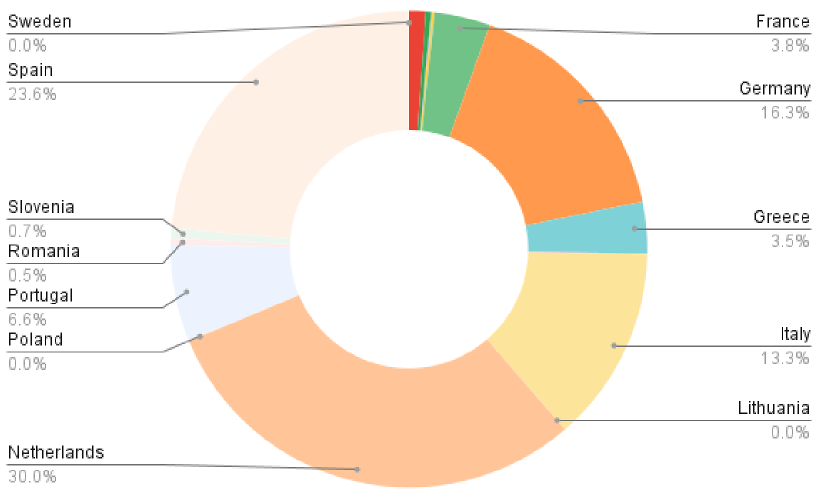


Figure 54. Share of deforestation risk attributed to soybeans exports to the EU (2003-2020).

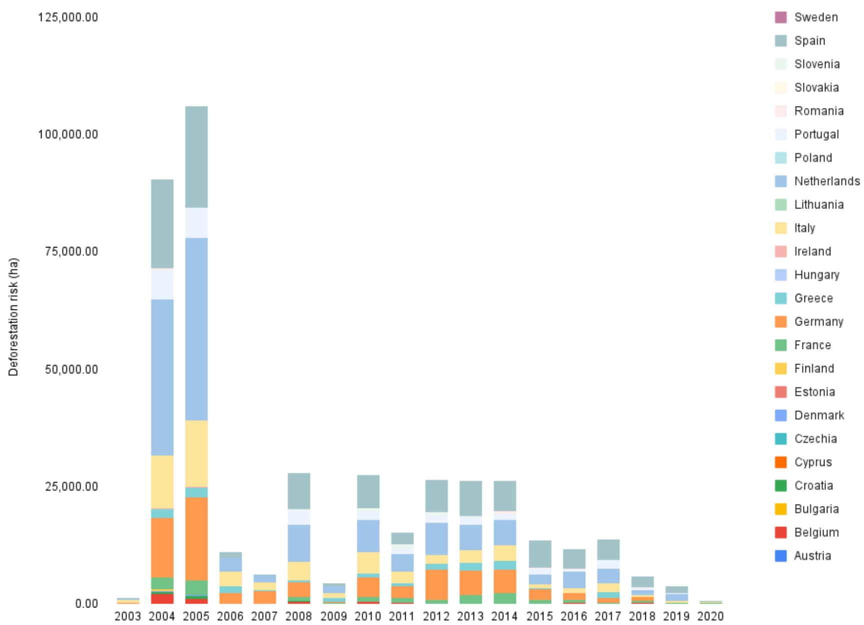


Figure 55. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of soybeans from tropical countries.

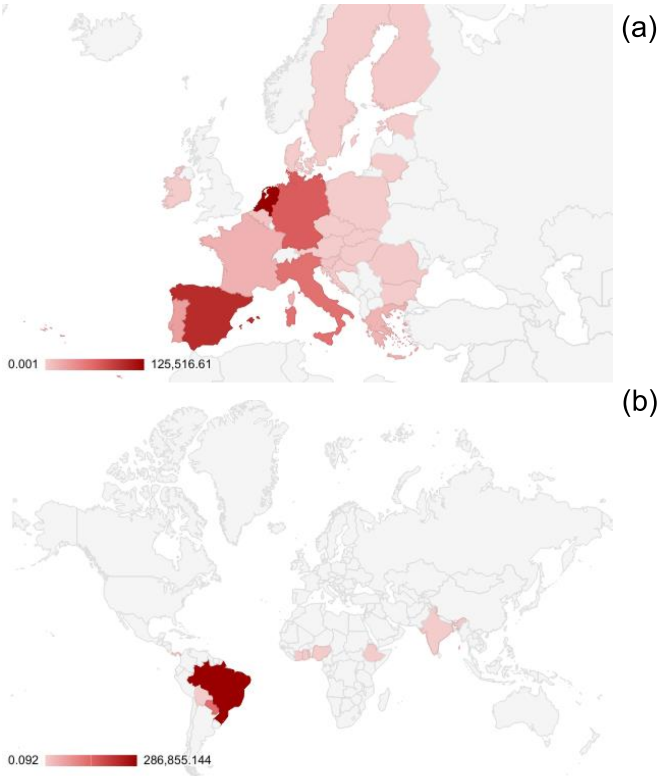


Figure 56. Geographical distribution of deforestation risk (ha) associated with trading soybeans in the EU among importing (a) and producing/exporting countries (b).

4.2.4.2 Soybean oil

Brazil is the country that exports the largest share of soybean oil to the EU (84%), followed by Paraguay (15.5%), as in the case of soybeans. Other countries, such as Suriname, Ecuador, Panama and Vietnam, have exported very limited amounts over the assessed period (7, 7, 13 and 15 tonnes, respectively). Even so, these countries made it to the top 15 exporters. This indicates high market concentration on the supply side as the soybean oil market is mainly driven by Brazil and Paraguay (Figure 57). The total imports from the EU add up to 2,635,321 tonnes, from which France has the largest share (30.7%) with 824,340 tonnes, followed by Spain (16%), Italy (14.7%), the Netherlands (13.9%) and Germany (13.2%), as can be observed in Figure 58.

In terms of deforestation risk, Figure 59 shows that France is responsible for the highest share of deforestation attributed to EU imports of soybean oil, with 7,115 ha (18.4%), closely followed by Spain, with 7,074 ha (18.4%). Of the total deforestation risk attributed to EU imports (38,699 ha), 38,593 ha were deforested in the top exporters' area.

Figure 60 shows the dynamic of deforestation embodied in EU imports from 2003 to 2020, indicating that imports from years 2005 and 2008 embodied more deforestation risk (9,469 and 8,761 ha, respectively). It is interesting to highlight that, differently to what other FRCs, soybeans imports did not embody the largest deforestation for 2008. The geographical distribution of deforestation risk (Figure 61) shows that some importers did not sustain embodied deforestation within their exports or imports, as it is the case of Ecuador and Panama. Conversely, Malaysia, Senegal and Suriname did not evidence deforestation risk, but caused it in other tropical countries for a total of about 106 ha, of wich Senegal caused 95 ha. Senegal, like Antigua and Barbuda and Malaysia, do not produce soybeans in its territory, completely relying on imports from other countries. Of these countries, only Antigua and Barbuda's imports did not cause deforestation risk in other tropical country.

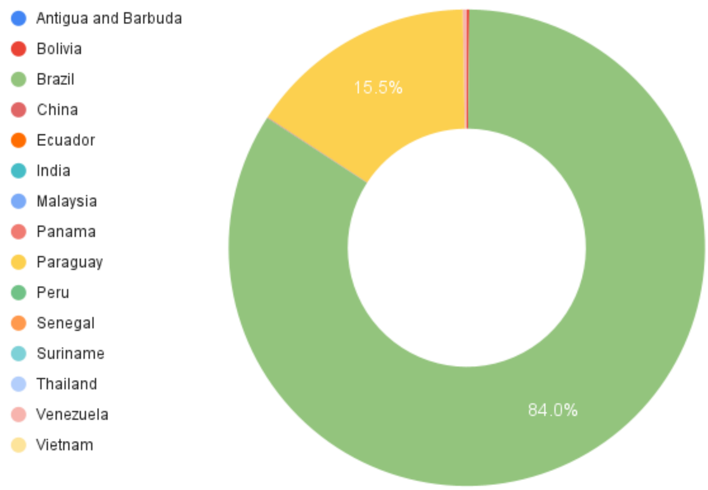


Figure 57. Share of soybean oil exports into the EU from tropical countries (2003-2020).

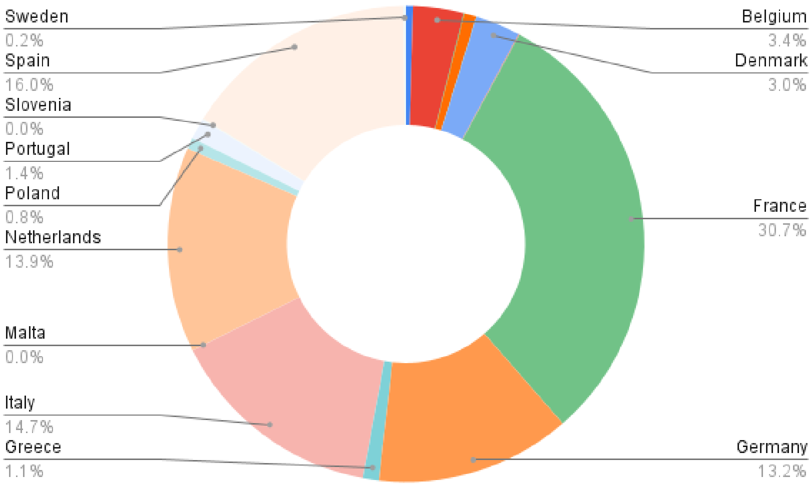


Figure 58. Share of soybean oil imports into the EU from tropical countries (2003-2020).

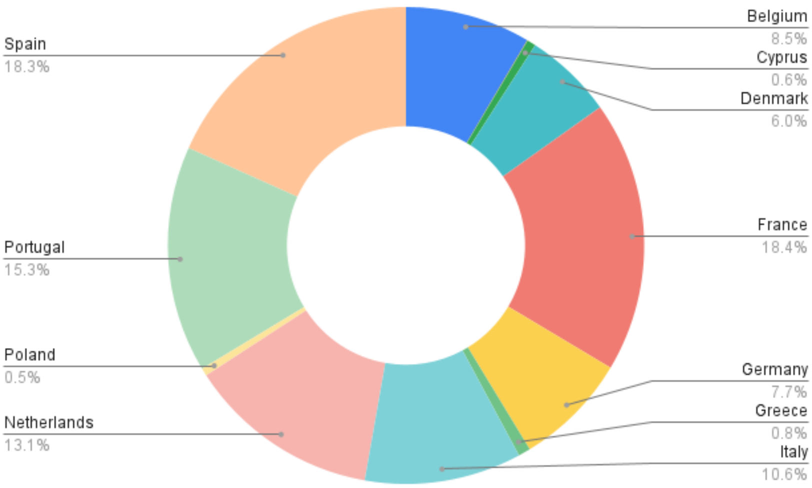


Figure 59. Share of deforestation risk attributed to soybean oil exports to the EU (2003-2020).

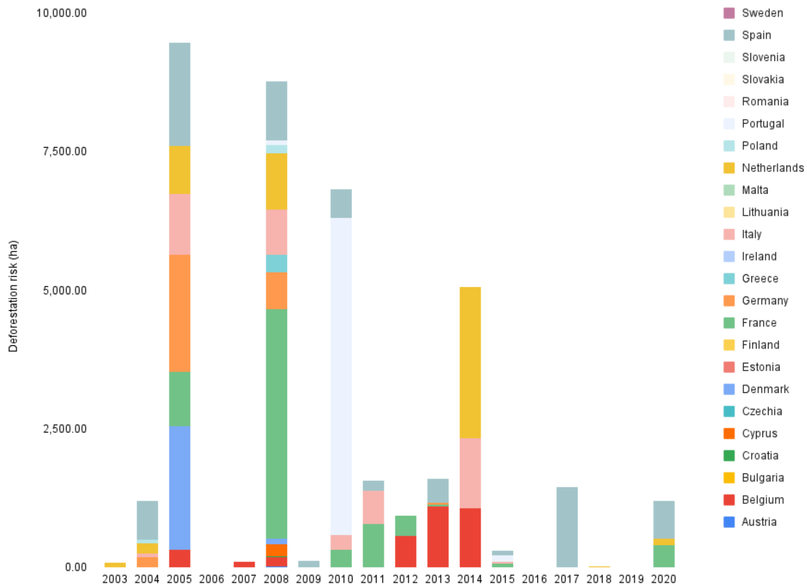


Figure 60. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of soybean oil from tropical countries.

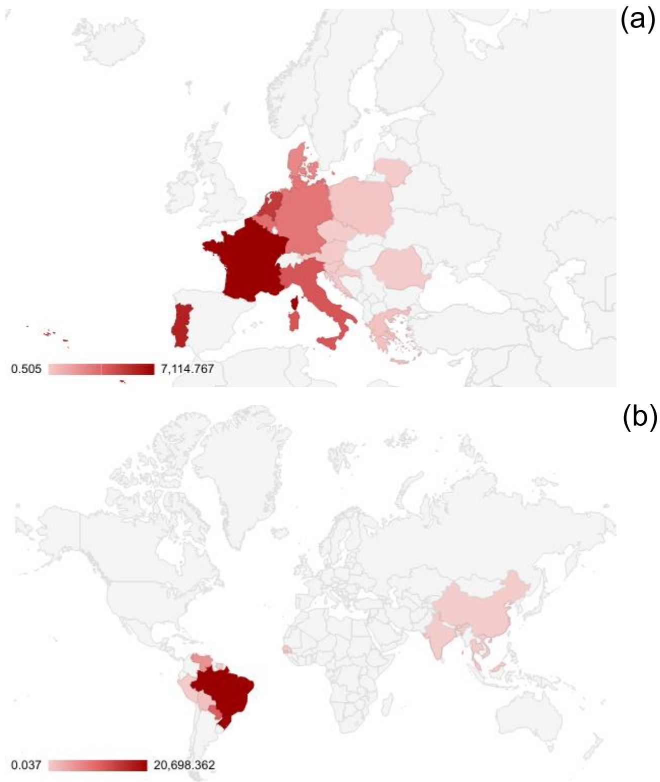


Figure 61. Geographical distribution of deforestation risk (ha) associated with trading in the EU among importing (a) and producing/exporting countries (b).

4.2.4.3 Soybean cake

During the period 2003-2020, 157,973,542 tonnes of soybean cake were exported from the top tropical countries into the EU market, of which 92.7% corresponded to Brazil's exports (Figure 62). The main importers were the Netherlands (27.9%), France (27.1%) and Germany (13%), as shown in Figure 63. With respect to the share of deforestation risk attributed to this FRC (Figure 64), it reached a total of 485,405 ha, mainly attributable to the main exporters: France (28.7%), the Netherlands (27.5%) and Germany (11.6%). Of the total deforestation risk, 484,736 ha of forest loss occurred in the exporting countries. This indicates that 668 ha were lost in other tropical countries where some exporting countries sourced themselves from to fulfil the EU demand (Antigua and Barbuda, Belize, Burkina Faso, Côte d'Ivoire, Panama and Trinidad and Tobago). Antigua and Barbuda, as well as Trinidad and Tobago, does not produce soybeans domestically; therefore, they are net importers, having caused 73 ha and 149 ha of deforestation, respectively, in other tropical countries. Belize, Burkina Faso, Cote d'Ivoire and Panama caused deforestation in other tropical countries as well, for a total of 90 ha, 31 ha, 60 ha and 265 ha, respectively. Data shows that Malta's imports did not cause deforestation in the assessed tropical countries, while EU's imports embodied the largest amount of deforestation in 2004 and 2005 (Figure 65). The geographical distribution of deforestation risk associated to soybean cake exports into the EU from tropical countries is presented in Figure 66.

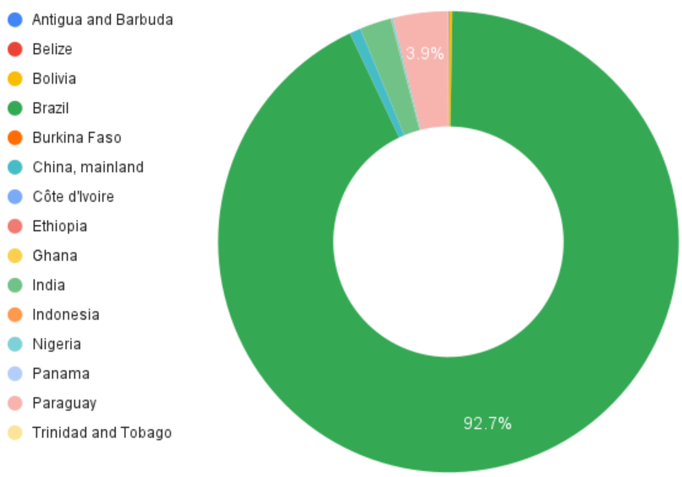


Figure 62. Share of soybean cake exports into the EU from tropical countries (2003-2020).

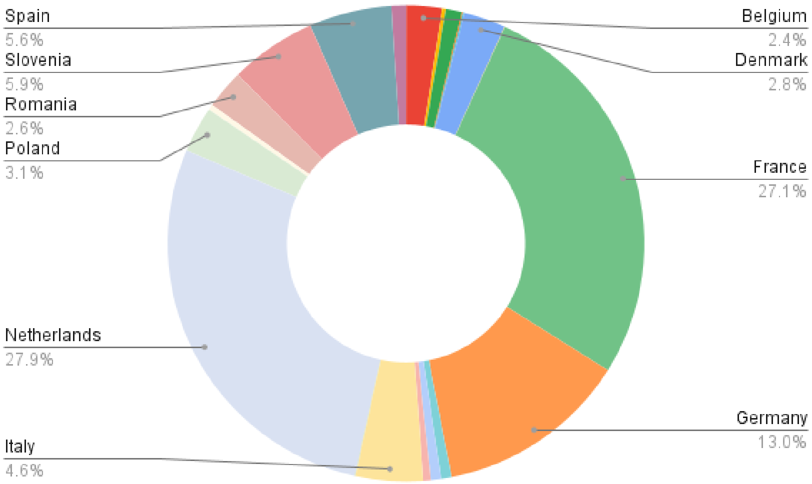


Figure 63. Share of soybean cake imports into the EU from tropical countries (2003-2020).

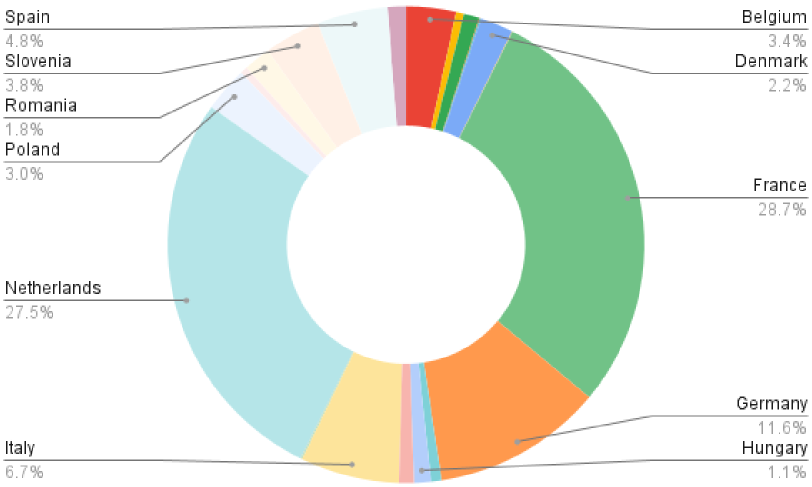


Figure 64. Share of deforestation risk attributed to soybean cake exports to the EU (2003-2020).

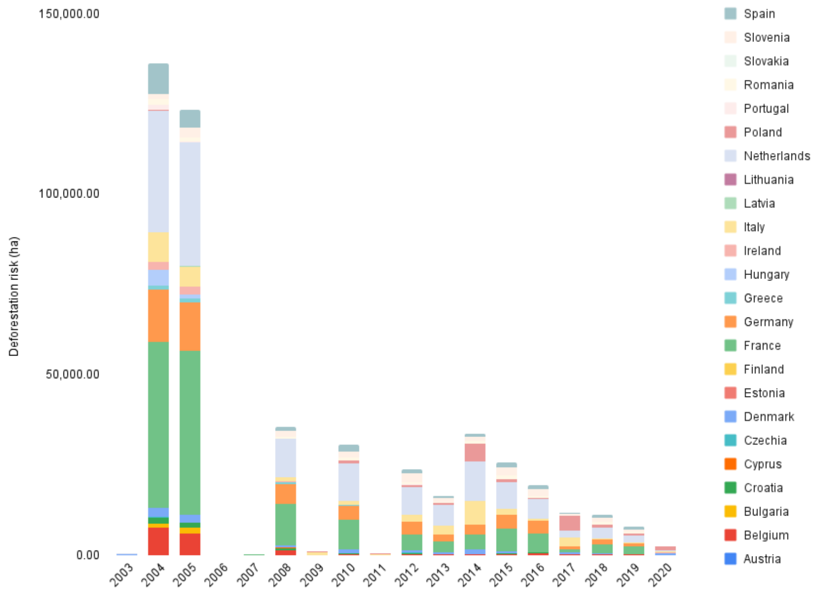


Figure 65. Deforestation risk attributed to EU countries during the period 2003-2020, based on their imports of soybean cake from tropical countries.

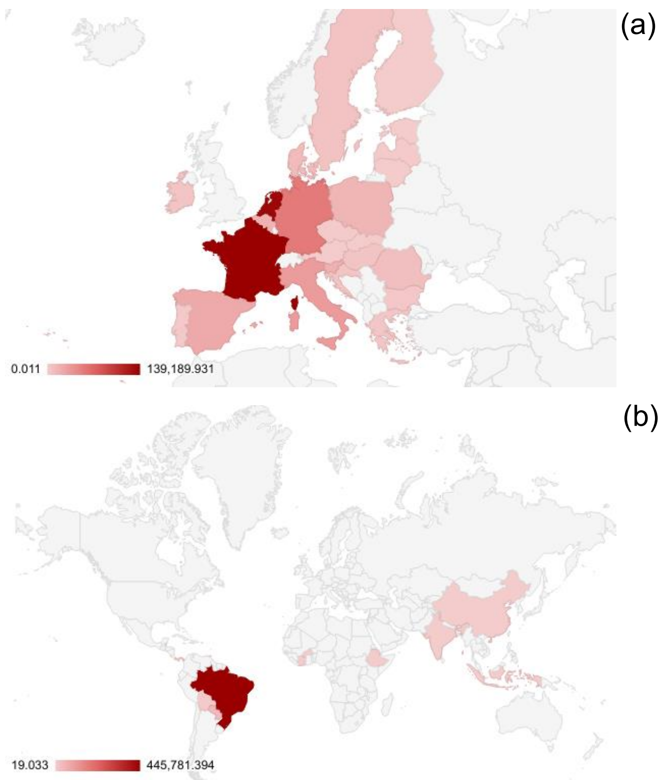


Figure 66. Geographical distribution of deforestation risk (ha) associated with trading soybean cake in the EU among importing (a) and producing/exporting countries (b).

4.3 Deforestation risk dynamics attributed to EU's imports of forest risk commodities

The Pearson correlation analysis showed both directly and inversely proportional values for the FRCs in terms of total deforestation risk in tropical countries (producers and suppliers' countries) and the amounts imported by EU countries. Especially the negative values suggest that deforestation risk is not directly linked with the imports and that other factors are at play behind these situations (e.g., imports to non-EU countries, price fluctuations over years). At the same time, it is important to note that correlation values express the broader picture and do not express year-specific correlations, which might be different depending on the case. For instance, i) if the *r* value of an FRC is negative, it does not imply that some years could not show positive correlation coefficients, and ii) if the *r* value of an FRC is positive, it does not imply that some years could not show negative correlation coefficients. Table 8 presents the correlation coefficient values for each FRC.

Table 8. Pearson correlation analysis of deforestation risk and EU imports of FRCs.

FRC	Pearson correlation (*r* value)
Cocoa beans	-0.50
Cocoa butter	-0.22
Cocoa paste	-0.20
Cocoa powder and cake	-0.20
Green coffee	0.25
Roasted coffee	-0.37
Palm oil	0.26
Palm kernel oil	-0.32
Palm kernel cake	0.11
Soybeans	0.32
Soybean oil	0.13
Soybean cake	0.44

All cocoa-related FRCs showed negative correlation coefficients, which were stronger for cocoa beans, and weaker for cocoa butter, cocoa paste, and cocoa powder and cake. In the case of coffee-related FRCs, deforestation risk due to green coffee imports by the EU showed to be weakly positively correlated, while roasted coffee showed a moderate negative correlation. As for oil palm FRCs, palm oil displayed a weak positive correlation, while palm kernel cake showed a negligible positive correlation and palm kernel oil was moderately negatively correlated. Finally, soybeans showed positive correlations, from which soybeans was moderate, soybean oil was weak and soybean cake was strong. Each year's dynamics are presented in Annex 8.

4.4 The social network analysis

All FRCs were analysed using the Gephi software. The SNA graphs were built considering two classes for the nodes' colour (green for tropical countries and pink for EU countries) and the weighted degrees for the nodes' size. In the graphs, green edges are feeding pink nodes and represent FRCs imports by the EU from tropical countries. Figures 67, 68, 69 and 70 show the SNA for aggregated data according to each commodity group (cocoa, coffee, oil palm and soybean, respectively), along with centrality measures (closeness centrality and eigenvector centrality). Besides that, this section also presents SNAs for the 12 FRCs considered in the study, providing more in-depth analysis.

In the case of the cocoa SNA, the results of closeness centrality show that the key EU countries in the trade of cocoa-related commodities are Germany (0.66), France (0.64) and the Netherlands (0.64), while the key tropical countries are China, Malaysia and Indonesia, with a score of 0.63 each. The countries displaying the lowest values are the Philippines (0.40), Finland (0.42) and Malta (0.42). On the other hand, the eigenvector centrality algorithm showed that, among EU countries, Germany is the country with more relevant connections (1.00), followed by France (0.99) and the Netherlands (0.99); among tropical countries, Malaysia, China and Cotê d'Ivoire displayed the highest values (0.98, 0.96 and 0.96, respectively).

As for the case of the coffee trade SNA, closeness centrality values among tropical countries are higher for Brazil and India, with 0.69 each, followed by Colombia, Ethiopia and Vietnam, with 0.67 each. EU countries with higher closeness centrality values are the Netherlands and Spain (0.65 each), followed by France and Germany (0.64 each). Panama, Senegal, the Dominican Republic, Malta and Ecuador displayed the lowest values (0.43, 0.44, 0.44, 0.45, 0.46, respectively). Likewise, higher eigenvector centrality values are shown by Brazil and India (1.0 each) among exporting countries and by the Netherlands and Spain (0.89 each) among importing countries.

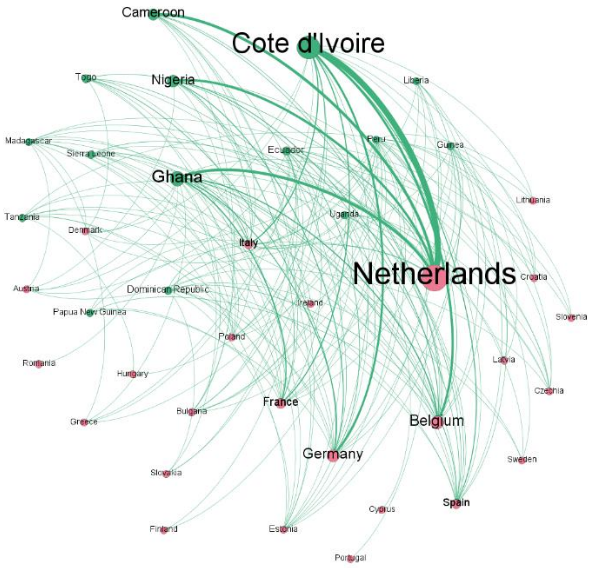


Figure 67. SNA for the cocoa trade.

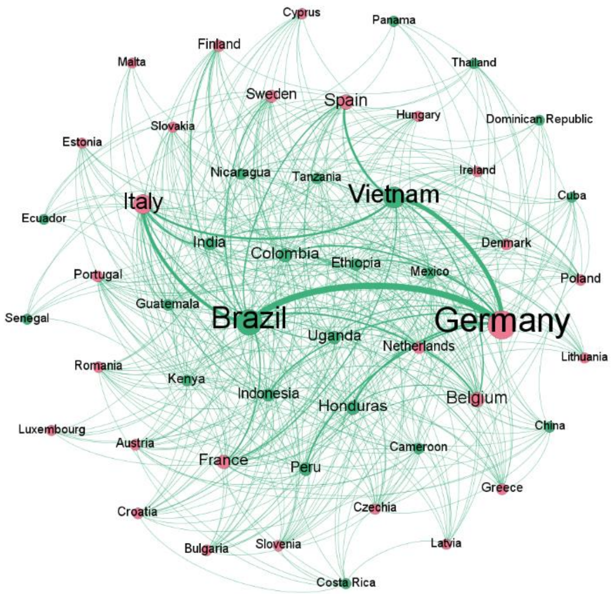


Figure 68. SNA for the coffee trade.

The SNA for oil palm-related FRCs shows that Indonesia, Malaysia and Singapore display the highest values in terms of closeness centrality (0.69, 0.69 and 0.60, respectively) among tropical countries. On the other hand, Germany, the Netherlands, Italy and Spain show the highest values among EU countries (0.57, 0.57, 0.56 and 0.56, respectively). The eigenvector centrality shows that Indonesia (1.0), Malaysia (1.0) and Singapore (0.92) have more relevant connections with EU countries, and that Germany (0.85), the Netherlands (0.85) and Italy (0.82) have more relevant links to tropical countries. Estonia, Finland and Malta show weaker connections among EU countries, with eigenvector values of 0.16 each.

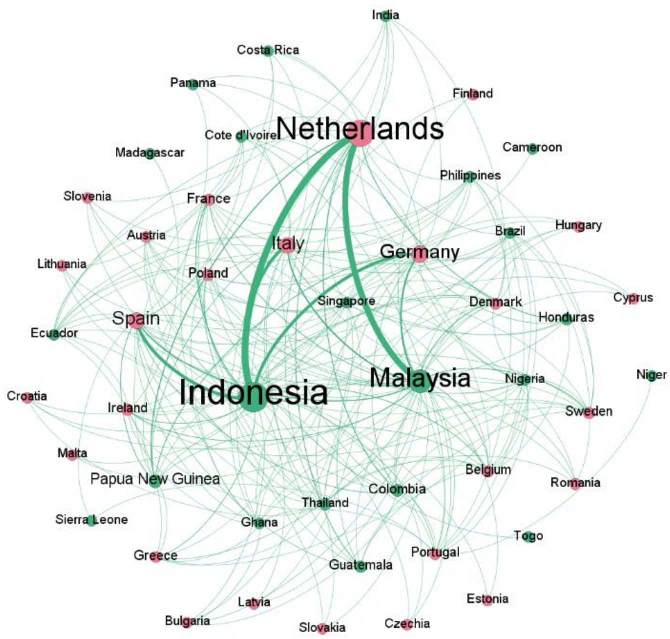


Figure 69. SNA for the oil palm trade.

The SNA for soybeans shows that Brazil, China, India and Paraguay have higher closeness centrality values among tropical countries (0.67, 0.65, 0.61 and 0.52, respectively). EU countries that display higher values are France, Italy and Spain (0.57, 0.50 and 0.50, respectively). Regarding eigenvector centrality scores, Brazil (1.0) is the country with more relevant connections within the network, followed by China (0.99), India (0.91) and Paraguay (0.71), and by France (0.71), Italy (0.62) and the Netherlands (0.59), among EU countries.

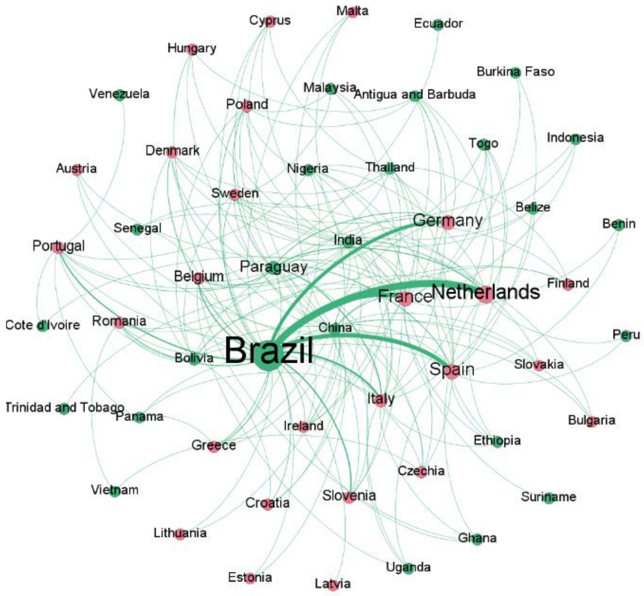


Figure 70. SNA for the soybean trade.

4.4.1 Cocoa

4.4.1.1 Cocoa beans

Based on the SNA for the cocoa beans trade (Figure 71) results of closeness centrality, the key actors are Peru (0.64), the Netherlands (0.62), Belgium (0.62), France (0.62) and Germany (0.62), while the countries displaying the lowest values are Cyprus (0.33), Romania (0.36) and Latvia (0.39). Amongst tropical countries, the eigenvector centrality algorithm showed that Peru is the country with more relevant connections (1.00), followed by Ecuador (0.90), Ghana (0.90), the Dominican Republic (0.73) and Uganda (0.73). As for EU countries, the Netherlands, Belgium, France, Germany and Italy displayed values of 0.96.

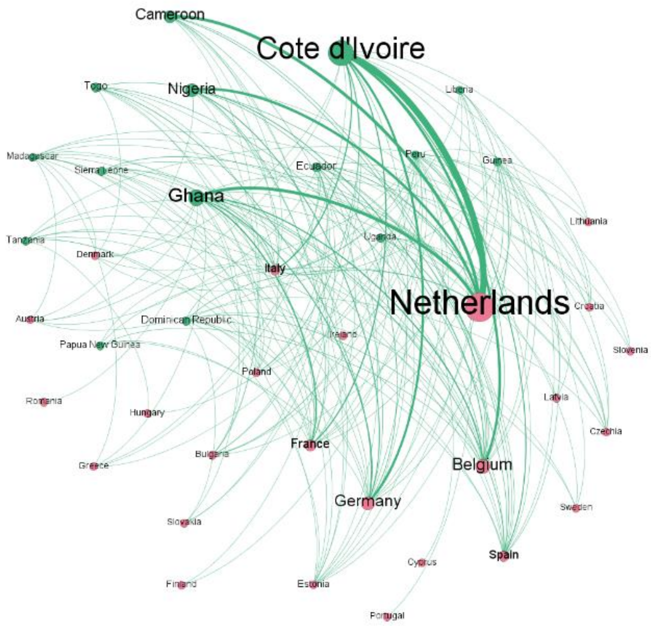


Figure 71. SNA for the cocoa beans trade.

4.4.1.2 Cocoa butter

The SNA for the cocoa butter trade is shown in Figure 72. Based on closeness centrality, the main actors involved in the cocoa butter trade network are the Netherlands (0.62), Cote d'Ivoire, Ghana, Indonesia, France and Germany (with a value of 0.60 each). According to the eigenvector centrality, Indonesia is the country with more relevant connections (1.0), followed by Ghana (0.99), Cote d'Ivoire (0.99), Malaysia (0.96) and the Netherlands (0.92). Conversely, Cyprus, Portugal and Austria showed the lowest values within EU countries (0.07, 0.17, 0.17, respectively), while Thailand, Mexico and Singapore showed the lowest values within tropical countries (0.30, 0.32 and 0.3, respectively).

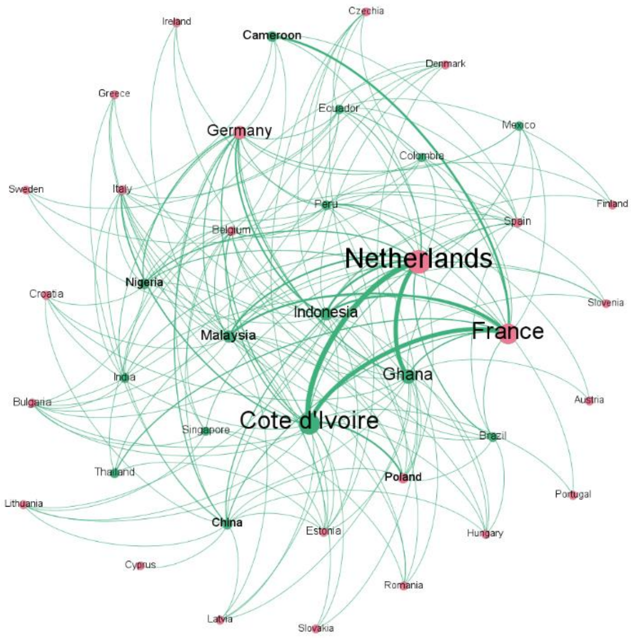


Figure 72. SNA for the cocoa butter trade.

4.4.1.3 Cocoa paste

Based on the SNA (Figure 73) results on closeness centrality, the key actors involved in the trade of cocoa paste are Cote d'Ivoire (0.66), Ghana (0.61), the Netherlands (0.58), Germany (0.58) and Belgium (0.55), while countries with the lowest values are India, the Philippines, Sweden (all of them with a value of 0.37), Madagascar (0.38) and Costa Rica (0.39). As for the eigenvector centrality, Cote d'Ivoire is the country with more relevant connections (1.0), followed by Ghana (0.96), the Netherlands (0.81), Ecuador (0.80), Peru (0.79) and Germany (0.79).

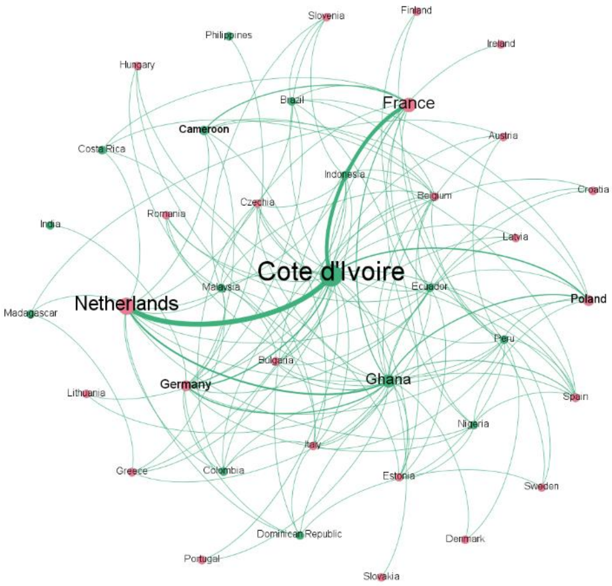


Figure 73. SNA for the cocoa paste trade.

4.4.1.4 Cocoa powder and cake

The SNA (Figure 74) shows that the key actors involved in the trade of cocoa powder and cake, based on closeness centrality, are China (0.69), Indonesia (0.67), Malaysia (0.67), Germany (0.62) and Spain (0.62). On the other hand, the countries with the lowest values of closeness centrality were Cuba (0.41), Cameroon (0.42) and Ireland (0.43). With regard to the eigenvector centrality, China is the country with more relevant connections and the highest degree (1.00), followed by Malaysia (0.99), Indonesia (0.97), Cote d'Ivoire (0.86) and Peru (0.84). Conversely, Ireland, Finland, Cuba, Malta and Austria held the lowest values (0.18, 0.20, 0.22, 0.23 and 0.29, respectively).

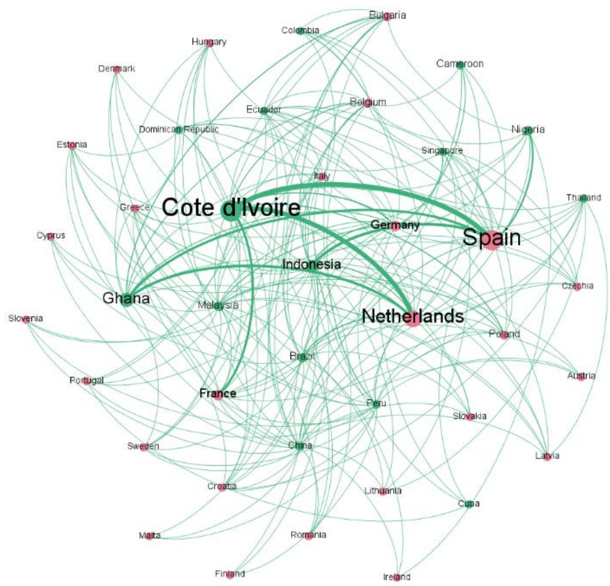


Figure 74. SNA for the cocoa powder and cake trade.

4.4.2 Coffee

4.4.2.1 Green coffee

The SNA chart for green coffee (Figure 75) shows a more complex graph compared to those reported for cocoa, as it displays more interactions between the actors. Brazil is the key actor involved in the trade of green coffee from the tropical domain side, based on its closeness centrality value (0.75), closely followed by Colombia, Ethiopia, India and Vietnam, with values of 0.72 each. Conversely, Cameroon showed the lowest value with respect to other tropical countries (0.61). Among EU countries, more than half showed the same closeness centrality score (0.61). Regarding the eigenvector centrality, Brazil has more relevant connections and the highest degree (1.0), followed by Colombia and Ethiopia with values of 0.98 each. On the other hand, Malta, Luxembourg, Estonia and Latvia held the lowest values (0.31, 0.36, 0.46 and 0.51, respectively).

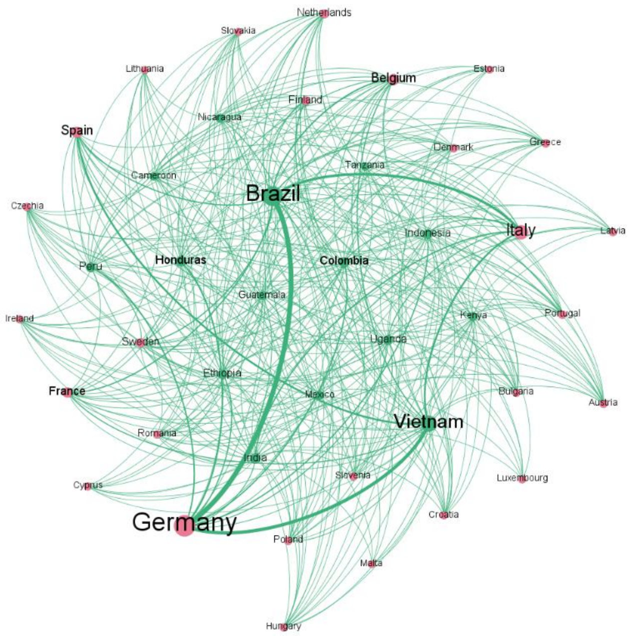


Figure 75. SNA for the green coffee trade.

4.4.2.2 Roasted coffee

According to the SNA (Figure 76), and as in the case of the green coffee trade, Brazil is the key actor involved in the trade of roasted coffee based on its closeness centrality value (0.71), followed by Vietnam (0.61) and Colombia (0.59) among tropical countries. In contrast, Honduras, Panama and the Dominican Republic showed the lowest values (0.42, 0.42 and 0.43, respectively). Regarding EU countries, France, Germany, and the Netherlands displayed the highest values (0.59 each). As for the eigenvector centrality, Brazil has more relevant connections and the highest degree (1.0), followed by Vietnam, Colombia, India and China, with values of 0.91, 0.88, 0.79 and 0.76, respectively. As for the EU countries, the lowest values were held by Luxembourg (0.09), Malta (0.09) and Latvia (0.13).

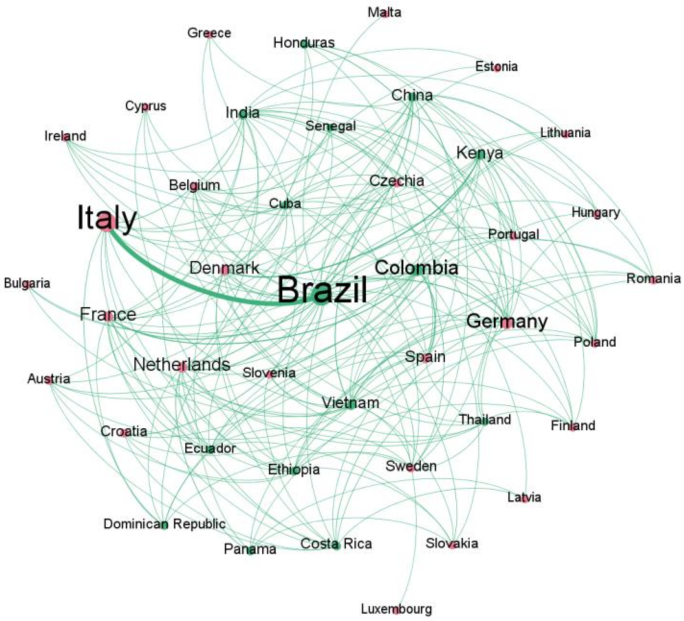


Figure 76. SNA for the roasted coffee trade.

4.4.3 Oil palm

4.4.3.1 Palm oil

The network of the palm oil trade between tropical and EU countries is presented in Figure 77. Based on the SNA, Malaysia and Indonesia are key network actors, with closeness centrality values of 0.74. They are followed by Singapore (0.63) and Thailand (0.53), while the lowest values correspond to Panama, Costa Rica and Honduras (0.41, 0.42 and 0.43, respectively). As for the EU countries, Germany, Italy, and the Netherlands showed meaningful participation amongst other importers, with values of 0.62 each. These countries also displayed higher scores among EU countries, regarding the eigenvector centrality (0.79 each). As for tropical countries, Malaysia and Indonesia showed to be the countries with more relevant connections, with a value of 1.0. Conversely, the countries with the lowest values were Estonia, Finland, Malta and Slovakia, all of them with a value of 0.17.

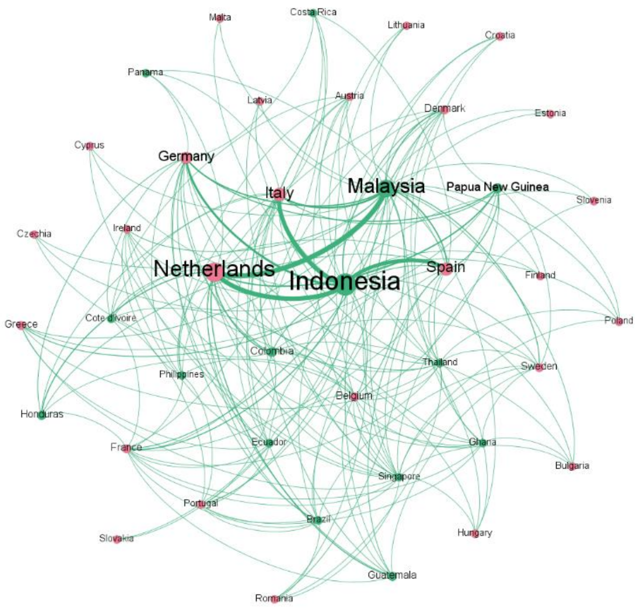


Figure 77. SNA for the palm oil trade.

4.4.3.2 Palm kernel oil

Regarding the SNA for the palm kernel oil trade (Figure 78), Malaysia and Indonesia showed the highest closeness centrality values (0.70 and 0.63, respectively), followed by Ghana (0.45). On the other hand, the Philippines, India and Colombia had the lowest values (0.42 each of them). Among EU countries, the countries with the highest values were Germany (0.62), the Netherlands (0.62), Belgium (0.58), Italy (0.57) and Spain (0.55), while Slovakia, Croatia and Finland showed the lowest values (0.39, 0.42 and 0.42, respectively). A similar scenario was found when looking at eigenvector centrality values. Malaysia, Indonesia, Germany and the Netherlands showed the most relevant connections in the network, with scores of 1.0, 0.94, 0.90 and 0.90, respectively.

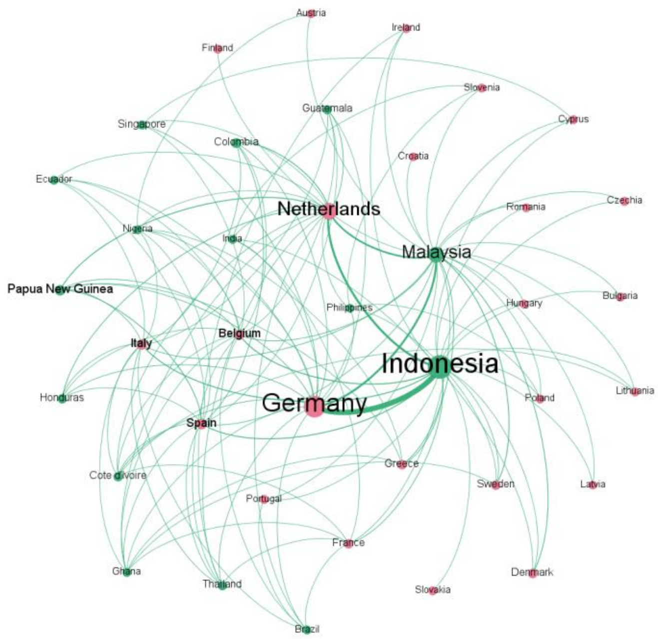


Figure 78. SNA for the palm kernel oil trade.

4.4.3.3 Palm kernel cake

The palm kernel cake SNA shows that Malaysia is the most relevant country in exporting FRCs in the network, followed by Indonesia, Nigeria, Poland, Spain and Ireland, with closeness centrality scores of 0.67, 0.53, 0.52, 0.51, 0.49 and 0.49, respectively. On the other hand, the countries with the lowest scores are Slovenia (0.28), Niger (0.33), Brazil (0.33) and Madagascar (0.33). Regarding the eigenvector centrality, Malaysia, Indonesia, Nigeria and Ghana showed the highest values amongst tropical countries (1.0, 0.82, 0.78 and 0.65, respectively). Amongst EU countries, Spain, Poland and Ireland displayed the highest scores (0.62, 0.60 and 0.59, respectively).

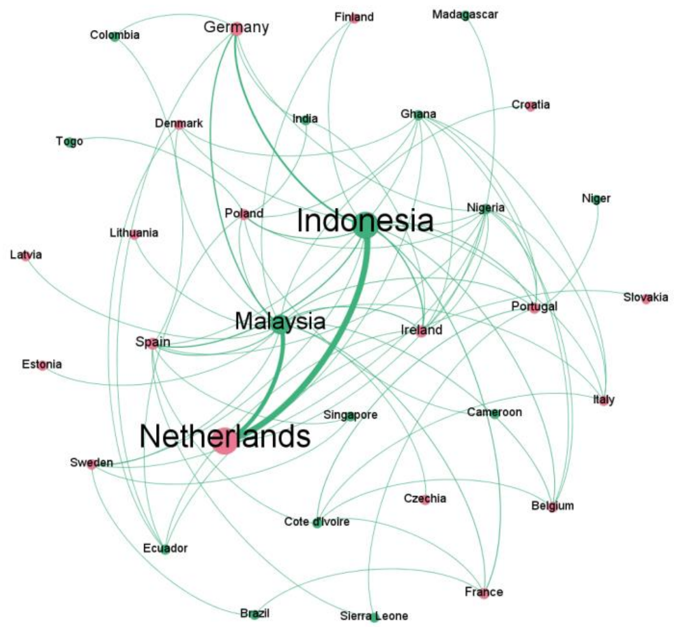


Figure 79. SNA for the palm kernel cake trade.

4.4.4 Soybean

4.4.4.1 Soybeans

The SNA for the trade of soybeans between tropical and EU countries (Figure 80) shows that, in terms of closeness centrality, Brazil, China and India are the most relevant actors in the network, with scores of 0.71, 0.65 and 0.65, respectively. Amongst EU countries, the highest values were displayed by France (0.52), Italy (0.52), Germany (0.51), the Netherlands (0.51) and Spain (0.51). Conversely, Cote d'Ivoire, Ghana and Burkina Faso showed the lowest values amongst all the actors (0.32, 0.34 and 0.34, respectively). Regarding eigenvector centrality, Brazil, China and India led the list of tropical countries, with values of 1.0, 0.96 and 0.91, respectively. As for the EU countries, Italy, France and the Netherlands displayed the highest eigenvector centrality scores (0.52, 0.51 and 0.49, respectively). On the contrary, Malta and Latvia showed the lowest values (0.10 and 0.11, respectively).

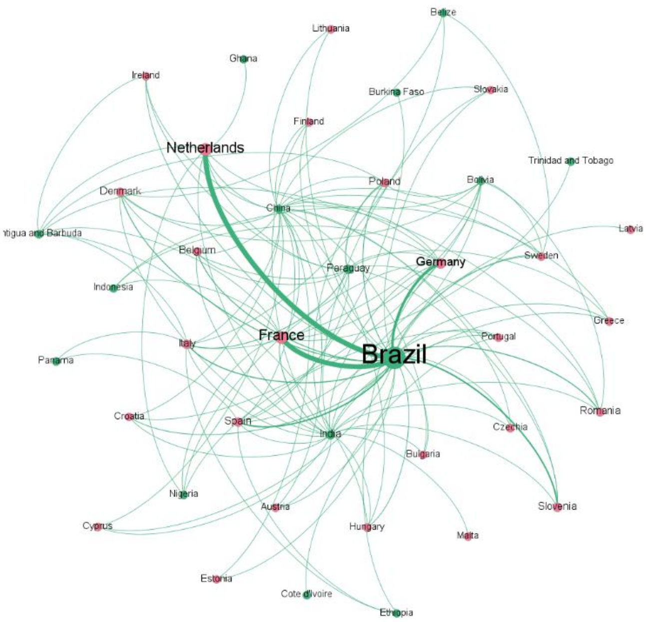


Figure 80. SNA for the soybeans trade.

4.4.4.2 Soybean oil

The SNA for the soybean oil trade between tropical and EU countries is presented in Figure 81. Based on the SNA, Brazil, France, Belgium and China are key network actors, with closeness centrality values of 0.66, 0.52, 0.37, and 0.46, respectively. The lowest values correspond to Romania (0.24), Finland (0.29), Ireland (0.29) and Venezuela (0.30). Concerning the eigenvector centrality, Brazil, China and Paraguay showed to be the countries with more relevant connections among tropical countries, with scores of 1.0, 0.71 and 0.51, respectively. On the contrary, the countries with the lowest values were Vietnam (0.04), Venezuela (0.06) and Panama (0.08). Among EU countries, the countries with the highest scores were France (0.62), the Netherlands (0.51) and Belgium (0.46).

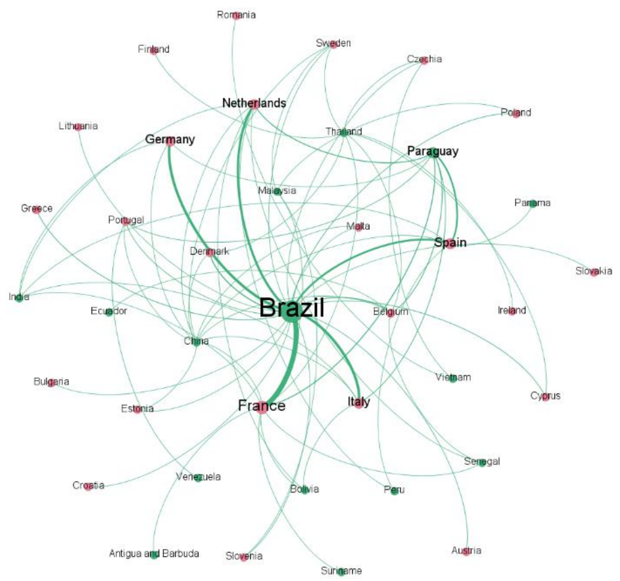


Figure 81. SNA for the soybean oil trade.

4.4.4.3 Soybean cake

The SNA for the soybean cake trade (Figure 82) showed that Brazil, China, India, France and Italy are key actors in the network due to their closeness centrality scores (0.71, 0.65, 0.65, 0.52 and 0.52, respectively). The countries with the lowest scores, conversely, were Cote d'Ivoire (0.32), Ghana (0.34) and Burkina Faso (0.34). Regarding eigenvector centrality scores, Brazil is the country with more relevant connections in the network, displaying a value of 1.0, followed by China (0.96), India (0.92), Paraguay (0.58), Italy (0.52) and France (0.52). Among EU countries, the lowest values were displayed by Malta (0.10), Latvia (0.11) and Estonia (0.11).

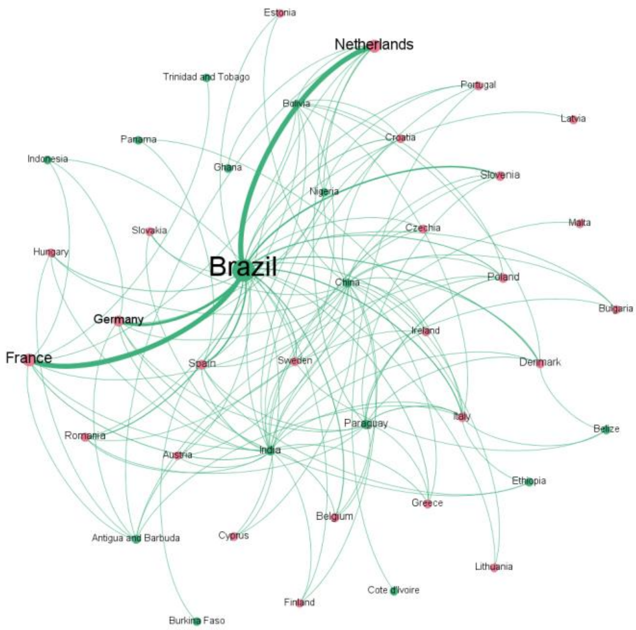


Figure 82. SNA for the soybean cake trade.

5. Discussion

This chapter discusses the implications of this study's findings based on a literature review (Section 5.1) while addressing the impact on management and decision-making (Section 5.2). In the end, the limitations of this study and the recommendations for further research are also presented (Section 5.3).

5.1 Discussion of results

5.1.1 The relevance of an integrated framework

This study relied on literature review to design an integrated framework for assessing the deforestation risk associated with the production and trade of FRCs in Europe. The integrated framework (Figure 4) was developed as a learning method to be used by actors involved in the supply chain of FRCs traded between tropical and EU countries. It incorporates environmental and socio-economic concepts to better understand the implications of trade in deforestation risk in tropical forests. An in-depth literature review guaranteed that the key processes and elements of interest were considered, creating relevant connections between them and allowing for a flexible interpretation based on each case scenario.

In this sense, the integrated framework opens the discussion to explore the role of current telecoupled systems in terms of the causes and effects in both sending and receiving systems (tropical countries and EU countries, respectively) with a clear view of the components in the supply chain of FRCs as deforestation drivers (Henders and Ostwald, 2014; DeFries et al., 2010; Pendrill et al., 2019a). These elements or components (i.e., systems, agents, flows, causes and effects) portray complex, interrelated relationships that hide gaps, costs and benefits that are revealed once they are analysed from a telecoupling perspective (Liu et al., 2013). Given its flexibility, the integrated framework also allows a more specific assessment of the systems. For instance, it can be narrowed to be more country or region-specific and could facilitate including other elements in the analysis in addition to those included in this study. For instance, water degradation or biodiversity loss could be analysed besides deforestation risk, and the analysis of spillover systems - for example, socio-economic ones - could be added to the assessment of receiving and sending systems.

Since the integrated framework gathers different concepts and components, it enhances the incorporation of a multidisciplinary approach in research that can combine scientific data with social data. This combination can boost policy-making and thinking based on reliable information, being helpful to the actors involved along the supply chain of FRCs. This way, the integrated framework is a point of departure for developing methodologies to retrieve data from the systems and then analyse them in light of plausible theories. It is important to highlight that the complexity of the systems and the interaction of their components do not make it feasible to simultaneously assess and link all the elements included in the integrated framework in all cases. Each element (e.g., corruption, soil degradation) should be understood as part of a different (bigger or smaller) system that, at the same time, interacts with other systems' components (Zhao et al., 2021; Liu, 2017) and is influenced at a scale that might be out of the scope of the research. From this perspective: i) the larger the scope of the analysis, the less feasible or practical it will be to combine many different elements in parallel, while ii) the narrower the scope, the more feasible it will be to combine many different elements at the same time.

5.1.2 Deforestation risk and the expansion of croplands

Deforestation can be attributed to expanding cropland, pastures and forest plantations (Pendrill et al., 2019a; Hoang and Kanemoto, 2021), besides to other proximate drivers (e.g., mining, infrastructure). In this line, the results presented in Figure 5 showed that cropland expansion is the main cause of forest loss in the 45 tropical countries analysed. This coincides with what has been previously stated in other studies in the tropics (Ceddia, 2020; Kuschnig et al., 2021; Hu et al., 2021; Houghton, 2012) and confirms the most recent data published by FAO (2022), according to which agricultural expansion is driving almost 90% of global deforestation. However, it is relevant to note main deforestation drivers may vary depending on the country and region. For instance, forest plantations have been responsible for most deforestation in Malaysian Borneo over the past four decades (Gaveau et al., 2016), whilst this study's results show that agriculture has been the primary cause of deforestation in the entire country (Malaysia). Similarly, Colombia showed more extensive forest loss related to expanding pastures than to expanding cropland, which coincides with data on deforestation that states that cattle ranching is the main deforestation driver in many regions in the country (Polanía-Hincapié, 2021; Murad and Pearse, 2018).

Especially in 2003 and 2017, it is possible to observe important peaks in terms of the expansion of cropland, corresponding to areas of over 9 million ha. However, FLA to cropland expansion was most prominent in 2009, 2016 and 2017. Concerning the 2003 expansion, countries such as Brazil, Nigeria, China, Indonesia and Sierra Leone displayed a significant increase in their cropland areas, while the 2017 expansion was mainly driven by Colombia, which accounted for an expansion of 6,165,800 ha, 67% of the total expansion of the 45 countries reported for that year. Nevertheless, the 2003 expansion did not generate as much deforestation as the expansions in 2007, 2009, 2016 and 2017, from which 2009 reported the highest (2,911,701 ha).

In 2009, important cropland expansions occurred in countries such as Indonesia, India, Thailand, Peru and Kenya. However, the largest areas of forest loss attributable to those expansions corresponded to Indonesia (1,600,000 ha), Bolivia (188,000 ha), Tanzania (143,354 ha), Venezuela (121,164 ha), Thailand (114,209 ha) and China (112,777 ha). Regarding Indonesia, which accounts for 55% of the total FLA to cropland expansion during that year, a study published by Austin et al. (2019) confirms that the main deforestation driver was large-scale oil palm plantations. The authors highlighted a decline in the trends of deforestation due to oil palm plantations after 2009, suggesting that this could be because of new policies and government interventions (e.g., Indonesia's national moratorium on new permits for the conversion of primary natural forests and peat lands, established in 2011), as well as voluntary commitments.

Regarding deforestation risk embodied in the FRCs assessed in this study, forest loss attributed to the expansion of soybeans and oil palm showed to be causing considerably more deforestation than the expansion of coffee and cocoa, from which coffee was the crop with less deforestation attributed (Figure 6). Furthermore, as presented in Table 6, forest loss attributed to oil palm expansion showed to be more correlated to the overall cropland expansion over the assessed period (2003-2020). It is important to highlight that this research focuses on a selected number of FRCs, assumed to be the most impactful ones at the global scale and with specific reference to EU imports. Other traditional tropical export crops, such as rubber or sugar, despite contributing little to embodied deforestation at the global scale might have a key role and a larger contribution at single country or sub-regional scales (Pendril et al., 2019a).

Indonesia and Brazil accounted for 56% and 15% of the total deforestation embedded in EU imports of FRCs, respectively. Indonesia is a major producer of palm oil, and it destines 66.2% of its production to exports, but also to food products (16.4%), oleochemicals (3.3%) and biodiesel (14.1%) to cover its domestic demand for energy (Farobie and Hartulistiyoso, 2022). In this regard, it recently banned oil exports to reduce price rising and ensure the availability -and affordability- of this resource for domestic supply (Guild, 2022). As for Brazil, it is one of the countries that, together with China and Argentina, dominate the global market of soybeans production and exports, from which Brazil's exports to the EU account for the most significant share of deforestation risk (Kuepper and Stravens, 2022). This also coincides with the results obtained in this study, which show Brazil as the major exporter of soybean commodities to the EU market.

On the other hand, cocoa and coffee, which displayed lower deforestation risk embedded in their production, have evidenced an important shift in the last decades in terms of moving towards more sustainable production systems. Business-oriented programmes, certification schemes and zero-deforestation commitments have established alternatives and criteria to halt and reduce deforestation attributed to the production of cocoa and coffee (Kouassi et al., 2021a; Grabs et al., 2021; Teague, 2020). For example, In Peru, one of the major producers of cocoa and green coffee sold to the EU, the Forest Law promotes agroforestry concessions aiming to prevent farmers from trespassing forest areas (Pokorny et al., 2021). Likewise, consumers' demand for certified coffee and cocoa products that respect the environment and society in their production increased in the last years (Wahyudi et al., 2020; Hajjar et al., 2019. This might be affecting the behaviour of the supply side, given the premium prices allocated to them (Teuber, 2019; Saravia-Matus et al., 2020).

5.1.2.1 Deforestation risk embodied in the cocoa trade

Cote d'Ivoire is the major exporter of cocoa beans, cocoa butter, cocoa paste and cocoa powder and cake to the EU, and also the country with more deforestation associated with its exports. Cocoa exports are said to support economic development in the country and represent a livelihood asset to smallholders (Löhr et al., 2021). Nevertheless, forest loss linked with full-sun cocoa farming (the country's most common cocoa cultivation system) has led to biodiversity loss and soil quality deterioration (Tondoh et al., 2015). This, despite cocoa farmers find deforestation in itself to be an activity that contributes to their livelihoods (85.6%) and that represents a source of income (88.6%), according to a household survey conducted by Kouassi et al. (2021b) in South-West Cote d'Ivoire, one of the principal productive areas of cocoa in the world.

Another issue strictly associated with cocoa production, which is far from being solved, is child labour. This issue and the critical deforestation numbers related to cocoa production in Cote d'Ivoire do not seem to have discouraged international trade. Around 790,000 children between 5 and 17 years old worked at cocoa farms in 2019 (NORC, 2020). Both certified and non-certified farms that sell to international trading companies rely on children for many field activities (Jouvin, 2021). Even though internationally recognised targets to reduce hazardous child labour have been made, trading companies are still failing at accomplishing them, not only in Cote d'Ivoire but also in Ghana and other African countries (Aboa et al., 2020).

Indonesia, Tanzania, Malaysia, Peru and Ghana, follow Cote d'Ivoire in terms of deforestation risk, even over countries that export more significant amounts than them in some cases, such as Cameroon, Nigeria and Ecuador, which evidenced less embodied deforestation. In this regard, shaded cocoa plantations are said to have several advantages when compared to full-sun cocoa plantations, maintaining tree cover and slowing down forest loss (Orozco and Lopez, 2021). Cocoa production systems in Cameroon, Nigeria and Ecuador are increasingly including tree species (Blomme et al., 2021; Bentley et al., 2004; Ramos et al., 2019), which could explain the lower deforestation risk reported for those countries. Nevertheless, shaded plantations do not seem to be the only solution to the deforestation issue; lower values are the result of more complex situations. For instance, Peru’s most common cocoa production system is under shade trees (Orozco and Lopez, 2021); despite this, extensive deforestation is still associated with this FRC in the country. Even so, full-sun cocoa is the most common production system in some of the biggest producing countries, besides Cote d'Ivoire (Belsky and Siebert, 2003; Witjaksono, 2016; Noble, 2017).

Even so, full-sun cocoa is the most common production system in some of the biggest producing countries, especially in Southeast Asia and West Africa (Belsky and Siebert, 2003; Witjaksono, 2016; Noble, 2017; USAID, 2020). Concerning deforestation and full-sun cocoa plantations in Ghana, Ruf (2011) mentioned that this cultivation practice is chosen over agroforestry systems because the adoption of sun-loving hybrids is more efficient in resource allocation and yield. Despite this, agroforestry systems are increasingly being adopted and encouraged in tropical countries because of their ecological benefits and their role in climate change mitigation and adaptation (Agence Française de Développement, 2022; Perry et al., 2016; Djuideu et al., 2021). Agroforestry systems have been promoted since decades ago as a way to contribute to forest and biodiversity conservation (Asare, 2006) and livelihood strategies (FAO, 2014).

Regarding importing countries, the results showed that the Netherlands is the European country with more imported deforestation risk, followed by France (61,340 ha). More specifically, the Netherlands generates more deforestation because of its cocoa beans imports than any other EU country. It is important to highlight Amsterdam's role as the biggest cocoa harbour globally. The Netherlands processes, mainly in Amsterdam, around 80% of the total volume of cocoa beans it imports (Logatcheva, 2014). The country is the second-largest exporter of cocoa beans in the region, after Belgium; however, Dutch exports of semi-finished cocoa products have been increasing in the last years (CBI, 2021). In general terms, the cocoa beans sector displays a growing production and consumption, which can be linked to the increasing demand for dark chocolate (Filová and Hrdá, 2018; Gavrilova, 2021). On the other hand, cocoa butter and cocoa paste imported by France embedded more deforestation with respect to other EU countries. France is one of the biggest producers of cocoa products and chocolate in the EU, with large chocolate companies having facilities/factories located in its territory, such as Ferrero, Nestlé, Mondelez, Lindt and Cémoi. In 2018, it exported 57% of its finished and semi-finished cocoa products worldwide, exporting around 50% to EU countries (CBI, 2020a). Based on available data, it is possible to state that the role that France and the Netherlands play in the cocoa sector reflects how trade operates in globalised and specialised markets, particularly in terms of re-exports of more processed products in supply chains with added value (Dupas et al., 2021).

On the other hand, the assessment of embodied deforestation associated with cocoa powder and cake imports positioned Spain as the country whose imports produce more deforestation risk in tropical countries. According to OEC (2022a), Spain is the fifth largest exporter of cocoa powder globally, which it imports from tropical countries, but also from EU countries such as the Netherlands, Germany, Portugal and France. The country widely consumes cocoa powder, which amounts to 25% of Spain's consumption of cocoa products (CBI, 2019) and makes it the first consumer of cocoa powder in Europe (Alarcón, 2018), with companies such as Idilia Foods, Valor, Mercadona and Alcampo leading the market. Here, it is relevant to note China's participation in re-exporting a product it does not produce domestically. For instance, Huanda Cocoa, a Chinese company that processes cocoa beans into cocoa powder and cake, sources itself from Ghana and Cote d'Ivoire. According to its website, Huanda Cocoa also produces cocoa powder in Indonesia and is one of the top 3 Chinese supplier and exporter of cocoa powder worldwide. This sheds light on the role that non-producing countries and countries with negative balances (in terms of production and exports) have in the trade of FRCs into the EU market.

Concerning the Dominican Republic, Lazzarini et al. (2022) mention that it is the leading country in exporting organic cocoa beans into the EU market. This country consistently showed no deforestation associated with its cocoa exports to the EU. More sustainable practices could be related to these results since cocoa agroforestry systems are organic in their majority, and farmers' practices mainly include diversification of cocoa plantations to enhance ecosystem services (Notaro et al., 2020).

As for the deforestation risk dynamics over time associated with EU imports of cocoa, they show different trends. Especially 2008 showed lower values than other years in some cases. At first glance, this could be attributed to the economic crisis of 2008; nevertheless, the results regarding trade data do not back up this assumption. For instance, the cocoa beans trade did not decrease in 2008 but showed a shortfall in 2015. Comparing this data with deforestation risk associated with EU imports, 2015 imports display the fifth-highest embedded deforestation over 18 years. This, together with the correlation analysis presented in the results (Table 7), suggests that deforestation dynamics are more complex than merely looking for one event to explain the overall trend, even more with so many countries and trends involved. Despite this, it is a fact that global crises have large impacts on deforestation and food production (Antonarakis et al., 2022).

The metacoupled systems theory is actually better at elucidating this: some systems can share the same agents and causes, but this does not ensure that the effects on each system will be the same, although they could be similar or share specific traits in some situations (Liu, 2017). Furthermore, since interrelationships between systems may not be linear, there could be time lags and legacy effects (Liu et al., 2007), which are worth analysing further and more precisely. In the case of the 2008 crisis, the effects could have been perceived in the same year, but also some years later. Another example is the international conflict between Russia and Ukraine, which has triggered a food security crisis. Food prices have considerably increased since transportation costs are higher, and fertilisers have become some sort of luxury good that, in some countries, only big companies can afford. The World Bank (2022) indicates that food production in many regions will face challenges in the future. In a metacoupled world, this will have several consequences, likely for a prolonged period, and not only in the international trade arena but also in terms of nutrition, social conflicts, poverty, etc.

What can be stated from the deforestation risk dynamics is that, whenever the deforestation risk was higher (or lower), independently of the amounts imported by the EU, those imports were more (or less) likely to have been produced as the consequence of forest clearing in the tropics. For instance, Figure 15 shows a significant increase in embodied deforestation in EU imports of cocoa butter in 2014, where Germany stands out, displaying higher numbers than in any other year. Nevertheless, total EU imports are not much different than in previous years, and even Germany's imports in 2016 were much higher. Still, they did not cause as much deforestation risk as the 2014 imports did. Therefore, the deforestation risk is attributable to Germany's partner countries (suppliers). Looking closely at 2014 data, Malaysia's exports to Germany embedded more deforestation risk than in any other year, which increased Germany's deforestation risk in 2014. This suggests that significant deforestation occurred in 2012 for cocoa plantations in tropical countries such as Cote d'Ivoire, Cameroon and Thailand, since Malaysia does not produce cocoa domestically, but is one of the biggest cocoa bean processing and grinding countries worldwide (MPIC, 2021). This example sheds light on the complexity of the systems and the need to analyse each year, country and case thoroughly to better understand the dynamics behind deforestation risk.

On the other hand, a significant decrease in deforestation risk embedded in EU imports was observed from 2016 to the last reported year (2020), strictly related to less deforestation from 2014 to 2018. This could be related to the increasing wave of large companies adhering to sustainability and environmental commitments, such as Hershey, Olam International, Mondelēz, Nestlé and Unilever (Mighty Earth, 2018). International commitments and more strict trading requirements could be triggering important shifts in cocoa-producing countries toward reducing and halting deforestation.

5.1.2.2 Deforestation risk embodied in the coffee trade

The coffee trade showed to be dominated by Brazil as the leading exporter of green and roasted coffee, while Germany and Italy are the main importers. According to Logatcheva (2014), the harbour of Hamburg is one of the main entrances of coffee into the EU, from where it is then re-exported to the Netherlands and other EU countries. On the other hand, Italy's coffee roasting industry is an important part of its economy, which contributes to the country's merchandise mark (Made in Italy), enhancing its reputation and generating jobs and wealth (Pascucci, 2018; Lanfranchi et al., 2016). Italy exports 60% of its roasted coffee to the EU, mainly to Austria, France and Germany (Matchplat, 2021), while it only re-exports 2% of its green coffee imports, mainly to Germany, France and the UK (CBI, 2020b).

Regarding deforestation risk, the results showed that imports from Tanzania, Indonesia and Uganda embodied more deforestation attributable to the production of green coffee, while the deforestation attributable to roasted coffee is negligible (47.7 ha) when compared with the scope of the assessment. Likewise, European imports from tropical countries focus on green coffee rather than roasted coffee. The results show a correlation between shares of imports and embedded deforestation in those imports. In this sense, Germany and Italy are responsible for most deforestation attributed to EU imports of green coffee. This, despite Germany shows an increasing growth of sustainability practices in the coffee sector, mainly led by big companies such as Tchibo and Jacobs, and large retailers such as Lidl and Aldi, which have incorporated certification schemes like Rainforest Alliance and Fairtrade (CBI, 2020c).

Recently, Uganda's exports of green coffee to Italy and the associated deforestation processes have been linked to 5.49 million risk cases of malaria, since deforestation is said to increase the transmission of this disease (Moreira Chaves et al., 2020). Likewise, coffee plantations in mountainous regions of Latin America have been associated with the transmission of leishmaniasis (Lana et al., 2021). This points out the fact that deforestation, intensive farming and climate change are driving zoonotic spillovers and infectious diseases to pop up (Austin, 2021).

On the other hand, the coffee rust crisis affected many producing countries in Latin America between 2008 and 2013. Production was considerably reduced in the affected countries, impacting smallholder's and harvesters' livelihoods (Avelino et al., 2015). Nevertheless, the results do not evidence shortcuts in the exports to the EU during those years among the top-producing countries. Deforestation risk was considerably higher in the period 2011-2013, which would correspond to deforestation that occurred in 2009-2011. An important part of this deforestation happened in Honduras and Peru, where the yellow rust attacked many hectares of coffee plantations (Peinado, 2013; BBC, 2013). At the same time, deforestation also happened in Asian and African countries, even though they were not affected by the yellow rust (Tanzania, Uganda, Vietnam and Cameroon). Hence, it is possible to suggest that the deforestation levels observed during those years result from more complex relationships between producing countries and other markets (domestic or international non-European markets). This, since the affected countries had to satisfy these markets' demands for green coffee besides the demand from EU countries; therefore, shortcuts could have taken place in those markets since they did not happen in the EU market. It is relevant to mention that Brazil, the top-exporting country of green coffee, was not affected by the coffee rust (Nahuamel, 2019).

Despite international commitments and new entry requirements to some niche markets, green coffee imports in 2019 embedded large deforestation risk, especially attributable to Germany imports. During that year, Germany's embedded deforestation was linked to Colombia, Peru and Vietnam, corresponding to deforestation in 2017. With respect to roasted coffee, it is interesting to point out that Italy, Germany and France imported from more sustainable sources than the Netherlands‘ ones, even though their exports were considerably larger than the Netherlands'. This could also be related to Dutch imports mainly coming from China and Senegal, which are non-producing countries but re-exporters, causing deforestation risk in other tropical countries.

5.1.2.3 Deforestation risk embodied in the oil palm trade

Oil palm plantations are widely known for being responsible for extensive deforestation in the tropics, especially in Asian countries (Qaim et al., 2020; Furumo and Aide, 2017). Moreover, oil palm is said to be involved in peatland forest drainage in South Asia, causing many other consequences, such as biodiversity loss and GHG emissions (Meijaard et al., 2020; Marwanto et al., 2019). Generally, before establishing an oil palm plantation, trees are removed and sold to cover the initial costs of the new plantation (Fitzherbert et al., 2008). Both big companies and smallholders are involved in oil palm production. Smallholders manage approximately 50% of the global area under oil palm plantations, and this cash crop is said to have increased incomes by generating income opportunities and reducing poverty (Qaim et al., 2020). The results display greater deforestation in Indonesia and Malaysia, attributable to their exports of each oil palm FRC (i.e., palm oil, palm kernel oil and palm kernel cake). Overall, oil palm FRCs exports to the Netherlands, Italy and Germany accounted for the largest deforestation risk in the top-producing countries.

Because of their saturated fat contents (50% and 80%, respectively), crude palm oil CPO and palm kernel oil PKO are destined for different industrial uses. In this sense, palm kernel oil is widely used for cosmetics, detergents and soaps, while crude palm oil is used for food production (Young, 2021). In the specific case of palm kernel oil, Germany was responsible for most of the embedded deforestation in EU imports. This data is linked to Germany being the top-importing EU country of palm kernel oil, which can be related to the fact that it has the largest cosmetics market among EU countries (Cosmetics Europe, 2019a). Nevertheless, many large companies have included sustainability commitments to reduce their social and environmental impacts, and are working closely with conservation projects and NGOs especially to halt forest loss and mitigate the industry's responsibility in contributing to climate change (Cosmetics Europe, 2019b).

On the other hand, palm oil is used mainly in food and animal-breeding industries and also as a biofuel. Nowadays, palm oil covers approximately 40% of the global annual demand for oil, animal feed and fuel (Meijaard et al., 2020). According to Mba et al. (2015), 90% of palm oil is destined for food production. Its high smoke point and semisolid state at room temperature have made it a proper ingredient in the food industry, despite its high contents of saturated fats (Kadandale et al., 2019). The countries that embody more deforestation risk in their palm oil imports are broadly known for their food industries. The EU has positioned itself as the world's leading exporter of food and drinks, with 145 billion euros in exports to non-EU countries in 2020 (FoodDrinkEurope, 2021). However, according to EPOA and IDH (2021), 90% of palm oil imports from EU27, the UK, Norway and Switzerland, destined for the food, feed and oleochemicals industry, are coming from sustainable sources. Even though certified palm oil has been linked to reduced deforestation, most plantations being certified are old (Carlson et al., 2017), which implies that oil palm plantations that got certified also generated deforestation, but back in the past. This coincides with the results of this study, since deforestation embedded in EU imports is considerably high, despite it seems to have been decreasing in the last years.

Nevertheless, attention is brought to the biofuel industry, which does not display the same level of commitment as the other industries. Based on data from 2018, around 53% of palm oil imports are used for biodiesel, and 12% for electricity and heating (Transport and Environment, 2019). Recently, the European Commission approved a measure to phase out palm oil-based biofuels by 2030, as part of the Renewable Energy Directive (RED II). Nevertheless, this measure, which will be progressively put into practice, does not prohibit the trade of palm oil for energy purposes but only rules it out of the category of biofuels (Jong, 2019). This implies that palm oil could keep being traded as a source of energy and generating deforestation in tropical countries as the demand for renewable energy increases. In this regard, it is essential to state that the shift in the cosmetics industry to purchase from sustainable palm oil sources was (and is) mainly happening because of the rising consumer awareness of the environmental impacts associated with cosmetics, which generates pressure on companies (Bom et al., 2019). In the energy industry, even though countries such as France, Austria and the Netherlands have already taken steps toward bringing RED II into force (Argus, 2021), the directive could be better addressed to prevent palm oil from sources that embody deforestation from entering the market. Furthermore, it is crucial to raise consumer awareness, as has happened in the other industries.

The results also show that the Netherlands embedded more than half the deforestation risk imported in EU countries regarding palm kernel cake imports. This by-product from the oil palm industry is mainly used for animal feeding (Boateng et al., 2008; Wilkinson and Yound, 2020). Therefore, it is reasonable to suggest that the high deforestation risk attributable to the Netherlands' imports could be related to its large animal industry. This country is the world's biggest exporter of eggs (OEC, 2022b) and the EU's largest exporter of meat, exporting beef and veal, poultry meat and pork (CBS, 2021). Hence, it is possible to state that the country's animal feed demands are large, making it dependent on imports mainly from Indonesia and Malaysia.

In Malaysia, the oil palm industry has existed since 1917 and has accelerated the economic and social development of the country, having an important contribution to the country's GDP (Kushairi et al., 2018). Nevertheless, as presented in the results, Malaysia shows alarming deforestation figures attributable to oil palm production. Similar is the Indonesian case, where oil palm has significantly contributed to the country's development (Purnomo et al., 2020). In 2005, Indonesia became the world's biggest palm oil producer and, in 2006, the largest producer of biodiesel (Santosa, 2008). This seems to have allowed the country to respond to the EU demand for energy from renewable sources, established in the 2009 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. In this regard, the results show a considerable increase in EU imports of palm oil since 2012, which could correspond to the higher demand for biofuels. As for deforestation risk, figures have fluctuated over time but show a significant peak in 2010, attributable to deforestation in 2008. This could be connected to a foreseen demand before the EU Directive was launched and to a global commodities boom after the financial crisis of 2008 (Maxton-Lee, 2018). Conversely, and after the revision of this Directive in 2018 (RED II), the deforestation risk in 2020 dropped.

On the other hand, countries whose exports to the EU caused deforestation in other tropical countries and, thus, are working as intermediaries or re-exporters could be playing an important role given the deforestation risk associated with their exports. Honduras and Papua New Guinea, which evidenced large deforestation figures attributable to other countries, relied on imports from other tropical countries because their domestic production was not sufficient to fulfil the EU market demand. Both countries have important oil palm processing plants. The same happens with Singapore (Samat, 2018), which is a financial and trade hub for many oil palm-producing companies in neighbouring countries and processes large quantities of palm oil, even though it does not produce oil palm domestically.

In terms of sustainable supply chains, many producing countries have adapted themselves to the market demand for more sustainable products by, e.g., getting certified. Initiatives such as the Roundtable on Sustainable Palm Oil (RSPO) and those present in each importing country (e.g., the Swedish Initiative for Sustainable Palm Oil and the Italian Union for Sustainable Palm Oil) have contributed to boosting a change in the supply chain of oil palm FRCs. However, despite these initiatives, the results show that deforestation remains high. Still, it is interesting to highlight the case of Ecuador, which has the only deforestation-free supply chain of palm kernel cake among the assessed countries. Furthermore, Ecuador shows many years of zero deforestation for palm oil and palm kernel oil. This could be related to the commitments of the country's oil palm sector to RSPO standards, which might have helped in creating a more sustainable supply chain (Johnson, 2022). However, there are still actions to be taken to secure sustainable oil palm production in Ecuador since plantations have been recently associated with social and environmental issues (Mongabay, 2021).

5.1.2.4 Deforestation risk embodied in soybeans trade

The results showed that Brazil is the leading exporting country of soybean-related FRCs (i.e., soybeans, soybean oil and soybean cake) to the EU, which also positions it as the country with the highest deforestation attributable to soybean production. The fast-growing soybean industry of Paraguay follows Brazil in terms of forest loss; however, the amounts of soybean exported from Paraguay to the EU is not near to the Brazilian figures, which almost dominate the EU market. Regarding Brazil, its principal commercial partner is China, which in 2021 imported 58.15 million tonnes of soybean (Reuters, 2022), followed by the EU. Brazil exports soybean products mainly to the Netherlands, Spain, France and Germany. According to Karlsson et al. (2021), the EU livestock sector largely depends on soybean imports for animal feeding, even more since growing soybean in the EU would imply reducing cultivated areas of other crops directly used for human consumption. The current soybean production among EU countries only amounts to 7% of what their industries require (Poultry World, 2022). EU imports of soybean cake during the assessed period were larger than its imports of soybeans, and so was the associated deforestation risk. This confirms that EU imports of soybean products are linked to animal feeding, but also implies that soybean processing occurs once the raw material (i.e., beans) is imported. In this regard, the difference between soybeans imports and soybean cake imports is related to a decrease in the EU's processing capacity (de Visser et al., 2014).

Soybean cake and soybean oil result from soybean crushing. Some of the largest processing plants in the EU are located in France, Spain, Germany, Italy and the Netherlands, which coincides with the fact that these countries are major importers of soybeans as raw material. For instance, the Netherlands has a large crushing and oil refining facility in the port of Amsterdam, while France has a crushing plant in the port of Brest (Bunge, 2017). The Netherlands, which is the second-largest importer of soybeans from the top-exporting tropical countries, accounted for the largest deforestation risk among EU countries. It is, once again, interesting to mention the country's role as a re-exporter, even more since its intra-EU exports embody big deforestation figures. According to Kuepper (2022), in 2021 the Netherlands exported 45% of its total soybean exports to Germany, transferring part of its responsibility for tropical deforestation. Likewise, it is worth highlighting that, notwithstanding Spain being the largest importer of soybeans based on our results, the deforestation risk embedded in its exports is smaller than the Netherlands'. This is mainly because Spain relied on more or less equal exports from Brazil and Paraguay (among other countries), whereas the Netherlands significantly relied more on Brazilian exports.

The previous sheds light on the critical situation of the Brazilian soybean sector. In Brazil, the Amazon Soy Moratorium was established in 2006, and it is said to have helped reducing deforestation attributed to soybean production in the Amazon biome, though the deforestation figures in the Cerrado biome remain alarming (Kuepper, 2022; zu Ermgassen et al., 2020). This is somehow related to the results, which show that embedded deforestation risk in Brazilian soybean exports has decreased in the last years. Especially since 2017 (corresponding to deforestation in 2015), deforestation risk has displayed a consistent downfall, which could be related to international commitments made since 2014, such as the Amsterdam Declaration and private commitments such as those made by

Cargill, Bunge and Archer Daniels Midland (zu Ermgassen et al., 2020). However, recent concern has been raised regarding the elimination of 93% of tariffs for products exported from the Mercosur region into the EU, which is part of a trade agreement between both parties approved in 2019. It is argued that it will increase forest loss in the Mercosur Member States, but particularly in Brazil (Arima et al, 2021).

Paraguay, on the other hand, showed continuous expansion of its soybean cultivation especially from 1991 to 2015, mainly driven by the increasing demand from the international market (Wesz, 2021). Our results show that, even though Paraguay is the country that exports the largest amounts of soybean right after Brazil, Paraguay's exports of soybeans to the EU have been falling in the last years. Conversely, Brazilian exports have been sustained at similar levels since 2010, but rose considerably in 2020. Despite this, the deforestation associated with Brazilian exports has decreased. As for soybean cake exports, both countries are showing fluctuating figures. In terms of soybean oil, Paraguay's exports to the EU overpass Brazilian exports since 2013, which also coincides with more deforestation risk attributed to this FRC linked to Paraguay than to Brazil in the last years. While palm oil will be phased out as a biofuel by 2030 as a result of the EU's Directive on Renewable Energy, soybean oil was not included under the high-ILUC (Indirect Land-Use Change) risk category (i.e., fuels produced from food and feed crops that embody indirect land-use change in producing countries), which makes it possible to keep using soybeans as a biofuel. In this sense, EU's demand for soybean oil as a biofuel is expected to generate 230,000 ha of additional deforestation by 2030 if no action is taken (Transport and Environment, 2020).

5.1.3 Social networks in FRCs trade in Europe

The SNA results showed that, while many countries are somehow isolated from the central focus in terms of trade (selling to/purchasing from a few countries), there are relevant actors that have positioned themselves as essential nodes in the supply chain of FRCs. Some EU countries play a re-exporting role in the EU market, thus, their presence as facilitators of the trade flows of FRCs is of major importance. The centrality analysis showed that the whole network would be affected if a relevant actor were to be removed from a given network (e.g., due to export bans and trade barriers). The consequence would be a gap that would generate more pressure on the other actors, which could ultimately prompt deforestation. For instance, if Brazil were removed from any soybean network, countries such as Paraguay and Bolivia would probably compete to cover the EU demand, increasing their production areas likely by clearing forests and displacing other crops or pastures.

A study by Dupas et al. (2021) showed that the production and trade of agricultural commodities are centralised between a few countries, and long-industrialised countries control re-export routes. In some cases, re-exports do not involve any transformation or processing; hence, re-exports within EU countries involve the same products initially imported from tropical countries. Nevertheless, FRCs re-exports in the EU represent a source of additional profit and employment for many EU countries, which has not encouraged the creation of policies for protecting producing countries from the monopolistic behaviour of EU importers (Elsby, 2020).

In this sense, given the role of some countries in trade logistics, it is very likely that imports (and, thus, deforestation embedded within them) are then re-exported to other countries where further processing activities are carried out or where final consumers are located. As discussed in the previous sections, some importing countries have large industries, so they play a crucial part in supplying other EU countries with, e.g., chocolate products and ground coffee. Big ports, such as Rotterdam in the Netherlands, Antwerp in Belgium, Hamburg and Bremerhaven in Germany, and Algeciras in Spain, have facilitated international trade. In many cases, they merely represent the point of entrance of certain products that will then be re-exported and traded within the EU market, still prevailing as essential actors among trade networks.

Conversely, international trade agreements have facilitated direct trade between tropical countries and the EU. The main producing countries can establish commercial relationships with the EU and sell their products without intermediaries. However, when analysing trade within tropical countries, it is necessary to note that some actors, like Singapore and Panama, have keylogistic hubs and important ports, whereas some others have a more active role in terms of production, like Ghana and Papua New Guinea. Hence, looking at logistics as an underlying force in trade relationships is relevant for better understanding dynamics between importers, exporters and re-exporters, since large industries of FRCs require significant investments in terms of transportation, handling, storage, etc. Some countries could be better at playing an intermediary role, while for others, it could be easier to rely on them for exporting/importing their products. Likewise, it is possible to state that countries exporting primary products and processed products at an early stage (e.g. cocoa beans, cocoa butter) generate less value-added than those that have invested in processing facilities. This implies a lower capacity to reinvest in the sector and to create better and more sustainable farming conditions.

5.1.3.1 The cocoa SNA

The general SNA for cocoa, which aggregates all cocoa-related commodities considered in the study (i.e., cocoa beans, cocoa butter, cocoa paste, cocoa powder and cake), shows that centrality scores (related to closeness, eigenvector, and betweenness centrality) are higher for Germany in all cases, despite the fact that the Netherlands is the largest importer of cocoa-related commodities. A way to elucidate it is to highlight that, during the assessment period, i) Germany imported from more tropical countries than the Netherlands, and ii) countries exporting to Germany were more influential in the network, based on the total amounts they exported to the EU. These reasons make Germany influential by itself. On the other hand, China, Malaysia and Indonesia share the highest centrality score among tropical countries, even though Côte d'Ivoire is the largest exporting country by far. As in the case of Germany and the Netherlands, it could be explained by noting that China, Malaysia and Indonesia export to more countries than any other tropical country. As for the eigenvector centrality, Malaysia shows more relevant connections, given the total amounts imported by its trade partners within the EU. As previously explained, a high eigenvector score means that a country is connected to well-connected countries (Hansen et al., 2020), which implies that Malaysia exports to large-importing countries.

In terms of the SNAs for the specific cocoa-related FRCs, the results show that Peru is the country that exports cocoa beans to more EU countries, which evidences that it is more specialised in exporting primary products than processed ones. Likewise, Peruvian exports are directed to countries that, at the same time, are large importers themselves, like the Netherlands, Belgium, France and Germany. The high scores for Peru could be related to the fact that Peruvian cocoa has been positioned as top-quality cocoa globally, mainly because of its high-quality varieties, which make the finest chocolates and cocoa paste (Nyland, 2017; International Chocolate Awards, 2017).

On the other hand, Côte d'Ivoire, Ghana and Indonesia exported cocoa butter to more EU countries than other tropical countries during the assessed period, while Indonesia exported to more well-connected countries. The first is linked to these countries' domestic cocoa processing industries, which allow them to sell products with added value to the EU market. As for Indonesia's connections, they are purchasing cocoa butter from other significant importing countries. In this context, the Netherlands is the EU country that imports from more trade partners in the tropics, which are also relevant within the network concerning their exports. A similar scenario is observed in the case of cocoa paste, where Côte d'Ivoire takes the lead for both centrality measures, which suggests the importance and great capacity of cocoa grinding facilities in Côte d'Ivoire, aimed at adding value to the primary product. In this regard, it is relevant to mention that domestic processing of cocoa beans before export in countries such as Cotê d'Ivoire and Ghana has been widely encouraged, mainly because it implies higher returns and a means for fighting poverty (Gro Intelligence, 2014; World Bank, 2019). Concerning cocoa powder and cake, the SNA shows that China exports to more countries than any other tropical country, and that its connections are well-connected simultaneously. Large companies such as Wuxi Baolai Trade Co. and Wuxi Huadong Cocoa Food Co. process and export cocoa powder and cake worldwide, which positions China as a key actor in terms of its relationships with importing countries.

5.1.3.2 The coffee SNA

The results show that Brazil and India take the lead in the SNA for the coffee trade that aggregates roasted and green coffee data. These countries are key actors regarding their relevant connections with large-importing countries from the EU. Likewise, they have more trade partners than other exporters, which positions them as influential actors within the network. It is interesting to note that Brazil is the largest exporter of coffee-related FRCs into the EU, but that Vietnam, Colombia and Honduras follow it before India. This suggests that, even though those countries are more prominent exporters compared to India, they are more specialised or limited in terms of which country they trade with, while India exports to all the countries in the EU. On the other hand, the EU countries with more relevant trade partners and which import from more tropical countries are the Netherlands and Spain. As in the case of India, Spain and the Netherlands are not the largest imports; however, they display the highest centrality scores. Spain is preceded by Italy, Belgium and Germany, while the Netherlands is below the previous and France and Sweden. This is related to the number of tropical countries they import from and how relevant those countries' connections are in terms of their other trade partners. The results coincide with what is stated by Sharma (2020), who mentions that i) more connections do not necessarily mean more money (in this case, a larger flow of trade) and ii) despite the number of trade connections, what actually matters is selling to the right ones, which in this case implies exporting more, despite those exports go to fewer countries.

As for green coffee and roasted coffee, Brazil has more connections with EU countries. Likewise, it has well-connected trade partners. In this case, it coincides with the fact that Brazil is the largest exporter of coffee to the EU among tropical countries. According to Dallmayr (2015), Brazilian coffee is low in acidity, a characteristic that many consumers prefer and that coffee from other countries does not have. Regarding EU countries, setting aside Ireland, Lithuania, Cyprus, Latvia, Estonia, Luxembourg and Malta, they import green coffee from the top-15 exporting countries, which also gives them the same eigenvector centrality score. In the case of roasted coffee, France, Germany and the Netherlands are connected to exporting countries in the same measure. Despite this, the SNA network for green coffee is stronger than the one for roasted coffee since the trade flows are considerably larger, making the connections among actors and their role within the network more valuable.

5.1.3.3 The oil palm SNA

Indonesia and Malaysia lead the SNA for oil palm-related FRCs, displaying the highest closeness centrality and eigenvector centrality measures, while Germany and the Netherlands do the same among EU countries. Even though Indonesia's exports to the EU exceed Malaysia's exports largely, both countries share the same scores for the two indicators assessed. A similar situation is observed in the case of the top-importing countries: the Netherlands' imports exceeded by almost three times Germany's imports; however, they also share the same scores. This is explained by the fact that these countries are involved in meaningful trade relationships engaging many countries, in spite of the amount being traded. Furthermore, and as previously mentioned, the large industries in these countries support their key roles within the network since they allow them to sell to/purchase from more countries in accordance with the demand and offer in the market.

The case of palm oil is reasonably related to the overall analysis, with Indonesia and Malaysia taking the lead among tropical countries and the Netherlands and Germany doing so among EU countries. However, the centrality scores are higher for Malaysia in the SNAs for palm kernel oil and palm kernel cake, showing that Indonesia, even though it is the largest exporter globally, does not export to as many countries as Malaysia. This makes Malaysia an important actor within the palm kernel network in terms of its connections.

Regarding EU countries, Germany, the Netherlands and Italy showed the highest score in terms of closeness centrality and eigenvector centrality in the palm oil SNA, being the most relevant trade partners for tropical countries. The SNA for palm kernel oil positions Germany and the Netherlands as the countries with more trade partners, which at the same time are well-connected. On the other hand, Poland and Spain take more relevance in the SNA for palm kernel cake among EU countries, suggesting more diversified, though relevant, trade relationships. These results imply that any political or institutional change on the demand-side towards achieving more sustainable supply chains might have larger consequences if they happen, for example, in Spain than in the Netherlands because of the complexity of Spain's trade relationships.

5.1.3.4 The soybean SNA

Concerning the aggregated SNA for soybean-related commodities, the results show that Brazil, China, India and Paraguay display higher scores on centrality measures. It is evident the role that China and India have within the network as exporting countries since none of them export as much as Paraguay does; even so, they are better connected and have more relevant trade partners. This could be linked to China and India's capacity to establish trade relationships with different countries in the EU: while they export soybeans to 25 and 22 EU countries, respectively, Paraguay exports to 15. Regarding importing countries, France is the country with more trade partners, which, at the same time, are well-connected to other importers. A more diversified supply network could imply that France's capability of dealing with any supply disruption will be higher (Dawson Consulting, 2018).

More specifically, the SNAs for soybeans, soybean oil and soybean cake display Brazil and China taking the lead in terms of their relevance within each network, coinciding with what was mentioned in the previous paragraph. In this context, a country with important processing facilities will likely import primary products and process them to finally export products with value-added. For instance, China exports large amounts of soybean cake to the EU and imports raw materials from Brazil (i.e., soybeans), which allows it to fulfil its domestic and international demand for soybean products (Forbes, 2018). At the same time, China is well-connected within the network because it has to maintain its status as an essential manufacturing hub worldwide (Raj et al., 2022). In the case of EU countries, France is the most influential country within the three networks, which means it could be able to persuade or affect it most quickly. On the other hand, Italy and France showed more relevant connections in the soybean and soybean cake networks, while France and the Netherlands were more well-connected in the soybean oil network.

5.2 Implications on management and decision-making

EU policies aimed at reducing deforestation in tropical countries due to FRCs should: i) provide stakeholders with information that would reduce their demand for FRCs, ii) cooperate with them to increase the demand for deforestation-free FRCs, iii) provide them with market-based instruments that would boost the production of deforestation-free FRCs, and iv) regulate them to protect forests (Bager et al., 2021). In this perspective, this study represents a point of departure for further analysing dynamics between importing and exporting countries involved in the trade of FRCs in the future, especially in terms of deforestation risk associated with their production. As explained before, the integrated framework helps pave the way for understanding the implications of trade in terms of deforestation risk in tropical countries. Furthermore, the methodology used to obtain the deforestation risk associated with each FRC, country and year, relied on readily available data, which implies that the results can be extrapolated from future studies, and adapted with local information whenever it is available. In this study, the actors involved in the supply chain of FRCs can find helpful information that highlights which countries display more deforestation risk associated with their exports/imports of FRCs. This would ultimately allow policy-makers, decision-makers, and actors in the academia and non-governmental organisations to step up and keep working on this issue from an informed perspective. At the same time, it allows for monitoring both developments in deforestation trends and in the implementation of policies and measures to tackle deforestation.

The results of this study make it clear that it is necessary to take urgent actions, especially in countries that evidenced the largest deforestation risk trends associated with their exports of FRCs. At the same time, importing countries associated with larger figures of embodied deforestation, despite of their specific role in the global market (i.e., direct consumers or re-exporters), should address their responsibility for tropical deforestation. This should not be done by only looking for more sustainable suppliers and banning those who do not comply with specific requirements. It is crucial to encourage better practices through funding, research and technical cooperation. In this sense, commitments are vital to conserve and protect forests, work towards sustainable supply chains and develop strategies that would allow producing countries to fulfil international market demands for FRCs, but from zero-deforestation production systems.

On the other hand, producing countries associated with lower deforestation risk figures, still represent a reason of concern. Since each country has different land and forest areas, the impacts of deforestation might be different in intensity and scale depending on each case. At the same time, indirect drivers, such as policies and market trends, might have a strong influence on deforestation trends and cause additional spillover effects. For instance, the increasing demand for energy crops could have major effects on food prices, threatening food security in the future (Liu et al., 2015). Likewise, if no clear actions are implemented to halt forest loss linked to the increasing demand for FRCs in general, livelihood strategies in forest-dependent communities in tropical countries will be even more at risk (Arnold & Ruiz, 2001; Colfer et al., 2006). For example, rural people in Madagascar depend on bushmeat to secure iron-rich diets. If they were to lose their access to bushmeat because of deforestation, there would be an increase of 29% in children with anaemia (Sunderland & Rowland, 2019). More examples could be cited in terms of increased social conflicts, sexually transmitted diseases, prostitution and violence directly or indirectly linked to FRCs plantations (Bennet et al., 2018; Brandão et al., 2019; Mongabay, 2021), besides environmental issues, such as biodiversity loss and the reduction of ecosystem services (Henders et al., 2015). All this draws attention to the importance of understanding how the current interconnected-globalised world functions in order to make informed decisions, considering the different systems (their sizes, roles, influence, vulnerability, etc.) and the causes and effects surrounding them.

5.3 Limitations and suggestions for future research

This study had some limitations, particularly regarding data availability. Some of those limitations were highlighted and explained within the Research methodology section (chapter 3). Regarding the initial data sets that were analysed, whenever not enough or good-quality data were available, it was necessary to make decisions in terms of i) leaving some information out of the study scope (e.g., the choice to focus on 12 FRCs and not more, and to work with final exporting countries and initial importing countries, independently of the location of final consumers), ii) estimating data (e.g., filling some gaps in the FAOSTAT production database), and iii) making assumptions (e.g., the use of conversion factors to assess all FRCs in terms of ppe).

The use of conversion factors represented a main limitation to this study. These conversion factors were helpful for the assessment of deforestation risk, but do not allow for aggregating deforestation risk data beyond a single category since it would imply overestimations on deforestation risk attributions. This is why the results were presented individually for all 12 FRCs, and should not be added up. As explained before, this issue did not compromise the deforestation risk calculations. However, given that all products were handled in terms of ppe, assuming some imbalances referred to produced and exported quantities may not represent reality accurately in all cases. This, since some by-products (e.g., soybean cake and soybean oil) are produced using the same raw material (e.g., soybean) as an input; thus, double-counting could have occurred (see section 3.3.1 for more details). At the same time, negative balances were not calculated considering other trade partners beyond the EU (e.g., Argentina, USA), since it was deemed not to be necessary. The negative balances were focused on tropical partners, considering re-exporting countries only in the tropical domain, but did not include other countries which could have supplied them with FRCs (e.g., USA, Bangladesh). Perhaps this, together with the overestimation of the imbalances, can explain the fact that even after analysing trade between tropical countries, some years in specific countries still showed negative values. This issue could certainly be address in the future by reducing the scope of the assessment to particular cases.

Another limitation of the study is that the calculations considered overall deforestation and then capped it between the exported amounts. This could have led to under and overestimations of the actually deforested area corresponding to the EU. This, since EU purchases are increasingly coming from more sustainable sources, such as those in compliance with certification schemes or under the scope of internationally-funded programmes (e.g., REDD+). Nevertheless, it was considered that, in a telecoupled and metacoupled world, the sole demand for those products could be triggering the deforestation that is happening in other markets. In this context, deforestation data also portrays a limitation to this study since the data set used for the calculation of deforestation risk was based on “tree cover loss”. Its definition contemplates forest degradation to some extent (more details in section 3.3.2), but, given that there is no globally agreed definition for forest degradation, this issue should be considered in future research and practical activities. Forest degradation, which is taken into account by the EUDR, is more challenging to identify, measure and monitor than just deforestation. This will represent a challenge for future research and practical activities. The last limitation of the study in terms of data availability is linked to land use and land cover data. This issue was handled by using rates to cover the missing years (2000 and 2020).

Regarding the SNA, it considered imported and exported amounts of FRCs to display trade relationships among the actors. However, further analysis could be carried out based on deforestation risk values in more specific studies. By narrowing the scope of research, it would be easier to glimpse all the details surrounding the relationships of a given supplier and purchaser, including all the other actors who could be playing a role that was not displayed in this research. For instance, re-exporters from both tropical and EU countries were presented directly linked to which country they sold to/purchased from. However, in a narrower scope, it would be possible to include producers that supplied tropical re-exporting countries, as well as intra-EU importers and final consumers. A more in-depth analysis would surely shed light on the specific dynamics each EU country is responsible for in the tropics. Still, triangulations among countries would be complex to make, and traceability along supply chains would be challenging; however, further analysis could facilitate these issues.

6. Conclusion

The integrated framework presented in this study portrays the basis for understanding the implications of the trade of FRCs in the EU on deforestation risk in tropical countries. From a telecoupling perspective, it addresses the issues surrounding supply chains that involve deforestation risks. It represents a flexible tool that can be adapted in future studies, especially in the current context of the EUDR. The assessment of deforestation risk embedded in each of the 12 FRCs analysed showed that the trade flows between tropical countries and EU countries are responsible for an overall deforestation risk of 5,128,711 ha over the period 2003-2020 in the 45 tropical countries that were considered. This deforestation risk corresponded to deforestation in 2001-2018, which suggests an annual forest loss of 284,928 ha.

The main cause of deforestation risk in the tropics is attributable to cropland expansion for producing oil palm fruit and soybeans, presenting considerably larger deforestation figures than coffee or cocoa commodities. More specifically, the strong correlations between cropland expansion and forest loss attributed to oil palm and soybean expansion suggest that whenever new land cultivates oil palm or soybean, it is very likely it was previously a forest. In this regard, Indonesia, Brazil, Malaysia, Paraguay and Colombia showed the largest deforestation risk associated with their exports of FRCs, which is related to their fast-growing oil palm-related and/or soybean-related industries.

Furthermore, it is relevant to highlight that cocoa and coffee commodities are still causing deforestation. However, national and international strategies working on creating a switch towards a more sustainable production seem to have some results. Agroforestry systems and certification schemes are increasingly being adopted, promoting the enhancement of ecosystem services and allowing producers to add value to their exports. Likewise, EU countries' commitments to reducing their responsibility for forest loss in the tropics are making importing companies purchase commodities from more sustainable sources. As for oil palm and soybeans, large industries related to cosmetics, animal feeding and energy still have a long road ahead.

The SNA results, on the other hand, showed that many countries have relevant roles within the networks even though they are not the largest exporters. This implies that some countries' trade relationships are more diversified, while other countries are more specific or limited in terms of which country they export to or import from. In this sense, an exporting country might be having impacts on many or a few tropical countries' forests at the same time, which suggests that developing policies and programmes to halt and curb deforestation might require more effort from those countries that are more and better connected within the network. Likewise, and despite the results not showing a positive correlation between EU imports and deforestation risk in all cases, the social network analysis allowed identifying the main actors involved in the trade of FRCs. This points out which countries should undertake more strict and meaningful measures to protect tropical forests and ensure deforestation-free supply chains.

This research opens the door for assessing specific cases more profoundly in future studies, perhaps considering the impacts of deforestation by including, e.g., biodiversity loss rates and social conflicts linked to the exports. Moreover, the same methodology could be applied to assess deforestation risk attributable to other import hubs like the USA, Japan, China, India or Australia. At the same time, future research could be focused on assessing the deforestation risk embedded in large-producing countries' domestic markets, as in Brazil and Indonesia's case, which could also imply assessing trade between tropical countries. In the policy arena, policies being developed, and those that will be developed in the future, besides taking a multisectoral approach, should also be harmonized among different regions and countries in order to avoid trade-offs and perverse dynamics that would give room for unsustainably sourced commodities being imported by the EU via intermediate trade partner countries. Furthermore, policy-makers, companies, research institutions and organisations must work on creating more awareness of the relevance of revising consumption patterns and styles toward more responsible consumption. It is necessary that importing and exporting countries create an articulate dialogue on this global issue. This dialogue should be aimed at finding sound solutions that would not merely prevent tropical countries from exporting their products but would encourage and empower them with tools and resources for a transition towards a world where forests are taken care of and not cleared for producing commodities.

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ANNEXES

Annex 1 - Forest-risk commodities considered in the EUDR

Forest-risk commodities as presented in the EU regulation	
Relevant commodities	**Relevant products**
Cocoa	Cocoa beans, whole or broken, raw or roasted Cocoa shells, husks, skins and other cocoa waste Cocoa paste, whether or not defatted Cocoa butter, fat and oil Cocoa powder, not containing added sugar or other sweetening matter Chocolate and other food preparations containing cocoa
Coffee	Coffee, whether or not roasted or decaffeinated; coffee husks and skins; coffee substitutes containing coffee in any proportion
Oil palm	Palm oil and its fractions, whether or not refined, but not chemically modified Palm nuts and kernels Crude palm kernel and babassu oil and fractions thereof Palm kernel and babassu oil and their fractions, whether or not refined, but not chemically modified (excluding Crude oil) Oilcake and other solid residues of palm nuts or kernels, whether or not ground or in the form of pellets, resulting from the extraction of palm nuts oils or kernels oils
Soy	Soybeans, whether or not broken Soybean flour and meal Soybean oil and its fractions, whether or not refined, but not chemically modified Oilcake and other solid residues, whether or not ground or in the form of pellets, resulting from the extraction of soybean oil

Annex 2 - Countries considered in the study

Annex 2.1 - European countries

Countries conforming the European Union	
Austria	Italy
Belgium	Latvia
Bulgaria	Lithuania
Croatia	Luxembourg
Republic of Cyprus	Malta
Czech Republic	Netherlands
Denmark	Poland
Estonia	Portugal
Finland	Romania
France	Slovakia
Germany	Slovenia
Greece	Spain
Hungary	Sweden
Ireland	

Annex 2.2 - Tropical countries included in the preliminary analysis

Africa		Asia and the Pacific		Latin America and the Caribbean	
West Sahelian Africa	Burkina Faso	South Asia	Bangladesh	Central America	Costa Rica
	Cape Verde		Bhutan		El Salvador
	Chad		India		Guatemala
	Gambia		Nepal		Honduras
	Guinea-Bissau		Pakistan		Mexico
	Mali		Sri Lanka		Nicaragua
	Mauritania	Continental South East Asia	Cambodia		Panama
	Niger		China	Caribbean Subregion	Antigua and Barbuda
	Senegal		Laos		Bahamas
East Sahelian Africa	Djibouti		Myanmar		Belize
	Ethiopia		Thailand		Cuba
	Kenya		Vietnam		Dominica
	Somalia	Insular South East Asia	Brunei		Dominican Republic
	Sudan		Indonesia		French Guyana
	South Sudan		Malaysia		Grenada
	Uganda		Philippines		Guadeloupe
West Africa	Benin		Singapore		Guyana
	Cote D'Ivoire	Pacific	Papua New Guinea		Haiti
	Ghana				Jamaica
	Guinea				Martinique
	Liberia				Puerto Rico
	Nigeria				Saint Kitts and Nevis
	Sierra Leone				Saint Lucia
	Togo				Saint Vincent
Central Africa	Cameroon				Suriname
	Central Africa Republic				Trinidad y Tobago
	Congo			Tropical South America	Bolivia
	Dem. Rep. of the Congo				Brazil
	Equatorial Guinea				Colombia
	Gabon				Ecuador
Tropical South Africa	Angola				Paraguay
	Botswana				Peru
	Burundi				Venezuela

	Malawi
	Mauritius
	Mozambique
	Namibia
	Rwanda
	Tanzania
	Zambia
	Zimbabwe
Insular Africa	Madagascar

Annex 3 - Technical conversion factors to obtain relevant commodity equivalents

FRCs		Technical conversion factor	Source	Assumptions/observations
Cocoa	Cocoa, beans	1	-	FAOSTAT data on area harvested, yield and production are available for cocoa beans, green coffee, oil palm fruit and soybeans; hence, these are considered the 100% input to produce the other commodities and then convert them to t/ha for the analysis.
	Cocoa, paste	0.82	UTZ. (2017)	
	Cocoa, butter	0.41	UTZ. (2017)	
	Cocoa, powder and cake	0.41	UTZ. (2017)	
Coffee	Coffee, green	1	-	
	Coffee, roasted	0.65	Rotta et al. (2021)	
Oil palm	Oil, palm	0.24	Papilo et al., 2017	
	Oil, palm kernel	0.023	Papilo et al., 2018	
	Cake, palm kernel	0.027	Papilo et al., 2019	
Soy	Soybeans	1	USSEC. (2015)	
	Oil, soybean	0.18	USSEC. (2015)	
	Cake, soybeans	0.79	USSEC. (2015)	

Annex 4 - List of tropical countries considered in the assessment of FRCs, based on their total exports to the EU (top 15 exporting countries for each product)

Cocoa							
Cocoa, beans		Cocoa, butter		Cocoa, paste		Cocoa, powder and cake	
Country	Exports (t)	Country	Exports (t)	Country	Exports (t)	Country	Exports (t)
Côte d'Ivoire	10,839,741	Côte d'Ivoire	994,227	Côte d'Ivoire	2,054,537	Côte d'Ivoire	1,027,798
Ghana	5,058,285	Ghana	459,503	Ghana	696,210	Ghana	446,539
Nigeria	3,219,374	Indonesia	338,719	Cameroon	116,449	Indonesia	304,070
Cameroon	2,733,710	Malaysia	266,713	Indonesia	31,563	Nigeria	114,976
Ecuador	828,491	Cameroon	150,096	Ecuador	21,828	Malaysia	93,570
Togo	667,499	Nigeria	132,582	Nigeria	11,805	Brazil	56,782
Dominican Republic	445,972	China	107,933	Malaysia	4,409	Cameroon	46,748
Peru	318,861	Peru	72,559	Brazil	4,290	China	37,848
Sierra Leone	233,541	Brazil	62,163	Dominican Republic	2,103	Peru	13,483
Guinea	190,680	Thailand	58,296	Peru	1,629	Ecuador	9,421
Uganda	158,432	Ecuador	53,482	Philippines	1,377	Singapore	5,971
Liberia	142,719	Mexico	31,144	India	1,300	Thailand	3,459
Papua New Guinea	117,578	India	24,150	Costa Rica	622	Dominican Republic	1,638
Madagascar	90,424	Colombia	17,929	Madagascar	596	Cuba	1,279
Tanzania	79,208	Singapore	11,422	Colombia	567	Colombia	1,258

Oil palm					
Cake, palm kernel		Oil, palm		Oil, palm kernel	
Country	Exports (t)	Country	Exports (t)	Country	Exports (t)
Indonesia	20,028,546	Indonesia	46,559,633	Indonesia	6,002,125
Malaysia	11,946,449	Malaysia	30,437,805	Malaysia	2,791,653
Côte d'Ivoire	352,082	Papua New Guinea	6,438,359	Papua New Guinea	713,903
Nigeria	161,158	Colombia	3,193,424	Colombia	425,893
Ghana	135,283	Honduras	2,500,068	Honduras	232,994
Togo	66,354	Guatemala	2,397,065	Côte d'Ivoire	152,118
Ecuador	39,885	Thailand	800,496	Guatemala	122,420
India	39,523	Brazil	393,137	Thailand	114,823
Brazil	23,570	Côte d'Ivoire	382,131	Singapore	60,190
Madagascar	11,936	Ecuador	349,619	Ecuador	28,308
Singapore	7,989	Costa Rica	167,641	India	27,058
Niger	5,122	Singapore	122,421	Brazil	26,642
Sierra Leone	2,640	Philippines	58,554	Ghana	21,640
Colombia	693	Panama	43,548	Nigeria	19,331
Cameroon	492	Ghana	39,803	Philippines	11,362

Soybeans					
Cake, soybeans		Oil, soybeans		Soybeans	
Country	Exports (t)	Country	Exports (t)	Country	Exports (t)
Brazil	146,407,544	Brazil	2,255,895	Brazil	115,975,269
Paraguay	6,105,563	Paraguay	415,780	Paraguay	20,606,227
India	3,477,471	Venezuela	6,714	China	292,268
China	1,251,442	Bolivia	4,309	India	215,511
Bolivia	319,393	China	1,121	Bolivia	188,998
Nigeria	204,370	Senegal	1,002	Togo	184,252
Antigua and Barbuda	82,509	India	157	Nigeria	110,409
Indonesia	44,843	Antigua and Barbuda	86	Panama	76,728
Trinidad and Tobago	28,117	Thailand	80	Burkina Faso	25,715
Belize	25,792	Malaysia	75	Uganda	21,058
Panama	8,455	Peru	60	Antigua and Barbuda	14,500
Burkina Faso	7,048	Vietnam	15	Ethiopia	10,466
Ethiopia	5,468	Panama	13	Benin	5,889
Ghana	3,542	Ecuador	7	Ghana	3,467
Côte d'Ivoire	1,985	Suriname	7	Côte d'Ivoire	1,316

Coffee			
Coffee, green		Coffee, roasted	
Country	Exports (t)	Country	Exports (t)
Brazil	14,786,432	Brazil	13,748
Vietnam	10,334,415	Colombia	3,692
Colombia	2,889,933	Kenya	2,037
Honduras	2,779,207	Vietnam	1,483
India	2,202,399	India	1,251
Uganda	2,177,293	China	1,178
Peru	2,104,970	Ethiopia	718
Indonesia	2,101,627	Honduras	690
Ethiopia	1,472,279	Costa Rica	498
Guatemala	781,292	Panama	472
Nicaragua	531,997	Ecuador	381
Kenya	513,383	Cuba	349
Cameroon	492,219	Dominican Republic	317
Mexico	486,249	Thailand	230
Tanzania	479,343	Senegal	219

Annex 5 - EU imports per FRC (2003-2020)

Country	Cocoa imports				Coffee imports	
	Cocoa beans (t)	Cocoa butter (t)	Cocoa paste (t)	Cocoa powder and cake (t)	Green coffee (t)	Roasted coffee (t)
Austria	1,142	104	529	1,264	162,627	180
Belgium	3,767,268	62,823	30,400	64,820	4,100,008	603
Bulgaria	50,025	8,160	39,407	63,011	332,742	32
Croatia	31,781	7,688	2,661	1,155	252,117	472
Cyprus	1	1	-	75	30,282	11
Czechia	22,933	132	284	1,393	205,283	868
Denmark	23,966	3,310	127	2,154	380,073	1,943
Estonia	80,061	8,332	10,962	5,569	1,845	14
Finland	48	53	51	49	1,111,410	161
France	1,817,419	925,616	863,533	189,619	2,863,431	2,450
Germany	3,423,696	363,437	338,581	174,740	17,137,878	3,641
Greece	4,027	1,018	8,971	4,008	498,513	58
Hungary	7	1,060	802	12,144	95,176	27
Ireland	64,571	325	244	13	48,993	79
Italy	1,322,293	70,767	20,267	6,823	8,254,798	11,236
Latvia	15,289	75	2,502	615	10,324	53
Lithuania	4,029	298	110	5,109	1,763	24
Luxembourg	-	-	-	-	668	4
Malta	-	-	-	9	297	74
Netherlands	12,918,189	1,181,316	1,244,601	638,707	1,301,275	2,379
Poland	175,560	100,733	303,654	54,039	551,188	227
Portugal	35	2,636	13,951	585	656,152	291
Romania	352	1,136	41	5,366	342,972	131
Slovakia	16,747	224	229	779	20,495	78
Slovenia	61	127	133	3,760	217,210	172
Spain	1,384,980	41,527	67,236	928,138	3,917,398	1,503
Sweden	35	20	9	896	1,638,120	552
Total	**25,124,515**	**2,780,918**	**2,949,285**	**2,164,840**	**44,133,038**	**27,263**

Country	Oil palm imports			Soybean imports		
	Palm oil (t)	Palm kernel oil (t)	Palm kernel cake (t)	Soybeans (t)	Soybean oil (t)	Soybean cake (t)
Austria	18,867	28	-	51	13,041	31,633
Belgium	1,612,035	502,569	508,744	4,093,346	91,624	3,811,877
Bulgaria	382,182	1,030	-	152	22	401,355
Croatia	102,396	45	5	328,009	1,365	1,699,007
Cyprus	9,952	762	-	2,010	22,034	125,571

Czechia	27,891	14,325	3	2,918	580	146,828
Denmark	2,173,431	204,452	11,550	158,106	81,635	4,494,937
Estonia	2,584	-	104	29	1,603	9,216
Finland	107,340	30	5,193	270,924	1	38,559
France	2,481,702	107,047	979,548	5,642,130	824,340	42,851,344
Germany	11,761,287	5,136,963	4,424,827	19,733,112	355,125	20,538,424
Greece	1,365,434	244,441	-	2,888,005	29,039	1,123,298
Hungary	47,966	5,912	-	2,719	-	1,107,830
Ireland	617,910	7,920	1,966,245	70,407	5	782,561
Italy	17,843,966	579,853	62,990	15,266,085	395,410	7,206,303
Latvia	3,247	1,670	67	10	-	53,901
Lithuania	27,295	713	241	3,702	130	15,062
Luxembourg	-	-	-	-	-	-
Malta	1,158	-	-	21	70	38
Netherlands	36,615,536	3,003,617	20,394,830	38,106,092	374,382	44,141,672
Poland	445,553	17,484	1,193,823	3,321	20,593	4,929,752
Portugal	295,503	11,801	1,073,999	10,478,168	37,975	590,544
Romania	285,353	15,882	-	799,166	5	4,182,344
Slovakia	8,037	369	13	344	547	2,069
Slovenia	3,101	904	-	775,807	1,153	9,302,219
Spain	16,148,300	670,931	2,073,986	39,085,478	429,935	8,858,158
Sweden	1,495,678	221,712	125,554	21,961	4,707	1,529,040
Total	93,883,704	10,750,460	32,821,722	137,732,073	2,685,321	157,973,542

Annex 6 - Deforestation risk embodied in the production of FRCs exported to the EU per each tropical country

	FLA to cropland expansion (ha)		FLA to FRCs exports to the EU in the period 2003-2020, linked to deforestation in 2001-2018 (in ha, per each FRC)												
Country	**2001-2020**	**2001-2018**	**Cocoa beans**	**Cocoa butter**	**Cocoa paste**	**Cocoa powder and cake**	**Coffee green**	**Coffee roasted**	**Palm oil**	**Palm kernel oil**	**Palm kernel cake**	**Soybeans**	**Soybean oil**	**Soybean cake**	**Total**
Indonesia	12,458,095	11,760,794	-	26,831	2,186	28,670	28,841	-	440,914	703,560	1,652,822	-	-	286	2,884,110
Brazil	6,212,938	6,124,235	-	1,731	108	928	4,487	3	1,012	539	147	286,855	20,698	445,781	762,291
Malaysia	1,544,667	1,544,667	-	32,115	249	10,088	-	-	76,231	80,751	240,839	-	10	-	440,282
Paraguay	1,565,640	1,540,189	-	-	-	-	-	-	-	-	-	128,809	10,956	36,165	175,929
Colombia	1,041,726	717,557	-	1,741	32	14	6,892	10	73,335	49,759	120	-	-	-	131,903
Côte d'Ivoire	611,235	611,235	53,337	13,358	12,577	13,746	-	-	3,879	9,268	14,344	9	-	60	120,577
Honduras	167,497	155,259	-	-	-	-	13,529	3	42,129	42,273	-	-	-	-	97,934
Singapore	130	130	-	694	-	430	-	-	11,944	71,238	5,066	-	-	-	89,372
Papua New Guinea	81,045	81,045	-	-	-	-	-	-	43,752	45,334	-	-	-	-	89,085
India	137,978	137,978	-	34	-	-	59	-	-	22,400	39,230	38	0	544	62,304
Tanzania	2,578,678	2,249,692	1,250	-	-	-	46,561	-	-	-	-	-	-	-	47,811
Peru	460,320	446,072	12,842	4,786	58	1,657	15,041	-	-	-	-	-	12	-	34,396
Ghana	129,010	129,010	26,011	2,301	2,023	1,760	-	-	107	37	1,070	7	-	-	33,316
Liberia	81,220	81,220	26,145	-	-	-	-	-	-	-	-	-	-	-	26,145
Uganda	203,610	203,610	5,592	-	-	-	20,257	-	-	-	-	-	-	-	25,849
Cameroon	194,395	194,395	8,863	410	594	258	6,330	-	-	-	4	-	-	-	16,460

Vietnam	955,241	707,011	-	-	-	-	12,827	3	-	-	-	-	1	-	12,831
Togo	15,546	15,546	2,351	-	-	-	-	-	-	-	9,306	435	-	-	12,093
China	773,586	773,586	-	6,824	-	2,612	-	7	-	-	-	22	0	19	9,483
Guatemala	388,369	388,369	-	-	-	-	95	-	5,447	3,728	-	-	-	-	9,270
Ecuador	137,935	125,680	6,390	452	259	60	-	4	139	186	-	-	-	-	7,491
Venezuela	1,842,462	1,564,162	-	-	-	-	-	-	-	-	-	-	5,679	-	5,679
Thailand	362,012	362,012	-	3,187	-	158	-	-	922	1,239	-	-	1	-	5,506
Nicaragua	187,673	187,673	-	-	-	-	5,171	-	-	-	-	-	-	-	5,171
Niger	-	-	-	-	-	-	-	-	-	-	4,217	-	-	-	4,217
Bolivia	1,813,749	1,715,618	-	-	-	-	-	-	-	-	-	657	1,247	1,686	3,590
Nigeria	279,263	279,263	2,506	160	11	136	-	-	-	47	699	0	-	-	3,559
Guinea	292,751	292,751	2,754	-	-	-	-	-	-	-	-	-	-	-	2,754
Ethiopia	265,794	251,501	-	-	-	-	2,436	2	-	-	-	11	-	26	2,475
Sierra Leone	287,925	287,925	1,994	-	-	-	-	-	-	-	89	-	-	-	2,083
Panama	29,494	29,494	-	-	-	-	-	7	364	-	-	922	-	265	1,557
Mexico	566,836	566,836	-	634	-	-	534	-	-	-	-	-	-	-	1,168
Costa Rica	93,742	93,742	-	-	72	-	-	0	726	-	-	-	-	-	799
Philippines	436,330	436,330	-	-	-	-	-	-	114	250	-	-	-	-	364
Belize	24,678	24,000	-	-	-	-	-	-	-	-	-	-	-	320	320
Madagascar	50,000	50,000	-	-	-	-	-	-	-	-	179	-	-	-	179

Trinidad and Tobago	-	-	-	-	-	-	-	-	-	-	-	-	-	149	149
Senegal	818	818	-	-	-	-	-	10	-	-	-	-	96	-	106
Antigua and Barbuda	-	-	-	-	-	-	-	-	-	-	-	-	-	74	74
Burkina Faso	91	91	-	-	-	-	-	-	-	-	-	-	-	31	31
Kenya	152,913	152,913	-	-	-	-	0	0	-	-	-	-	-	-	0
Cuba	101,286	81,204	-	-	-	-	-	0	-	-	-	-	-	-	0
Suriname	27,908	27,908	-	-	-	-	-	-	-	-	-	-	0	-	0
Benin	26,245	26,245	-	-	-	-	-	-	-	-	-	-	-	-	-
Dominican Republic	14,192	14,192	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	36,595,022	34,431,958	150,035	95,257	18,170	60,518	163,061	48	701,015	1,030,606	1,968,132	417,764	38,699	485,405	5,128,711

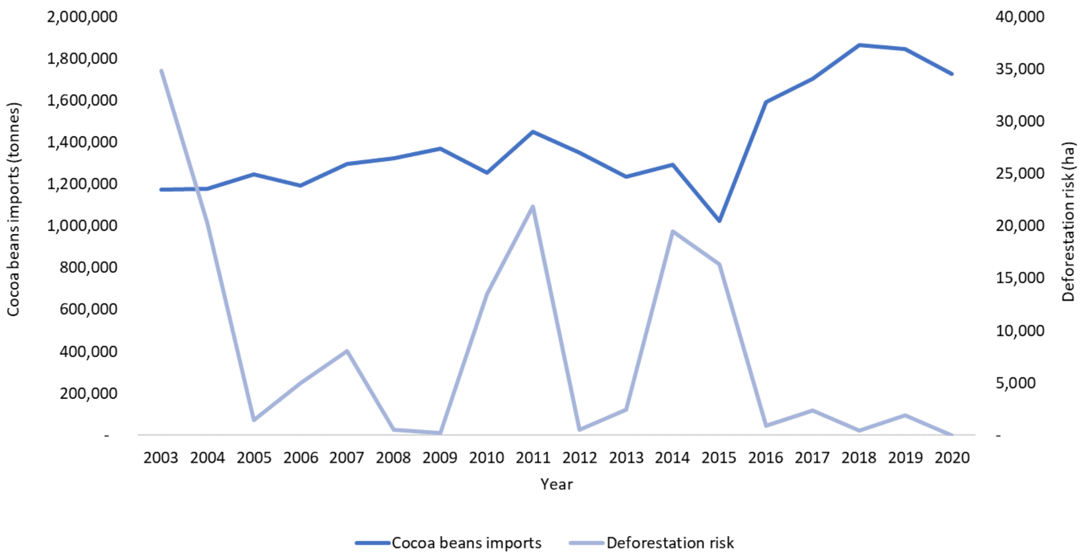
Annex 7 - Deforestation risk embodied in EU imports of FRCs

FLA to EU imports of FRCs in the period 2003-2020, linked to deforestation in 2001-2018 (in ha, per each FRC)													
Country	**Cocoa beans**	**Cocoa butter**	**Cocoa paste**	**Cocoa powder and cake**	**Coffee green**	**Coffee roasted**	**Palm oil**	**Palm kernel oil**	**Palm kernel cake**	**Soybeans**	**Soybean oil**	**Soybean cake**	**Total**
Austria	10	7	5	40	436	1	57	-	-	0	19	49	624
Belgium	24,793	3,365	175	2,785	21,013	0	14,518	45,129	39,013	4,744	3,288	16,358	175,181
Bulgaria	4	86	227	2,449	2,119	0	1,901	150	-	0	-	2,634	9,569
Croatia	608	203	31	104	214	0	468	0	0	1,433	10	5,043	8,114
Cyprus	-	0	-	7	13	0	207	356	-	2	227	221	1,032
Czechia	339	10	7	143	541	5	152	1,470	-	0	1	404	3,073
Denmark	486	75	1	795	1,602	0	11,242	17,778	198	255	2,332	10,874	45,640
Estonia	2,390	669	52	849	2	0	9	-	1	0	-	97	4,069
Finland	2	4	2	5	3,993	0	459	-	158	757	-	122	5,502
France	9,143	42,579	6,137	3,481	8,233	3	18,548	12,605	66,765	15,808	7,115	139,190	329,607
Germany	33,030	15,730	3,996	2,968	64,036	6	104,449	550,527	318,343	68,049	2,993	56,140	1,220,266
Greece	61	27	74	569	556	-	9,681	14,973	-	14,613	318	3,454	44,326
Hungary	0	129	37	1,318	119	0	258	169	-	0	-	5,504	7,534
Ireland	865	8	11	0	324	0	2,215	235	144,539	299	-	4,958	153,453
Italy	9,684	1,205	123	340	34,146	9	124,486	53,843	5,197	55,496	4,115	32,508	321,152
Latvia	-	1	0	103	8	0	29	115	-	-	-	420	676
Lithuania	7	4	0	200	1	0	103	24	2	8	2	67	418
Luxembourg	-	-	-	-	2	0	-	-	-	-	-	-	2

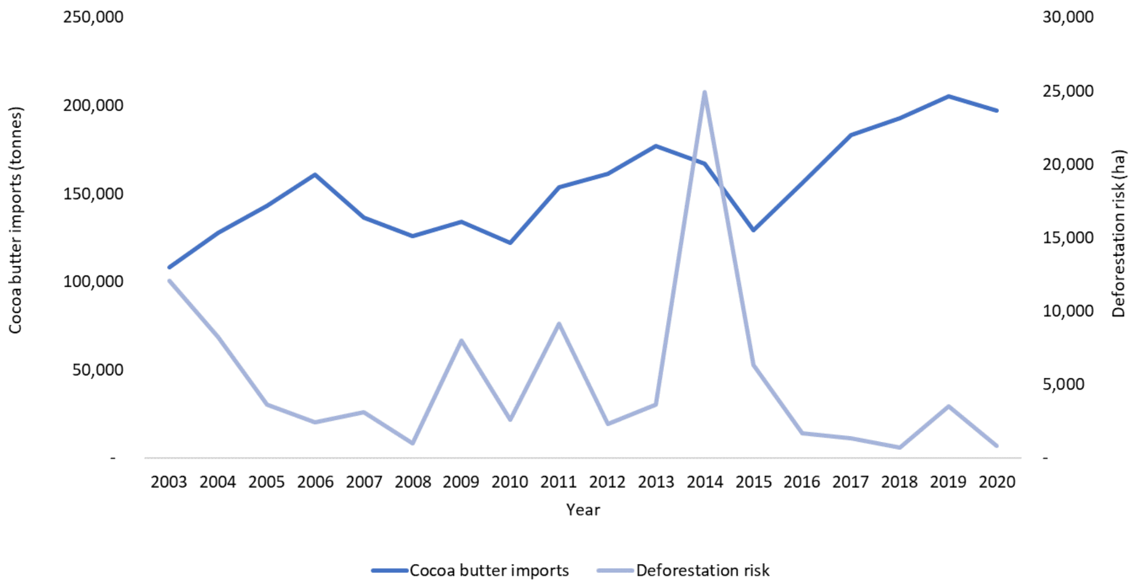
Malta	-	-	-	1	0	-	2	-	-	-	-	-	3
Netherlands	56,478	28,101	5,486	8,725	3,181	11	284,234	262,074	1,108,435	125,517	5,048	133,583	2,020,873
Poland	1,265	1,958	1,479	2,863	1,993	0	2,893	2,105	98,940	6	203	14,787	128,493
Portugal	1	36	101	122	2,988	0	2,818	1,936	60,806	27,401	5,933	2,369	104,513
Romania	8	69	0	263	2,229	0	1,051	636	-	1,922	1	8,871	15,050
Slovakia	374	14	8	110	60	0	51	48	-	2	-	0	667
Slovenia	1	5	2	281	304	0	23	5	-	2,935	2	18,436	21,995
Spain	10,485	971	215	31,977	9,520	7	116,372	60,083	117,747	98,489	7,074	23,294	476,234
Sweden	1	1	0	19	5,430	4	4,789	6,346	7,987	28	18	6,022	30,645
Total	150,035	95,257	18,170	60,518	163,061	48	701,015	1,030,606	1,968,132	417,764	38,699	485,405	5,128,711

Annex 8 - FRC's dynamics related to EU imports and embodied deforestation risk in the period 2003-2020

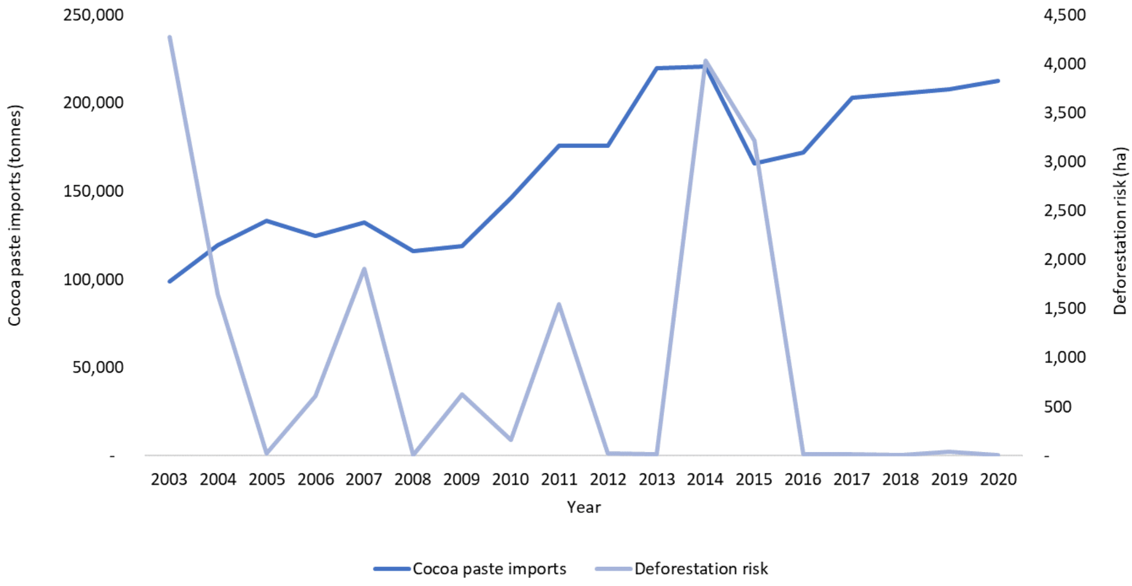
Annex 8.1 - EU imports of cocoa beans from tropical countries and their attributable deforestation risk



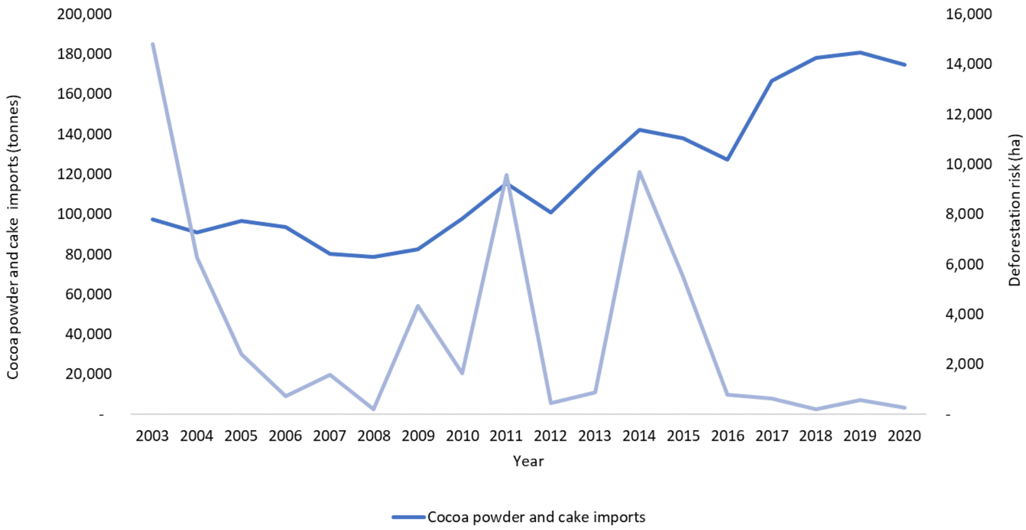
Annex 8.2 - EU imports of cocoa butter from tropical countries and their attributable deforestation risk



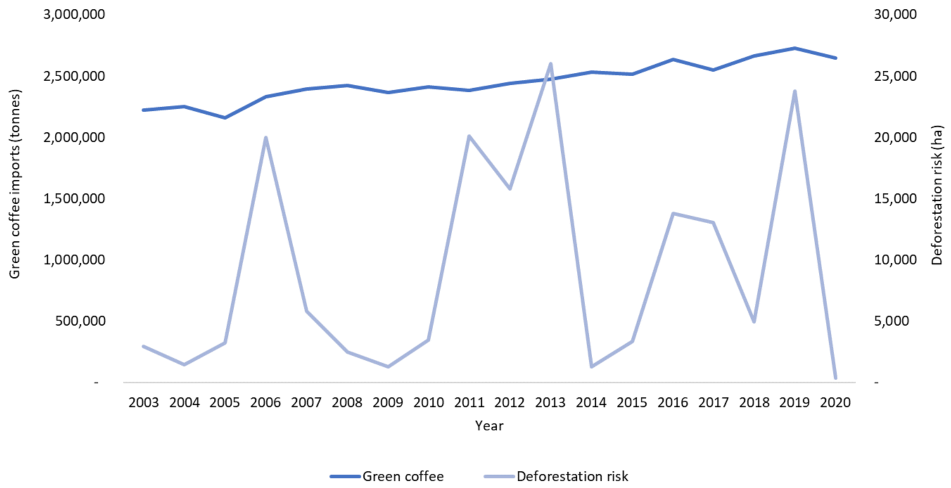
Annex 8.3 - EU imports of cocoa paste from tropical countries and their attributable deforestation risk



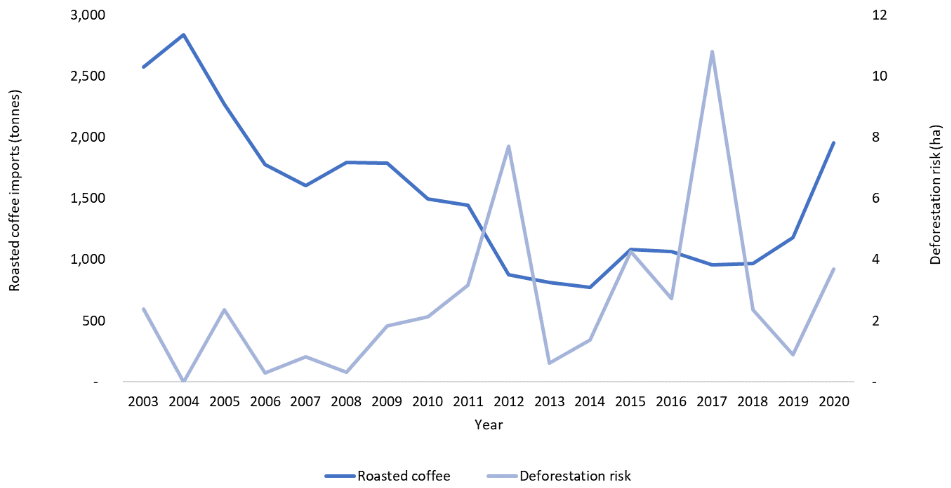
Annex 8.4 EU imports of cocoa powder and cake from tropical countries and their attributable deforestation risk



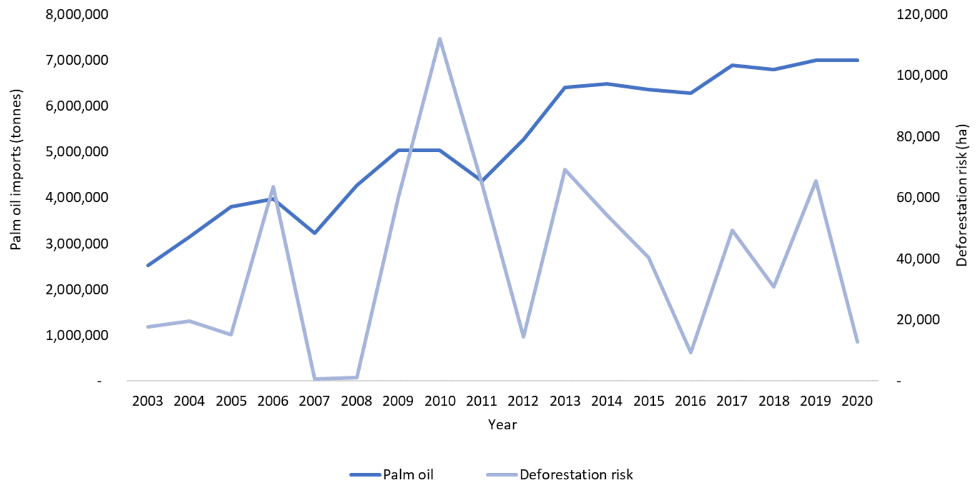
Annex 8.5 – EU imports of green coffee from tropical countries and their attributable deforestation risk



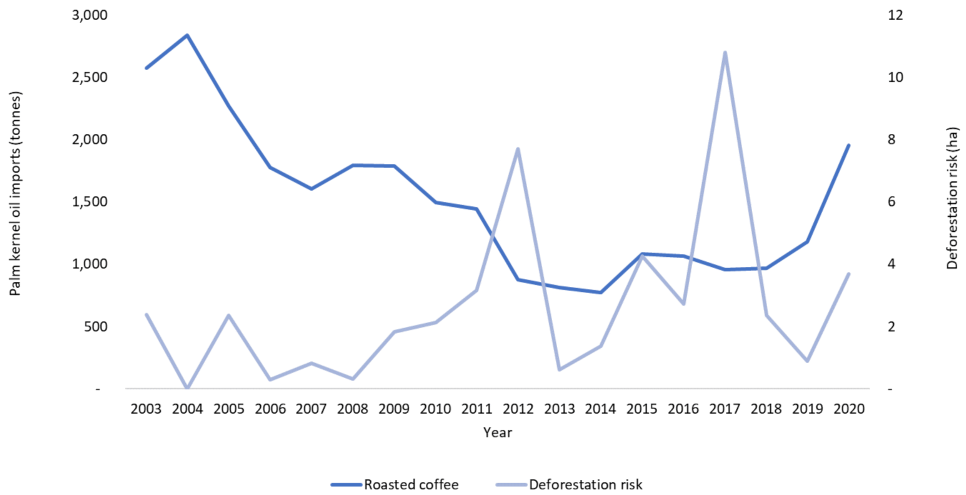
Annex 8.6 - EU imports of roasted coffee from tropical countries and their attributable deforestation risk



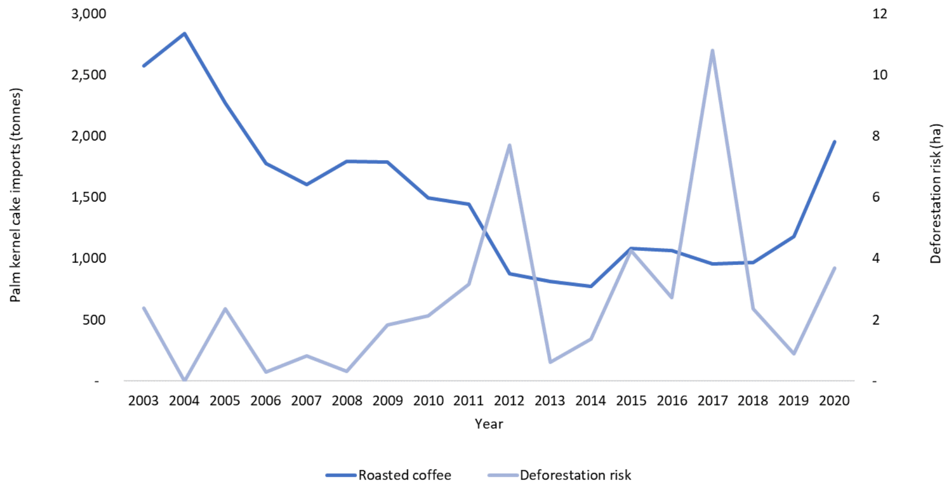
Annex 8.7 – EU imports of palm oil from tropical countries and their attributable deforestation risk



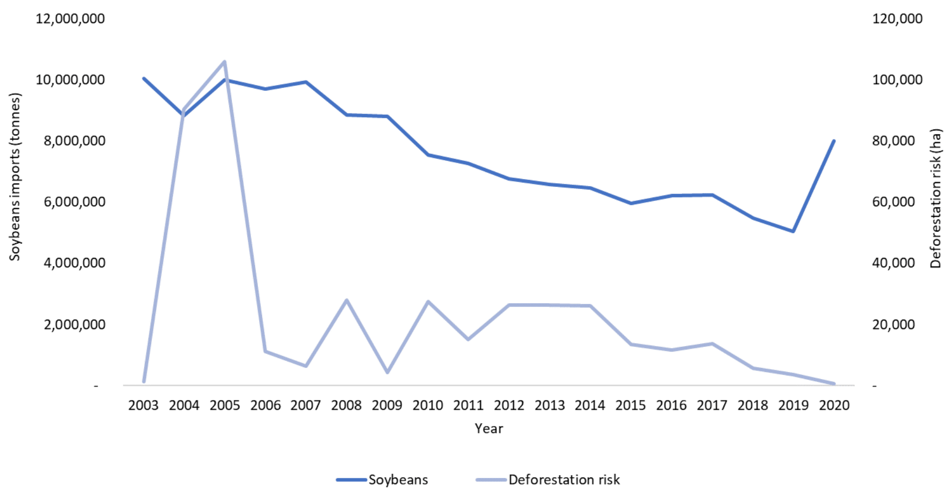
Annex 8.8 – EU imports of palm kernel oil from tropical countries and their attributable deforestation risk



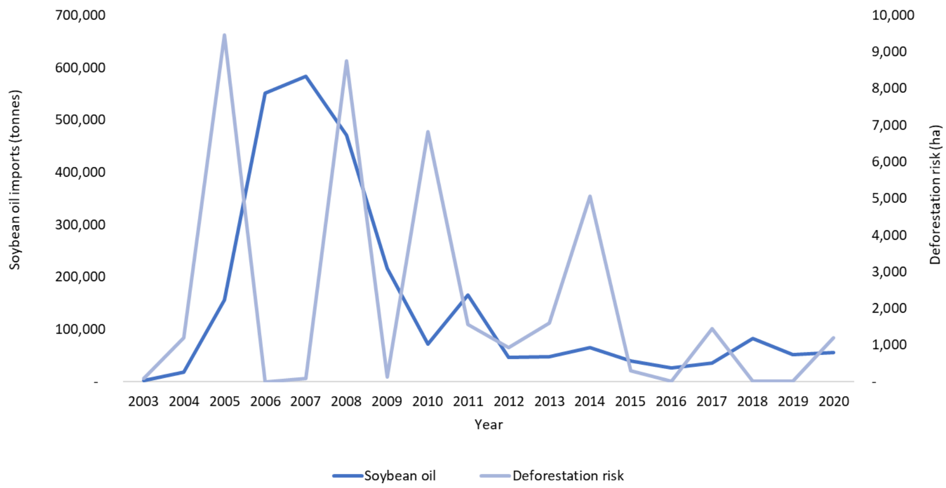
Annex 8.9 – EU imports of palm kernel cake from tropical countries and their attributable deforestation risk



Annex 8.10 – EU imports of soybeans from tropical countries and their attributable deforestation risk



Annex 8.11 – EU imports of soybean oil from tropical countries and their attributable deforestation risk



Annex 8.12 – EU imports of soybean cake from tropical countries and their attributable deforestation risk