Trading Forests: Quantifying the Contribution of Global Commodity Markets to Emissions from Tropical Deforestation

Martin Persson, Sabine Henders, and Thomas Kastner

Abstract

This paper aims to improve our understanding of how and where global supply-chains link consumers of agricultural and forest commodities across the world to forest destruction in tropical countries. A better understanding of these linkages can help inform and support the design of demand-side interventions to reduce tropical deforestation. To that end, we map the link between deforestation for four commodities (beef, soybeans, palm oil, and wood products) in eight case countries (Argentina, Bolivia, Brazil, Paraguay, Democratic Republic of the Congo, Indonesia, Malaysia, and Papua New Guinea) to consumption, through international trade. Although few, the studied countries comprise a large share of the internationally traded volumes of the analyzed commodities: 83% of beef and 99% of soybean exports from Latin America, 97% of global palm oil exports, and roughly half of (official) tropical wood products trade. The analysis covers the period 2000-2009. We find that roughly a third of recent tropical deforestation and associated carbon emissions (3.9 Mha and 1.7 GtCO2) can be attributed to our four case commodities in our eight case countries. On average a third of analyzed deforestation was embodied in agricultural exports, mainly to the EU and China. However, in all countries but Bolivia and Brazil, export markets are dominant drivers of forest clearing for our case commodities. If one excludes Brazilian beef on average 57% of deforestation attributed to our case commodities was embodied in exports. The share of emissions that was embodied in exported commodities increased between 2000 and 2009 for every country in our study except Bolivia and Malaysia.

JEL Codes: Q23, Q54, L73, Q02, Q17

Keywords: Climate change, Forests, REDD+, Commodities, Commodity supply chains, Energy, Food, Agriculture.

CGD Climate and Forest Paper Series #8

Center for Global Development
www.cgdev.org

Working Paper 384
October 2014

Trading Forests: Quantifying the Contribution of Global Commodity Markets to Emissions from Tropical Deforestation

Martin Persson
Chalmers University of Technology

Sabine Henders
Centre for Climate Science and Policy Research (CSPR),
Linköping University

Thomas Kastner
Institute of Social Ecology Vienna, Alpen-Adria Universität Klagenfurt

In addition to the Center for Global Development, the research presented in this report has been supported by grants from the Swedish Research Council FORMAS (project REDDleaks), the Norden Top-level Research Initiative subprogramme 'Effect Studies and Adaptation to Climate Change' through the Nordic Centre of Excellence for Strategic Adaptation Research (NORD-STAR), the Swedish Energy Agency (STEM), and the European Research Council within ERC Starting Grant 263522 LUISE. We are grateful for valuable comments from Jonah Busch, Frances Seymour, and Sara del Fierro, as well as three anonymous reviewers.

CGD is grateful for contributions from the Norwegian Agency for Development Cooperation in support of this work.

Martin Persson, Sabine Henders, and Thomas Kastner. 2014. "Trading Forests: Quantifying the Contribution of Global Commodity Markets to Emissions from Tropical Deforestation." CGD Working Paper 384. Washington, DC: Center for Global Development.
http://www.cgdev.org/publication/trading-forests-quantifying-contribution-global-commodity-markets-emissions-tropical

Center for Global Development
2055 L Street, NW
Fifth Floor
Washington, DC 20036

202.416.4000
(f) 202.416.4050

www.cgdev.org

Contents

Foreword

This paper is one of more than 20 analyses being produced under CGD's Initiative on Tropical Forests for Climate and Development. The purpose of the Initiative is to help mobilize substantial additional finance from high-income countries to conserve tropical forests as a means of reducing carbon emissions, and thus slowing climate change.

The analyses will feed into a book entitled *Why Forests? Why Now? The Science, Economics, and Politics of Tropical Forests and Climate Change.* Co-authored by senior fellow Frances Seymour and research fellow Jonah Busch, the book will show that tropical forests are essential for both climate stability and sustainable development, that now is the time for action on tropical forests, and that payment-for-performance finance for reducing emissions from deforestation and forest degradation (REDD+) represents a course of action with great potential for success.

Commissioned background papers also support the activities of a working group convened by CGD and co-chaired by Nancy Birdsall and Pedro Pablo Kuczynski to identify practical ways to accelerate performance-based finance for tropical forests in the lead up to UNFCCC COP21 in Paris in 2015.

This paper, "Trading Forests: Quantifying the contribution of global commodity markets to emissions from tropical deforestation" by Martin Persson, Sabine Henders, and Thomas Kastner, was commissioned by CGD to provide an original analysis of the extent to which consumers in rich countries are responsible for emissions from tropical deforestation through their consumption of beef, soy, palm oil, and wood products. The paper discusses demand-side interventions that can contribute to reducing deforestation in the tropics.

Frances Seymour
Senior Fellow
Center for Global Development

Jonah Busch
Research Fellow
Center for Global Development

Executive Summary

With the recognition that the drivers of tropical deforestation have become increasingly commercialized and globalized, the focus in the forest conservation policy debate is broadening to also include demand-side measures. There is emerging evidence that demand-side interventions can contribute to reducing deforestation in the tropics, as shown for instance by the Brazilian Soy Moratorium or regulations targeting trade in illegal tropical timber. However, to exploit the full potential of demand-side interventions we need a better picture of how and where global supply-chains link consumers of forest-risk commodities[i] across the world to forest destruction in tropical countries.

The aim of this paper is to map the link between deforestation for the four main forest-risk commodities (beef, soybeans, palm oil, and wood products) in eight case countries (Argentina, Bolivia, Brazil, Paraguay, Democratic Republic of the Congo, Indonesia, Malaysia and Papua New Guinea) to consumption, through international trade in the period 2000-2009. Although few, the studied countries comprise a large share of the internationally traded volumes of the analyzed commodities: 83% of beef and 99% of soybean exports from Latin America, 97% of global palm oil exports, and roughly half of (official) tropical wood products trade.

These are our key findings:

- Roughly a third of recent tropical deforestation and associated carbon emissions (3.9 Mha and 1.7 $GtCO_2$) can be attributed to of our four case commodities in our eight case countries.

- Beef was the leading source of deforestation and associated carbon emissions, accounting for half of total emissions (739 $MtCO_2$, of which 645 $MtCO_2$ in Brazil) and over two thirds of deforestation (2.6 Mha) in our analysis. Wood products, including pulp and paper, was the second largest source of carbon (481 $MtCO_2$), partly due to large emissions from the drainage of peat soils in Indonesia, while soy had the second largest deforestation footprint (0.5 Mha).

- On average a third of analyzed deforestation was embodied in agricultural exports, mainly to the EU and China. However, in all countries but Bolivia and Brazil export markets are dominant drivers of forest clearing for our case

[i] Defined as globally traded goods originating from forest ecosystems, either directly from within forest areas, or from areas previously under forest cover, whose extraction or production contributes significantly to deforestation and degradation.[3]

commodities. If one excludes Brazilian beef on average 57% of deforestation attributed to our case commodities was embodied in exports.

- The share of emissions that was embodied in exported commodities increased between 2000 and 2009 for every country in our study except Bolivia and Malaysia.

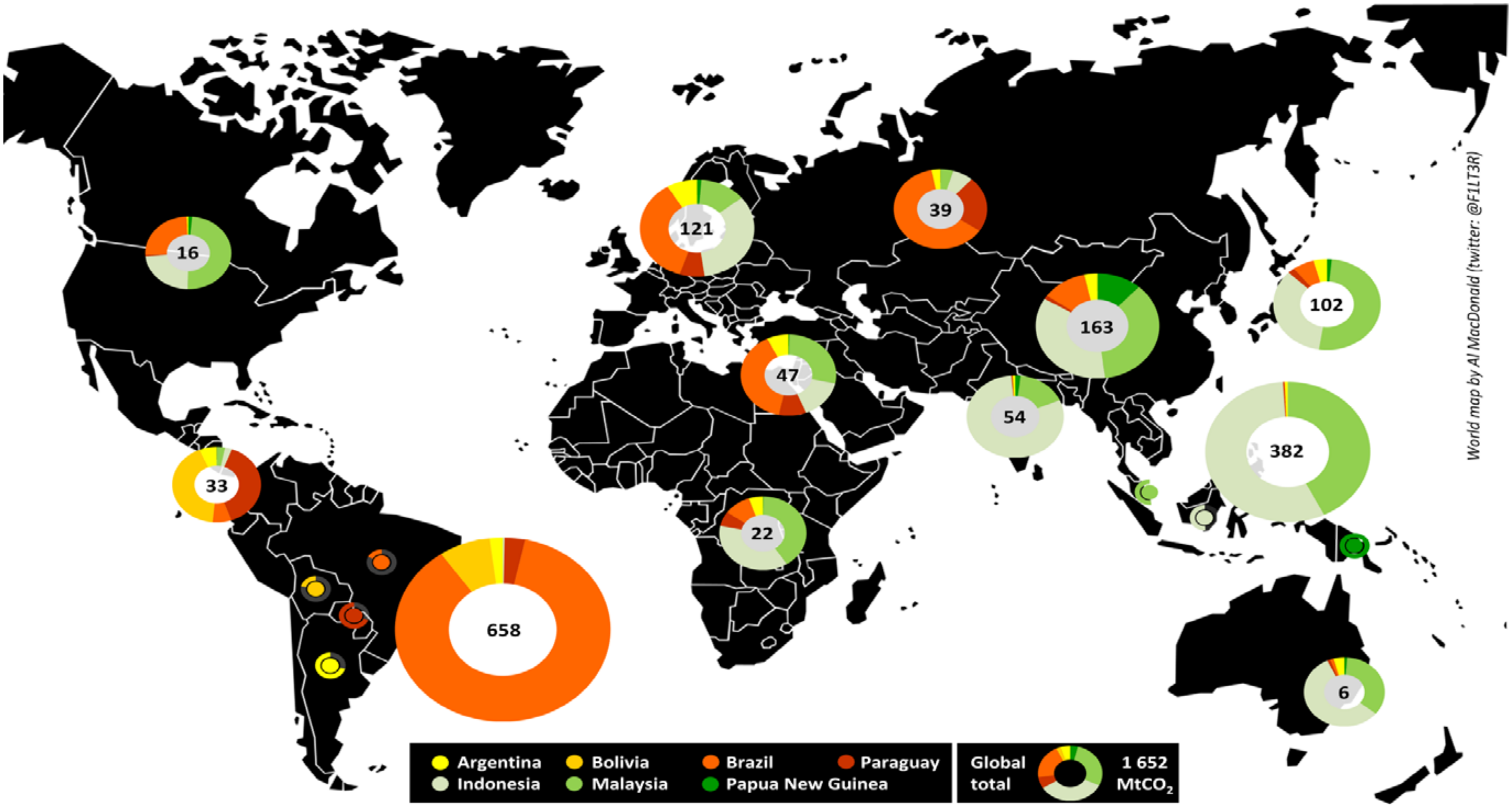

Fig. 1: *Carbon dioxide (CO_2) emissions from deforestation embodied in consumption of beef and soybeans from Argentina, Bolivia, Brazil, and Paraguay, palm oil from Indonesia, Malaysia and Papua New Guinea, and wood products from Brazil, Indonesia, Malaysia and Papua New Guinea, in 2009. Numbers inside pie-charts express the magnitude of emissions embodied in consumption in each region (in $MtCO_2$): North America, the four Latin American case countries, the rest of Latin America, Europe, North Africa & Middle East, Sub-Saharan Africa, Former Soviet Union, the three Southeast Asian case countries, India, China, Rest of Asia, and Oceania. Circles around source country markers denote the share of emissions embodied in production that is exported.*

Global Supply Chains and Tropical Deforestation – The Context

Procter & Gamble, Kellogg's, Johnson & Johnson, Mars, L'Oréal, Colgate, Disney, McDonald's, Nestle, Office Depot, and Unilever, even clothing companies like H&M and Zara; these companies are all among the growing list of corporations that have adopted a 'zero-deforestation' policy in the last couple of years. Pressured by environmental organizations and consumer advocacy groups they have pledged to rid their supply chains of products sourced from land recently cleared of carbon-rich forests.[2]

The market power of some of these retailers, together with that of large financial players (e.g., Norwegian pension funds) have in turn forced commodity producers to promise to clean up their environmental act and adopt forest conservation policies (although with a varying degree of stringency). Among the first out was the Brazilian Association of Vegetable Oil Industries (ABIOVE) and the National Association of Cereal Exporters (ANEC), who in 2006—following demands from a coalition between Greenpeace, McDonalds and leading food retailers—agreed not to buy soy produced on forest land cleared after July 2006. The 'Soy Moratorium', as it became known, has been renewed annually since and has effectively halted the clearing of Amazon rainforests in Brazil for large-scale soy plantations.[4, 5]

The risk of failing to live up to environmental and forest conservation standards was clearly felt by paper giant Asia Pulp & Paper (APP) who after fierce public criticism of its role in converting large areas of Indonesian rainforests and peatlands to fast-growing timber plantations found itself losing dozens of major customers within the time span of a few years. As a result, in 2013 APP announced a new corporate policy, committing itself to stop the conversion of high carbon stock and high conservation value forests, working more closely and transparently with local communities affected by new plantations, and allowing independent audits of its policy by credible environmental organizations. The APP's forest conservation pledge was modeled after a similar agreement already signed in 2011 between Golden Agri-Resources Ltd (GAR)—the world's second largest palm oil plantation company—and The Forest Trust. Following in the steps of GAR and APP, the world's largest palm oil trading company, Singapore-based Wilmar, established an even more

---

[2] More information on corporate action on (tropical) forest conservation can be found in the following news archive: http://news.mongabay.com/news-index/corporate%20role%20in%20conservation1.html

stringent forest protection policy later in 2013 that applied to third party suppliers as well as its own operations.

The underlying reason for the recent interest in demand-side measures for tropical forest conservation—such as certification schemes and consumer campaigns—as well as for the tentative claims for their effectiveness[1, 6], is the fact that the drivers of tropical forest loss have become increasingly commercialized and globalized in the last decades: commercialized as the agents of deforestation have shifted from smallholders clearing forest for subsistence farming to large-scale agricultural corporations clearing for profits[7, 8]; globalized as the agricultural commodities produced on the cleared land to a rising extent are destined for export, rather than domestic, markets[9, 10].

Across the globe, forests are currently lost at a gross rate of approximately 10 Mha per year[11, 12]. With 350 million people, many of them poor, relying on forests as a key source for their livelihoods, the deforestation has a profound impact on the provisioning of vital ecosystem services locally, such as water, energy and food security[3]. In a global perspective, tropical deforestation constitutes the single largest threat to biodiversity in terrestrial ecosystems[13] and is the source of carbon dioxide (CO_2) emissions of approximately 4.5 $GtCO_2$[14, 15] annually[3], substantially contributing to climate change.

Ascribing this massive global loss of tropical forests to a single factor is in most cases difficult, as land-use change processes are the result of complex interactions among a broad set of demographic, economic and institutional factors (population dynamics, poverty, quality of governance, infrastructure, etc.), the combination of which is often referred to as the *underlying drivers* of deforestation.[3, 16] But even at the level of *proximate drivers* (i.e., the land uses replacing forests after clearing) there is a considerable lack of empirical evidence. Still, there is consensus on the general picture: the expansion of agriculture land is currently the prime reason for forest loss across the tropics.[3, 16-20] It has been estimated from the analysis of satellite images that over 80% of new agricultural land brought into cultivation between 1980 and 2000 came at the expense of forest.[21] Other studies indicate that over 70% of recent deforestation has been due to agricultural expansion.[18, 19, 22]

Ultimately, this expansion of agricultural land is driven by the world's population growing larger and wealthier. Rising incomes induces shifts in diets towards more land demanding

[3] Both and Harris et al.[15] and the recent analysis of Grace et al.[14] find that the gross flux of carbon from deforestation is 3 $GtCO_2$/yr, with emissions from peat drainage and fires adding 1.0-2.0 $GtCO_2$/yr. In addition to this, there are also carbon losses from forest degradation, shifting and fuel wood harvest.

products (i.e., animal proteins and vegetable oils). On top of this comes increased demand for land to produce bioenergy and biofuels, driven by concerns for energy security and climate change. A successful long-term strategy for forest conservation therefore must contain, *inter alia*, elements of forest protection (i.e., raising the value of standing forests to counteract the increased profitability of clearing as land demand rises[23]), measures to curb demand growth (e.g., inducing diet shifts away from animal products or limiting demand for bioenergy[24]), and demand-side policies that aim to steer agricultural expansion away from sensitive ecosystems, such as natural forests.

Recently, several studies have proposed a host of options for demand-side measures promoting tropical forest conservation, ranging from governmental actions (e.g., public procurement policies, tariff reductions for sustainable products, or bilateral agreements between producer and consumer countries) to private sector initiatives (e.g., certification schemes, codes of conduct, or moratoria) and consumer campaigns. However, in order for these measures to be effective in stemming forest loss we must better understand which commodities are driving deforestation where, so that interventions can be targeted where they have the highest potential impact. Our current incomplete understanding of the drivers of deforestation therefore presents an obstacle to formulating efficient forest conservation policies, both at a national and global level.[18]

In this study we take a bottom-up approach to attribute deforestation in some of the countries with the highest amounts of forest loss (either relative or absolute)—Argentina, Bolivia, Brazil, and Paraguay in Latin America, the Democratic Republic of the Congo (DRC) in Africa, and Indonesia, Malaysia, and Papua New Guinea in Asia—to four *forest-risk commodities* that are commonly identified as the main tropical deforestation culprits in the literature[1, 17]: beef, soybeans, palm oil and wood products (i.e., timber, pulp and paper). We then trace the land-use changes and associated carbon emissions to consumers, both domestic and international, using a physical trade model.[23] This allows us to quantify the extent to which international market demand for the analyzed commodities is driving deforestation, how this has changed over time, and which countries or regions are the main consumers of the land-use change impacts embodied in these products. It is our hope that this analysis will contribute to an improved understanding of different commodity supply-chains' contribution to tropical deforestation and form a basis for more effective demand-side forest conservation measures.

An Approach to Linking Deforestation to Consumption of Forest-Risk Commodities

In this section we present a brief overview on how drivers of deforestation differ across the tropics, motivating our choice of country-commodity cases to analyze. We show that through a careful case selection it is possible to cover a large share of total forest loss, as well as production and trade in the main forest-risk commodities across the tropics. We then provide a short, non-technical, introduction to the methods used to estimate deforestation embodied in the production and consumption of beef, soybeans, palm oil and wood products in different regions. This is done in three steps (see Fig. 2). In the first we utilize a recently published methodology[24] for calculating so-called *deforestation footprints* to estimate the amount of deforestation and resulting carbon emissions that accrue due to the production of different forest-risk commodities. The second step uses a method for tracing environmental impacts from producers to countries of apparent consumption[23]. In the third step the results from the two previous steps are brought together to estimate the amount of deforestation, and associated carbon emissions, that is embodied in the consumption of different forest-risk commodities in a given country or region.

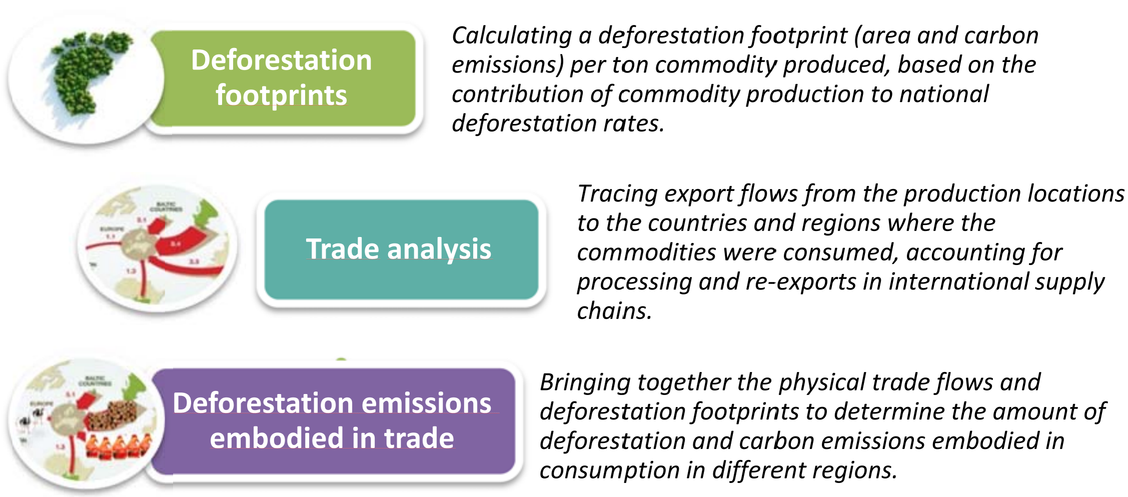

Figure 2: Methodology. *Schematic overview of the main calculation steps involved in in estimating the deforested area and associated carbon emissions embodied in the consumption of forest risk commodities in a given country or region.*

(i) Scope and study period

The analytical method used here is a bottom-up approach to country-by-country assessments of deforestation for export commodity production and the related carbon emissions from vegetation clearing, combined with bilateral trade flow data identifying the countries where these commodities are consumed. We base our analysis on a compilation of data on deforestation rates, emission factors, and the attribution of emissions to the respective drivers in the eight case countries, rather than on a top-down allocation of tropical deforestation emissions to different commodities. The main information source of deforestation parameters and drivers was the scientific literature, and bilateral trade flows were obtained from the FAO database (http://faostat.org). Whereas the following provides a short summary of the main characteristics and the assessment scope, further details are described in the technical appendix:

- Although uncertainties in underlying data undoubtedly exist (see results section), in this report we have tried to reduce them to a minimum by using the most recent and best scientific information sources that are currently available. Wherever possible, deforestation rates and forest cover loss data used in our analysis are based on remotely sensed information (rather than, for instance, FAO country data). We consider not only forest and forest loss in the strict sense but also include clearing of natural vegetation in forest-like ecosystems, such as the South American Cerrado and Chaco biomes.

- Emissions were determined on the basis of the converted forest area, considering the net loss of living biomass (i.e., difference between aboveground and belowground biomass in natural vegetation and the land use replacing it). To that end we used average biomass stocks as reported in local or regional case studies. Due to limitations in data availability and because of high uncertainties we omit soil carbon emissions, except for the case of oil palm and timber plantations on Southeast Asian peatlands, which give rise to significant soil emissions. For peatlands we therefore account for one-time emissions from clearing and draining as well as subsequent annual emissions from peat oxidation.

- Due to the availability of underlying data from the FAO trade database, our analysis covers the years 2000-2009. Note that, according to the footprint methodology used, the emissions and area footprints for the respective study years take into account deforestation processes occurring in the last ten years before the production of the commodity (except for wood products from natural forests, see details below), so that the underlying deforestation and drivers data goes back to 1990. Also, to decrease the information gap between the last year of our analysis and the present (2014) we included a description of trends since 2009.

- The trade assessment is based on physical trade data (in tons, rather than in monetary units as commonly used in other studies). Trade flows are expressed in primary commodity equivalents for the agricultural products, and in carbon equivalents in the case of wood products.

(ii) What is driving tropical deforestation – rationale for the choice of country-commodity cases

The bulk of the world's tropical moist forests is found in three major regions: the Amazon Basin in Latin America, the Congo Basin in Africa, and in Southeast Asia. With as much as 50% of the tropical forests worldwide having been cleared, some of these regions have seen high rates of deforestation in the last decades.[11] Tropical dry forests or wooded grasslands experienced even higher clearing rates, such as the *Cerrado* of Brazil or the *Chaco* forest of Argentina, Bolivia and Paraguay, with over half of the original extent across the tropics converted to agricultural uses.[17] While the loss of tropical rainforests has attracted most of the public attention, dry forests store substantial amounts of carbon (albeit at a lower density than humid forests) and exhibit high levels of biodiversity and endemism.[25]

The proximate drivers of deforestation differ markedly across the tropical regions. In Latin America, which until recently accounted for as much as half of the global tropical forest loss[26], deforestation has historically been caused primarily by expanding pastures for beef production. Cash crops like sugar cane and cotton have also contributed to forest clearing in some countries, but in the last decades soybeans have emerged as a major driver of deforestation across South America. In particular, in the Brazilian *Cerrado* and Argentinian *Chaco* biomes millions of hectares have been cleared for the establishment of large-scale soybean plantations.[25, 27, 28]

Southeast Asia has also sustained high rates of forest loss in the last decades. A third of the region's remaining forests are located in Indonesia, a country currently experiencing the world's second highest annual rate of forest loss.[11, 26] Timber extraction from natural forests has been, and still is, a dominant driver of deforestation in Southeast Asia, but both shifting cultivation and plantation agriculture (e.g., rubber) have also played important roles. In recent years the latter, in the form of oil palm and short rotation timber plantations for pulp and paper production, have gained in importance as deforestation drivers, especially in Indonesia[24, 29, 30].

In contrast to Latin America and Southeast Asia, where large-scale commercial agriculture is rapidly expanding into natural forests, the tropical forests of the Congo Basin are still relatively undisturbed, with historical deforestation rates of less than 0.15%.[31] The dominant drivers of deforestation and forest degradation are primarily small-scale and local, e.g., shifting cultivation, demand for fuel wood and charcoal, and artisanal logging.[3, 32] However, with large areas of forest land suitable for the production of agricultural commodities and biofuels, there are signs of mounting pressure on the remaining African rainforests, as indicated by, e.g., large-scale land acquisitions for oil palm and other crops[3, 33] and a doubling of basin-wide deforestation rates to 0.26% (and degradation to 0.14%) between 2000 and 2005.[31]

The brief exposé of the proximate drivers of tropical deforestation above again highlights the role of four main commodities in driving tropical forest loss: beef, soybeans, palm oil, and wood products. We therefore focus our analysis here on these commodities, with the aim to quantify their contribution to deforestation and linking production to consumption, both domestically and internationally through exports. This focus then guided our choice of case countries; we aimed to include countries that both have seen high levels of deforestation (to be as comprehensive as possible in terms of total forest clearing) but that also are major producers and primary exporters[4] of these commodities.

For beef and soy we focus on Argentina, Bolivia, Brazil, and Paraguay, four countries that together incurred over 80% of total forest loss in Latin America in the 2000s.[11, 26] These countries collectively account for 73% of the total beef production in Latin America, and 84% of the region's primary beef exports in 2009. Although most of the beef produced in Latin America—and the world in general—is still consumed domestically (see Fig. 3), beef exports from these countries have also increased sharply in the 2000s, especially from Brazil.

[4] Production and trade data are taken from the FAOSTAT database (http://faostat3.fao.org). We will use the term *primary exporters* here to refer to exports from the countries where a given commodity was produced, thereby excluding trade from countries that imported and then re-exported the commodity. E.g., because of its position as a trade hub and processor of primary crop products, the Netherlands is listed as the world's fourth largest exporter of soybeans and the world's third largest exporter of palm oil products, despite producing neither of the two crops.

For soy our case countries comprise close to all (99%) of both Latin American production and primary exports from the region, or roughly 60% of global primary soybean exports (the remainder mainly coming from North America and India). Most (60-100%) of the soy production in our case countries is also destined for international markets, somewhat higher than the global average (Fig. 3).

Palm oil production and trade is highly concentrated, with Indonesia and Malaysia accounting for 82% of global production and 97% of global primary exports (Fig. 3). Papua New Guinea, the world's third largest palm oil exporter, accounts for roughly half of the remaining global primary exports. These three countries, together accounting for around two thirds of total Asian deforestation in the 2000s[11, 26], were therefore chosen as our palm oil case countries.

Finally, in analyzing the role of consumption and exports of wood products to deforestation and associated carbon emissions, we focus mainly on four of the countries already included in our selection: Brazil, Indonesia, Malaysia and Papua New Guinea. Taken together, these countries' production and exports of wood products represent just over half of the total volume from tropical regions; Brazil accounts for half of the Latin American wood product exports while Indonesia, Malaysia and Papua New Guinea account for two thirds of Asian exports.

In addition, we qualitatively assess the contribution of timber exports from one African country, Democratic Republic of the Congo. However, our focus in the quantitative analysis is on Latin America and Southeast Asia, because data on deforestation rates and drivers is scarce for the DRC, but also because deforestation in Africa to an overwhelming extent is currently driven by non-commercial activities, both in terms of demand for wood and agricultural land. Nevertheless, this situation might change in future, as it is countries such as DRC, Liberia, or Tanzania that are seen as future sources of new, large-scale land and labour resources. It is therefore important to keep these regions in mind and include them in future assessments as soon as better data becomes available.

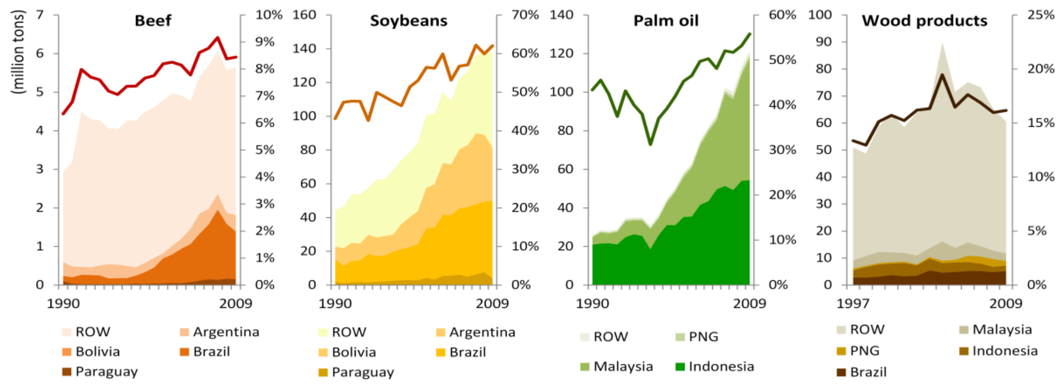

Figure 3: Global trade in case commodities. *Total global primary exports (left axis) of the four forest- risk commodities analyzed, for the period 1990-2009, highlighting the amount of exports coming from our case countries for each commodity. The share of global production that is traded on international markets is also displayed for each commodity (right axis). All units are in million tons, except wood product values which are in million tons of carbon. Data: own calculations based on FAOSTAT (http://faostat3.fao.org).*

(iii) Calculating deforestation footprints of forest-risk commodities

To ascertain the amount of deforestation associated with the consumption of forest-risk commodities from our different case countries we estimate so-called deforestation footprints for each product. These express the area that is deforested, and the magnitude of the resulting carbon emissions, due to the production of, e.g., one ton of beef in Brazil or one ton of palm oil in Indonesia. Because agricultural production occurs over an extended period of time, following a one-time deforestation event, we distribute the deforestation and resulting carbon emissions equally over all the beef or palm oil produced on the cleared land in the ten years following forest clearing. In doing so we account for land-use dynamics such as degradation and abandonment of pastures, or the temporal yield dynamics of perennial crops such as oil palm or acacia. The choice of amortization period over which land use change emissions are distributed is ultimately arbitrary[26], but a ten year period is reasonable balance between data availability and quality (a longer amortization period would imply extending data series to before the 1990s) and the yield profile of some of the analyzed commodities (i.e., for oil palm taking three years from planting to first harvest, or acacia plantations having a six-year rotation period). This yields deforestation footprints in terms of area and carbon emissions that accrue per ton of commodity produced *on deforested land.*

However, because international trade statistics do not carry information on whether exported goods have been produced on cleared land or not, we proceed to calculate average deforestation footprints at the national scale by adjusting the results from the first step by the share of total national production of the commodity that is sourced from land cleared in the last ten years. This yields the average load of deforestation (*area footprint*) and carbon emissions (*carbon footprint*) per ton of the respective commodity produced in the case country in a given year[5]. These footprints will be higher the larger the amount of clearing for a given commodity over the last ten years and hence the larger the share of total production occurring on recently cleared land. The carbon footprint will also be higher, the larger the carbon content of the cleared vegetation.

For wood products we differentiate between the deforestation for the establishment of short-rotation (acacia) plantations for pulp wood, which has been a significant driver of forest loss in Indonesia, and the extraction of timber from natural forests, either through clear-cutting or selective logging prior to the clearing for agricultural crops. While we can apply the carbon footprint methodology to the former, timber extraction from natural forests does not involve a temporal lag between forest clearing and production, which is why here we take a different approach.

Firstly, where clearing for agricultural production is preceded by timber extraction, all the carbon lost through logging (including logging damages[34]) is allocated to wood products. The deforested area, however, is allocated solely to the agricultural product (beef, soybeans, palm oil). Secondly, we allocate deforestation to wood products where remote sensing studies find forests replaced by bare land (i.e., likely the result of clear-cutting for timber or fire following forest degradation by logging), adding the resulting carbon loss to that from logging prior to agricultural conversion. Note, however, that if there is a lag between logging and planting, this may result in too much deforestation being attributed to timber products (on the other hand, the fact that there are large areas of forest cleared in, e.g., oil palm concessions, but not planted with oil palm[22], may also indicate that it is the timber revenue that is driving forest loss).

The important distinction between how wood products from natural forests and agricultural and plantation commodities are treated is that while deforestation for the latter is distributed over a ten year period, for the former the area cleared and resulting emissions are allocated to production in the same year as deforestation occurs.

[5] A detailed account of the calculation procedure, as well as a discussion and illustration of how results change with different amortization periods, can be found in Reference [24].

A key input to the estimation of the above deforestation footprints is the share of deforestation caused by the respective commodities. We surveyed the available literature on proximate drivers of tropical deforestation and national deforestation contexts, in order to quantify the extent to which the production of beef, soybeans, palm oil and wood products contributes to land clearing in our case countries. The results for each country are displayed in Fig. 4 (the data and references underlying our assumptions can be found in the Technical Appendix to this paper and the full dataset of the results presented here can be obtained from the authors upon request).

Overall, the share of deforestation in our case countries that is attributed to our case commodities increased in the 1990s, from just under 70% to close to 80%, but the remained stable at that level during the 2000s. This share is a somewhat higher than other recent studies attributing 50-70% of recent tropical deforestation to commercial agriculture[18, 22], which is reasonable given that the selection criteria for our case countries was that they are major producers and primary exporters of forest-risk commodities.

As seen in Fig. 4, in our Latin American case countries most of the deforestation can be attributed to beef and soy production, whereas in Southeast Asia a somewhat larger share of deforestation is driven by other proximate drivers than those accounted for here, such as other plantation crops (for instance, in Indonesia the area under estate crops such as rubber, coffee, cacao, and sugar cane increased by 2.3 Mha in the period 2000-2009, or nearly two-thirds of the increase in area under oil palm) and, to a lesser extent, shifting cultivation.[22, 29]

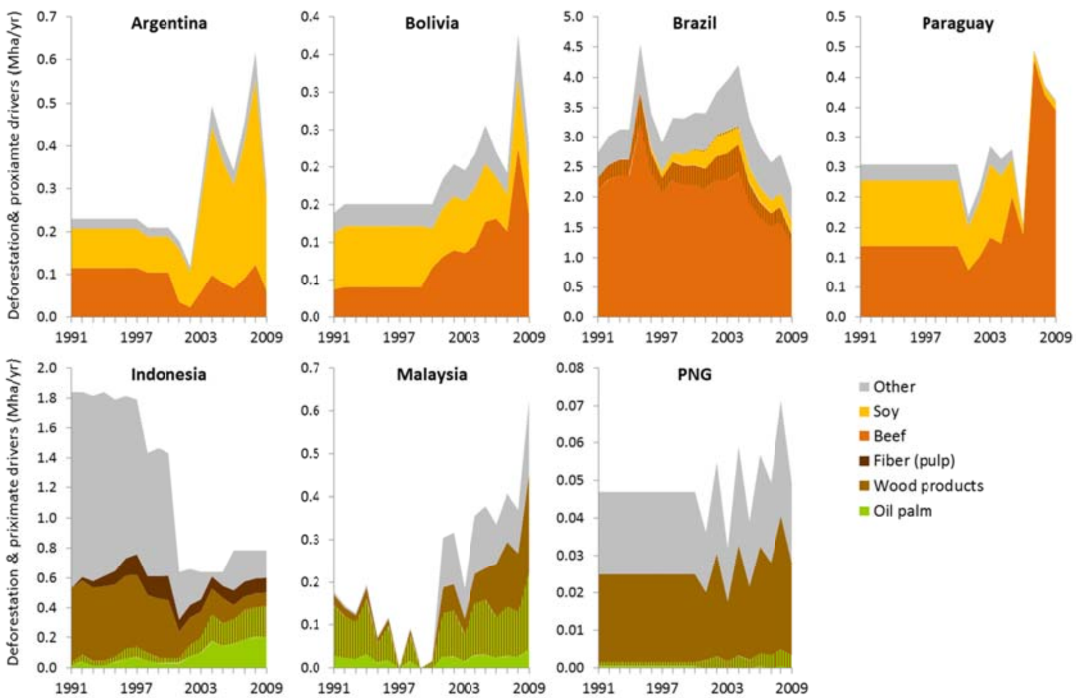

Figure 4: Attribution of deforestation to our case commodities. *The rate of deforestation in each of our case countries in the period 1990-2009, mainly based on results from remote sensing studies (with differing temporal resolution). Shaded colored areas represent deforestation attributed to each of the four analyzed commodities – beef, soybeans, palm oil and wood products – with striped areas representing forests areas selectively logged prior to clearing. The lack of annual deforestation data for most countries prior to 2000 explains the apparent flat levels of deforestation in the 1990s. See the Technical Appendix to this paper for further details and underlying data sources.*

(iv) Tracing forest-risk commodities from production to consumption through trade

The second step of our analysis serves to assess where in the world forest-risk commodities from our case countries are consumed. It builds on a methodology for tracing environmental impacts from producers to countries of apparent consumption[6], by accounting for processing and re-exports in international supply chains. The analysis is based on bilateral trade data from the FAOSTAT database and covers primary and major secondary commodities; e.g., for soybeans also soybean oil and soybean cake, for cattle meat also offals and meat preparations, for palm oil also palm kernel oil and palm kernel cake, and for wood

[6] See reference [23] for a detailed description of the trade flow methodology.

products roundwood, sawn wood, wood boards and paper products (for the analysis of Indonesian deforestation for short-rotation pulp plantations, only the latter is used).

Along with production data for our commodities, these trade data are used to establish consistent links between primary exporters and consuming countries. For the agricultural commodities in our analysis we use data from a previous study.[35] These figures include feed contained in traded animal products, based on data on feed use from FAOSTAT. For instance, if Dutch pork, fed with soy cake originating from Argentina, is exported to Italy, our results will show the link between consumption in Italy and soy cultivation in Argentina.

For wood products we use the same approach as in a previous study[36], but updated the data to cover the period from 1997 to 2012. Based on these datasets, Fig. 3 presents global trade totals for the four commodities, highlighting the role of the selected case countries. By attaching the estimated deforestation area and carbon footprints to these trade flows, we then can quantify to what extent international market demand and consumption is fueling deforestation in the tropics.

Results

A quick overview of the results from our analysis, in terms of levels and trends in deforestation for each commodity and country, commodity production and exports, and deforestation area and emissions embodied in production and exports, are summarized in Table 1. Below we present the detailed results, first of the estimated deforestation footprints—as differences between countries and temporal dynamics in these are important determinants of the final results—then turning to the results of deforestation emissions embodied in trade.

(i) Commodity deforestation footprints – the bad and the worse

The estimated deforestation area and carbon footprints for each of the three agricultural commodities in the period 2000-2009, by country, are displayed in Fig. 5. For beef, the carbon footprint ranges from just over 4 tCO_2/t beef in Argentina, to a staggering 203 tCO_2/t beef in Bolivia. These numbers can be compared with the average lifecycle emissions (other than those from land-use change) for beef production in Latin America of 48 tCO_2/t beef[37]. This means that including the carbon emissions from deforestation more than doubles the carbon footprint of Brazilian beef, and raises that of Bolivian beef by six times. This is for a product that already is one of the most carbon intense of all food commodities, with Latin American beef production having among the highest lifecycle emissions in the world.

Table 1: *Levels (numbers) and trends (highlight colors) in deforestation (average 2000-2009), production and exports, and deforestation area and emissions embodied in production and exports, for each commodity and country in 2009. Average trends (in absolute numbers) in the period 2000-2009 are highlighted as rapidly increasing (dark red, >5%/yr), increasing (light red, 2.5 – 5%/yr), decreasing (light green, -2.5 – -5%/yr) and rapidly decreasing (dark green, <-5%/yr); no shading implies no clear trend (-2.5-2.5%/yr).The total deforestation for our four case commodities in 2000-2009 (40.9 Mha) constitutes 77% of all forest loss in our case countries in this time frame.*

		2000-2009	2009					
					Deforestation embodied in…		CO_2 emissions embodied in…	
Country:	Commodity:	Gross deforestation (Mha)	Prod. (Mt)	Exports (Mt)	Prod. (kha)	Exports (kha)	Prod. ($MtCO_2$)	Exports ($MtCO_2$)
Argentina	Beef	0.75	3.4	0.4	79	10	15	2
	Soybeans	2.35	30	30	161	161	30	30
Bolivia	Beef	1.16	0.2	0.0	110	0.4	41	0
	Soybeans	0.66	1.9	1.1	71	41	24	14
Brazil	Beef	22.5	9.3	1.2	2247	297	645	85
	Soybeans	2.73	57	46	236	191	47	38
Paraguay	Beef	2.04	0.3	0.2	205	99	38	18
	Soybeans	0.62	3.9	3.9	40	40	26	26
Indonesia	Palm oil	2.67	90	63	182	128	204	144
	Pulp & paper	0.98	2.2	1.2	82	43	101	53
	Wood products	1.61	14	2.0	92	14	119	18
Malaysia	Palm oil	1.27	88	54	108	67	100	62
	Wood products	1.08	5.8	2.8	233	110	214	102
PNG	Palm oil	0.04	1.8	1.8	2.5	2.5	1.3	1.3
	Wood products	0.46	1.7	1.7	25	25	22	22
All	All	40.9			3 872	1 229	1 652	626

The main reasons for the low Argentinian footprint is the relatively small share of recent deforestation in the country being driven by expanding pastures, with most of Argentinian beef production occurring outside of the Chaco region where deforestation is concentrated, combined with the low carbon content of Chaco forests. Notable also is the fact that the beef footprint is decreasing in Brazil, due to a recent reduction in Amazon deforestation, while it is sharply increasing in Bolivia and Paraguay, due to increases in both total deforestation rates and the share attributed to cattle ranching (see Fig. 4).

The opposite holds for the soybean footprints in Bolivia and Paraguay, which decreased rapidly in the 2000s as a result of a reduction in the share of deforestation driven by soy expansion (see Fig. 4), though both countries' deforestation footprints still are substantially higher than those in Argentina and Brazil. The reduction of the Paraguayan soy footprint can largely be attributed to the country's implementation of a 'Zero Deforestation Law' in 2004, aimed at reducing land clearing in the country's remaining Atlantic forest[7], the biome where clearing for soybean cultivation in Paraguay has been concentrated.

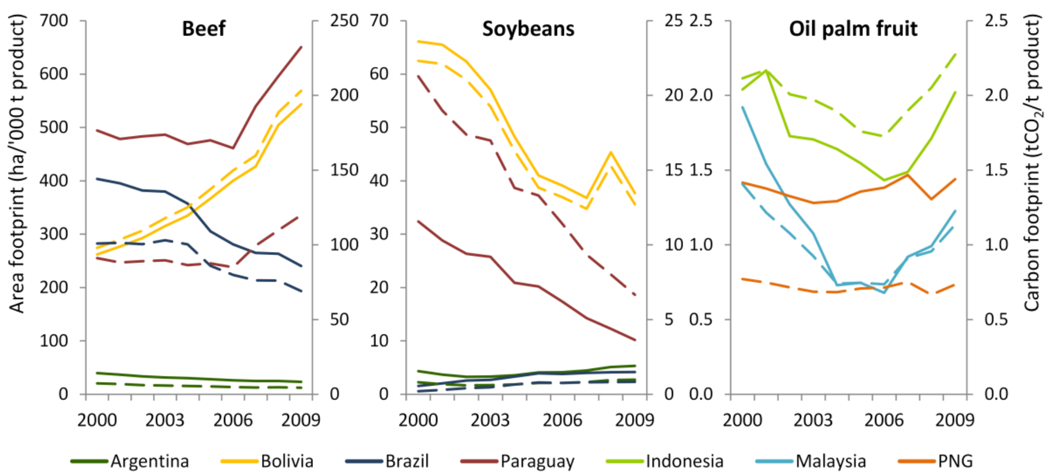

Figure 5: Deforestation area and carbon footprints. *Deforestation (solid lines, left axis) and emission (dashed lines, right axis) intensity of the production of beef, soybeans, and palm oil in our case countries, when averaged over total domestic production. We here refer to these indicators as deforestation area and carbon footprints, respectively.*

Lower soybean deforestation footprints in Argentina and Brazil are the result of the lower carbon content of the vegetation cleared for soy cultivation (dry forests in the Chaco and

[7] WWF, "Deforestation rates slashed in Paraguay" (http://www.wwfca.org/?uNewsID=79260, accessed May 27, 2014)

Cerrado biomes) and a larger share of total production originating not on recently cleared land. Still, the carbon footprints for soy in Argentina and Brazil were 1.0 tCO_2/t and 0.8 tCO_2/t soybeans, respectively, in 2009, which implies more than a doubling the total lifecycle greenhouse gas emissions for soy production in the two countries (compared to estimates excluding deforestation emissions).[38, 39]

Deforestation footprints for oil palm products in Southeast Asia see diverging trends. In Indonesia the carbon footprint increased in the last years of our analysis due to a rising share of forest clearing for oil palm plantations (see Fig. 4), though this is partly counteracted by a rapidly increasing total palm oil production in the country (reducing the average footprint). The deforestation footprint of Malaysian palm oil, on the other hand, saw a rapid decrease during early the 2000s, as a result of declines in the amount of deforestation for palm oil in the late 1990s (remember that the deforestation footprint accounts for forest clearing for a commodity in the previous ten years). However, the Malaysian palm oil deforestation footprint stabilized in the late 2000s, as deforestation for oil palm recommenced but total production volumes increased sharply. In both Indonesia and Malaysia, where a substantial share of oil palm plantations are established on peatlands[40], the carbon emissions resulting from peat drainage[41] constituted roughly half of the estimated palm oil carbon footprints in 2009.

(ii) Deforestation and associated carbon emissions embodied in domestic demand and trade

Figs. 6 and 7 display the results from the analysis of deforestation area and emissions embodied in the consumption of the four forest-risk commodities, where the former figure displays the emissions embodied in consumption by commodity and country in absolute terms, while the latter displays the relative importance of international demand and domestic consumption of these commodities in contributing to overall deforestation in each country.

In total, beef was the main driver of forest loss across our case countries, accounting for nearly half of the embodied carbon emissions (739 $MtCO_2$ in 2009, of which 645 $MtCO_2$ in Brazil) and over two thirds of the embodied deforestation (2.6 Mha in 2009). Production and consumption of soybeans were the second largest source of embodied deforestation area (0.5 Mha in 2009), whereas wood products (including Indonesian plantation pulp and paper) was the second largest source of embodied carbon emissions (481 $MtCO_2$ in 2009). The reason for the latter is threefold. First, the forests cleared in Southeast Asia have a higher carbon content than those in Latin America (especially compared to *Cerrado* and *Chaco* vegetation where soy has mainly expanded). Second, because much (50-80%) of forests cleared for oil palm in Southeast Asia is selectively logged prior to conversion, around 20% of the carbon emissions also from oil palm clearing is allocated to wood products. Third, the high emissions from the drainage of peatlands for pulp timber plantations production, leads to large CO_2 emissions per hectare deforested for this commodity.

Looking at the individual commodities, and starting with beef, in Bolivia and Paraguay where deforestation for cattle ranching has increased recently, associated carbon emissions embodied in total beef consumption follow suit, whereas in Argentina and Brazil they have decreased due to recent reductions in the total clearing for pastures. Figs. 6-7 clearly demonstrate that the bulk of Latin American beef, and hence also the embodied carbon emissions from deforestation, was consumed domestically. The exception is Paraguay, where around half of total production in 2005-2009 was destined for export markets, primarily to the rest of Latin America and to Russia. Still, with expanding pastures being the prime land use replacing forests in both the Amazon and the Cerrado, Brazil accounts for roughly 85% of deforestation linked to beef production across our four Latin American case countries. Thus, despite a high share of domestic consumption in Brazil, the country is still the leading exporter of embodied deforestation emissions. In total exported beef emissions amounted to 85 $MtCO_2$ in 2009, with the EU, Russia and MENA (Middle East and North Africa) being the main importers.

Compared to beef, the situation for soy is almost reversed. Firstly, most (70-100%) of the soy across the four countries is produced for export markets, with the EU accounting for roughly 30% of the international demand in 2009, and China and the rest of Latin America adding 20% each. Also, the embodied carbon emissions were more evenly spread across our four case countries. Nevertheless, both Argentina and Brazil accounted for a proportionally much larger share of embodied deforested area due to the clearing of soy mainly in low carbon content biomes, *Chaco* and *Cerrado*; Brazil alone accounted for nearly half the deforested area embodied in Latin American soy production in 2009.

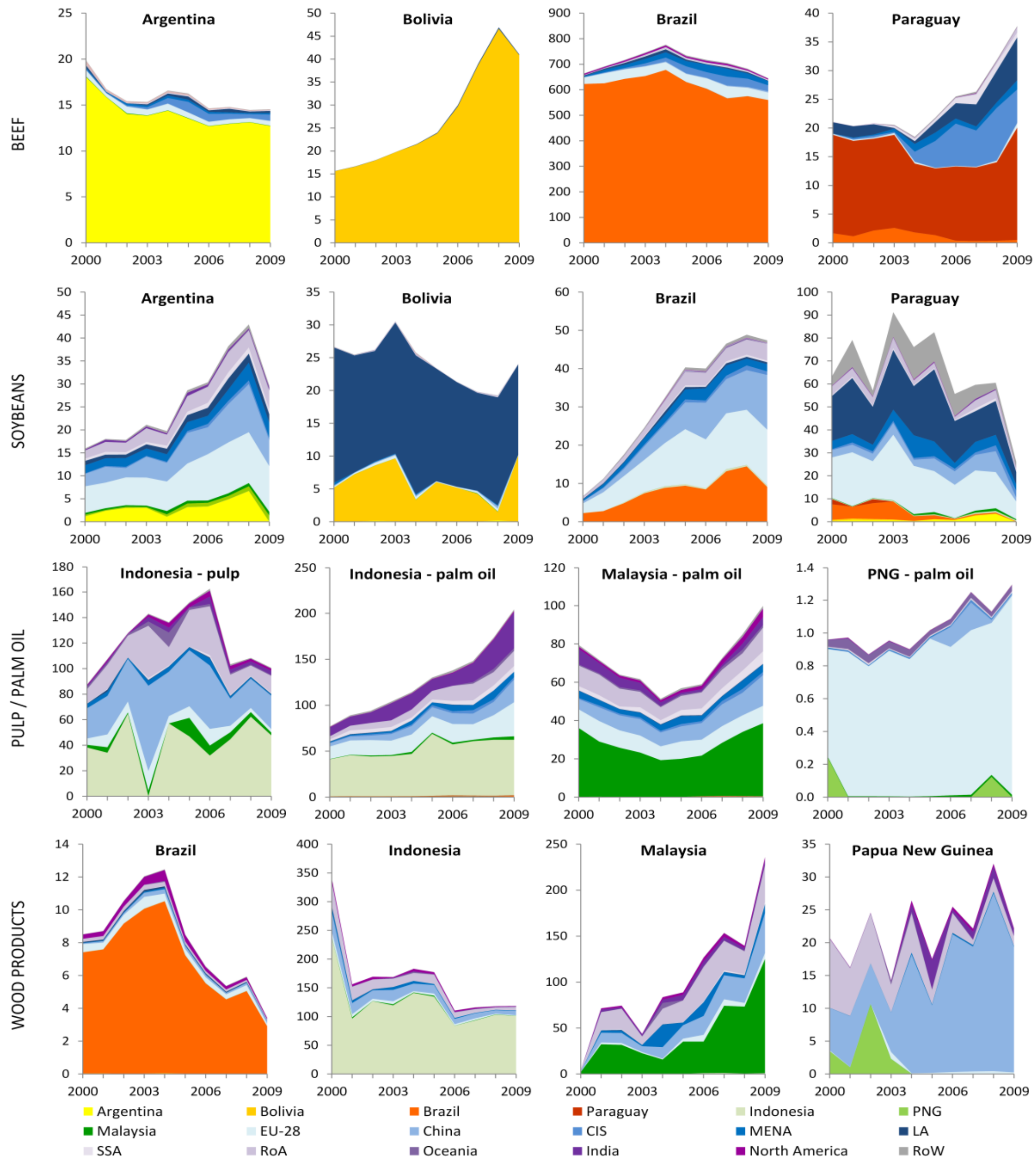

Figure 6: Share of total embodied carbon emissions from deforestation by consuming country. *Each panel shows the carbon emissions (in* $MtCO_2$*) embodied in the consumption of one of four forest-risk commodities – beef, soybeans, palm oil, and wood products, with the latter in Indonesia divided between wood products extracted from natural forests and paper and pulp products sourced from plantations – produced in one case country, according to the country or region where it is consumed. See main text for details. Abbreviations: PNG = Papua New Guinea; CIS = Former Soviet Union; MENA = Middle East & North Africa; LA = Latin America; SSA = Sub-Saharan Africa; RoA = Rest of Asia; RoW = Rest of the world.*

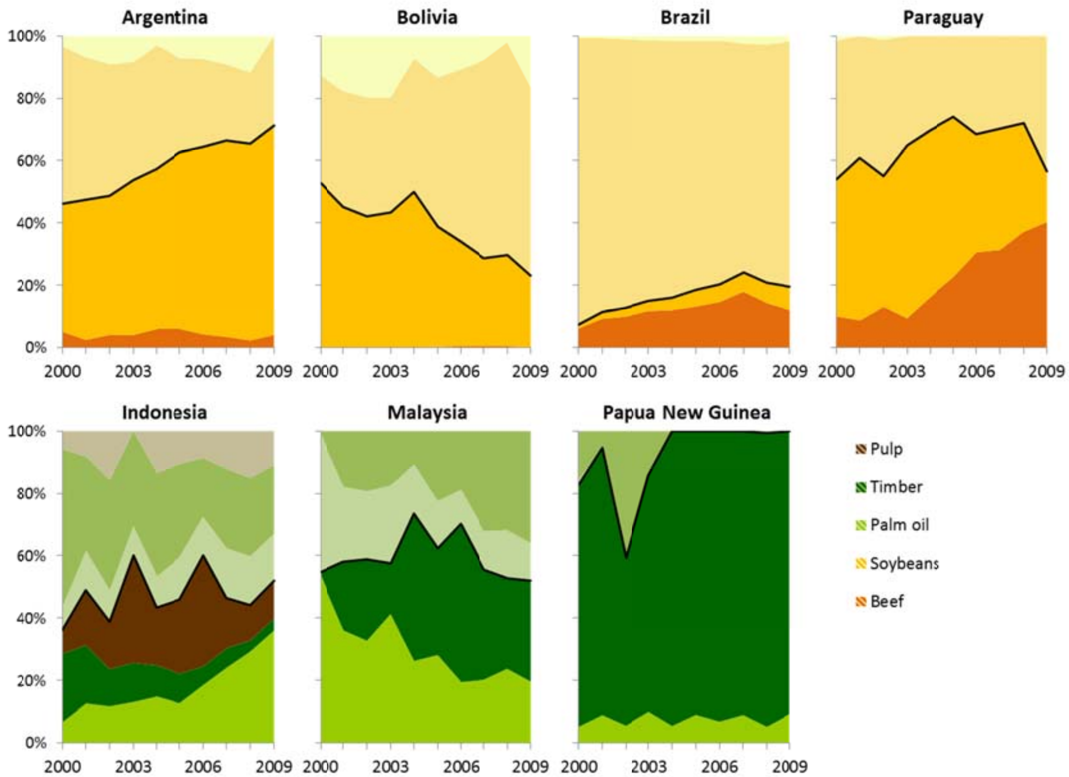

Figure 7: Share of deforestation for case commodities embodied in exports.
Distribution of total deforestation for our case commodities in the period 2000-2009 between domestic consumption (lightly shaded areas) or exports (darkly shaded areas). The thick black line represents the share of deforestation attributed to export markets for the four commodities. For all countries but Bolivia and Malaysia the share of deforestation embodied in exports has been increasing.

Secondly, with direct deforestation for soy cultivation decreasing markedly in Bolivia and Paraguay, these countries have seen reductions in carbon emissions embodied in soy production, while Argentina and Brazil exhibit opposing, rapidly increasing, trends. For both Argentina and Brazil emissions embodied in soy production dipped in 2009, but for different reasons. For the former the dip was due to a severe drought, leading to a large, but temporary, reduction in soy production and associated deforestation. In Brazil, the implementation of the Soy Moratorium in 2006 started to impact the deforestation emission footprint (which lags annual deforestation due to the temporal disconnect between deforestation and subsequent agricultural production) and therefore likely signals the onset of a reversal in the trend of deforestation emissions embodied in the country's soy production (though not necessarily the deforestation area footprint, as there are indications of an increased clearing of the *Cerrado* in recent years).

For palm oil all of our three case countries saw increases in the amount of carbon emissions embodied in production in the second half of the 2000s, Malaysia reversing the decreasing trend in the first half of the decade. Indonesia accounted for the majority (67%) of both embodied deforestation area and emissions in 2009, with Malaysia contributing nearly all the rest (close to 33%). In both countries around one third of total palm oil production was consumed domestically, implying that most of the Southeast Asian palm oil production - and the embodied deforestation and carbon emissions – were consumed by export markets, with the EU, India and China accounting for 24%, 23% and 20% of total export demand in 2009, respectively.

Over 90% of the carbon emissions embodied in wood products from the four case countries assessed originate from Indonesia and Malaysia, with trends in embodied emissions directly following from the trends in deforestation rates and drivers (Fig. 4). But with much of the wood products from these two countries (especially in Malaysia) consumed domestically, Papua New Guinea still accounted for a substantial share (15%) of emissions embodied in wood product exports. Note, however, that we may underestimate the share of wood products being exported in Indonesia and Malaysia, partly because a large share of logging and wood trade is illegal and not recorded in official statistics[22], and partly because our trade statistics do not account for secondary or tertiary products such as joinery or furniture (accounting for about 10% of Indonesian wood product exports)[8]. China accounted for nearly half of the international wood product demand from our four case countries in 2009, with the rest of Asia (including India) accounting for a third of total demand.

We also analyzed the timber exports from the Democratic Republic of the Congo (DRC), as timber is the sole commodity where exports potentially contribute to deforestation in this country, harboring the second largest area of contiguous moist tropical forest left in the world. Although the major part of the produced timber remained in the country or supplies regional markets[42], our trade data shows that the second largest consumer was the European Union (official data may also underestimate the share of logs exported, especially to neighboring countries[43]). Until 2005, the DRC consumed 96-99% of its total timber production domestically and the EU stood for 0.2-3%, but between 2006 and 2010 the domestically consumed share decreased to 92-95%, with the EU increasing its share to 4-7% of the total. Since 2010, EU imports of timber from DRC have been decreasing to 1-2% of total production, with China consuming 2-5% and 94-95% remaining in the country.

[8] See http://www.globaltimber.org.uk/indonesia.htm.

However, given the relatively small volumes of total timber exports from DRC, we decided not to include the attribution of LUC emissions from timber harvest to consumer countries in our quantitative assessment.

While most of the analyzed countries exhibit an increasing share of deforestation embodied in commodity exports (Fig. 7)—consistent with the empirical evidence suggesting that the drivers of tropical deforestation are become increasingly commercialized and globalized—this trend is not universal. Bolivia has seen a reduction in the share of deforestation embodied in exports, as the proximate drivers of deforestation have shifted from soy (which is largely exported) to beef (which is primarily consumed domestically). Similarly, in Malaysia oil palm expansion has been supplemented by logging as a substantial cause of forest loss in the last decade (Fig. 4), the export share of embodied deforestation has been relatively stable in the 2000s (since a larger share of timber and wood products being consumed domestically).

Overall we estimated that 32% of the total deforestation embodied in the production of our case commodities were embodied in exports. However, the export share varies greatly between case countries and commodities (see Table 2). As noted above, the export share is higher for soy and palm oil compared to beef and wood products. Also, for all but two countries—Bolivia and Brazil—export markets is the dominant driver of deforestation. Consequently, excluding Brazilian beef results in an average export share for the rest of country-commodity combinations of 57%.

Table 2: *Share of deforestation embodied in export by country and commodity in 2009.*

	Beef	Soy	Palm oil	Wood products	*Country average*
Argentina	13%	100%			*71%*
Bolivia	0.4%	58%			*23%*
Brazil	13%	81%			*20%*
Paraguay	48%	100%			*57%*
Indonesia			71%	33%	*52%*
Malaysia			62%	47%	*52%*
Papua New Guinea			100%	100%	*100%*
Commodity average	*15%*	*85%*	*68%*	*44%*	*32%*

In Fig. 8 we shift the focus from the producers of forest-risk commodities to the countries and regions consuming the embodied deforestation and associated carbon emissions. As can be seen, in 2009 Brazil's consumption of the four forest-risk commodities analyzed here constituted just over half of the total deforestation area and over a third of carbon emissions embodied in the production of all commodities and case countries analyzed. This mainly reflects the fact that Brazil accounted for over 60% of total deforestation in our seven case countries in the period 2000-2009 (see Fig. 4), and that most of this was due to expansion of cattle operations supplying domestic demand for beef.

Indonesia and Malaysia accounted for an additional 13% and 10%, respectively, of total 2009 carbon emissions embodied in consumption, mainly due to domestic demand for wood products. A total of 37% of carbon emissions embodied in forest-risk commodities were demanded in markets outside of the tropics, with the EU and China being the dominant consumers. It should be noted that the US does not appear a major consumer country in our analysis, as they produce significant quantities of beef and soy commodities and thus are an important supplier of deforestation-free commodities to the world market.

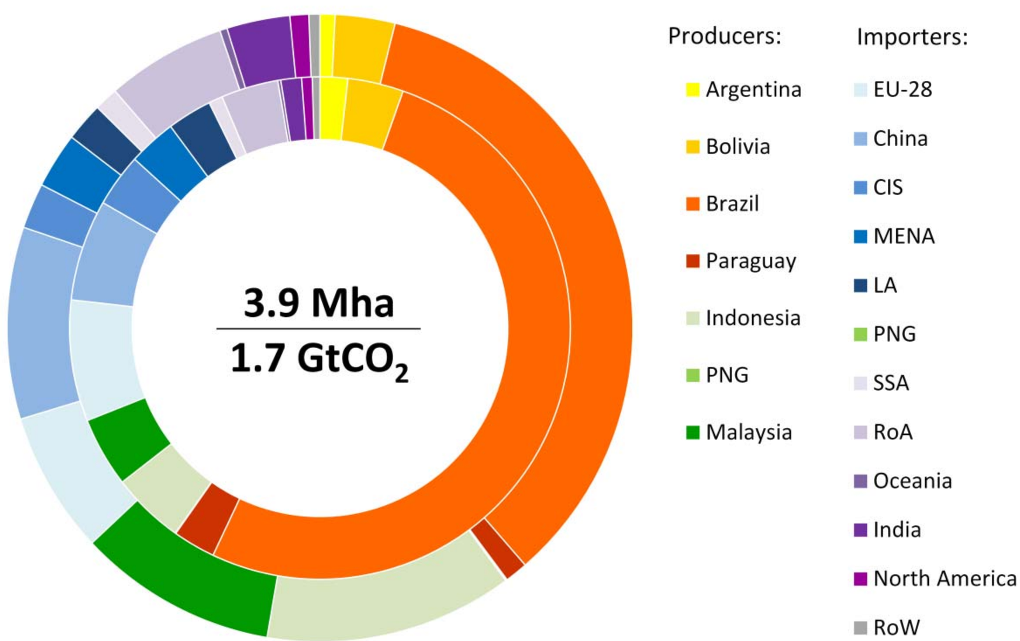

Figure 8: Consumption responsibility for deforestation and carbon emissions. *Total deforestation (inner circle) and associated carbon emissions (outer circle) embodied the consumption of beef, soybean, palm oil and wood products sourced from seven of our case countries (Argentina, Bolivia, Brazil, Paraguay, Indonesia, Malaysia and Papua New Guinea) in 2009, by country or region of consumption. Abbreviations: PNG = Papua New Guinea; CIS = Former Soviet Union; MENA = Middle East & North Africa; LA = Latin America; SSA = Sub-Saharan Africa; RoA = Rest of Asia; RoW = Rest of the world.*

No major changes in the trends displayed here have occurred since 2009. As of 2014, Indonesia still ranks among the world's top deforestation countries, with export production playing a leading role in land-use changes. The Indonesian government has set ambitious timber and oil palm concession targets that involve 9 Mha new timber plantations by 2016[45] and an additional 4 Mha oil palm plantations until 2020[46], which have been maintaining or even increasing incentives for the conversion of natural forests in the last few years. Also, because palm oil production lags deforestation (due to the yield profile of oil palm plantations), the increasing share of Indonesian deforestation being driven by oil palm expansion in the 2000s is not fully reflected in our results.

Malaysia has also been intensifying its deforestation rates from 0.43 Mha in 2010 to 0.55 Mha in 2012[9], accompanied by increases in palm oil exports from 13.9 Mt in 2009 to 15.8 Mt in 2011. In the latter half of the 2000s short-rotation pulpwood plantations have also started to expand at the expense of forests in Malaysia.[22, 47] Although production on these lands is still nascent, this will also have contributed to increasing deforestation and associated emissions beyond 2009. Taken together, this means that the emissions intensity of Southeast Asian palm oil and wood products has, if anything, further increased since 2009 and can be expected to remain high also in the near future.

After years of declining deforestation rates, forest conversion in the Brazilian Amazon increased by nearly 30% to 0.58 Mha between 2012 and 2013[48]. While this still represents the second lowest annual forest loss in absolute terms, it shows that the declared target to reduce Brazilian deforestation by 80% in 2020 could be undermined by factors that are beyond the control of the government. The decreasing trend of deforestation emissions embodied in Brazilian beef might therefore not continue in future. On a positive note, it seems that deforestation and emissions embodied in soy commodities have decreased even further since 2009, as deforestation for soybean expansion has been further declining over time in both Brazil and Paraguay.

(iii) How do our results compare to findings by others, and where are the main uncertainties?

This paper complements a number of other recent attempts at linking tropical deforestation to final consumers of the products originating from cleared land. Our results show that around 37% of deforestation in our case countries is driven by the consumption of forest-risk commodities in regions like Europe, Asia or Russia. This is in line with other findings, that 33-49% of deforestation embodied in crop products was traded internationally between 1990 and 2008[22, 49], and that 30% of Brazilian deforestation emissions between 1990 and 2010 were embodied in the country's beef and soy exports[50]. While several studies roughly agree in the identified trends and the share of deforestation emissions embodied in trade, the absolute results of these studies however show clear differences and are not directly comparable, due to different methods and data sources used.

The Global Canopy Programme's 'Little Book of Big Deforestation Drivers'[3] gives an overview of the supply chains for the same deforestation risk commodities we analyzed here: beef, soybeans, palm oil, and wood products. However, the supply chain mapping serves mainly as an illustration in order to outline potential responses for different actors and the report does not attempt to more precisely link, or quantify, the contribution of each commodity to deforestation in any given country.

This is done in a 2013 report from the European Commission[49], where country-level deforestation data across the tropics is linked to agricultural expansion in the producing countries, and then traced to final consumers through the use of a Multi-Regional Input-Output (MRIO) model. However, because of the top-down approach of the study, deforestation is allocated not to the commodities produced on the cleared land, but to the crops that increased in area in each country. This undermines the suitability of the results for informing demand-side measures. For instance, in Brazil 17% of deforestation is allocated to sugar cane cultivation, despite the fact that there is hardly any direct clearing of forests for sugar cane in the country, and consequently demand-side measures targeting this crop would have little impact on deforestation.

A more similar analysis to ours, taking a bottom-up approach to estimating the share of deforestation attributed to commercial agriculture, is the recent study by Lawson.[22] This study focuses on the legality of deforestation, finding that over two-thirds forest clearing for commercial agriculture is illegal. However, the study also estimates that half of the illegal clearing for commercial agriculture is driven by export demand. This result is slightly higher than the average of 37% we find for our case countries. Because the Lawson study covers all of the tropics and commercial agriculture in general (not just a few commodities) the results are hard to compare directly. However, differences may partly be explained by different approaches to the trade analysis; Lawson solely uses primary export data but include some secondary products that we do not (e.g., furniture from timber), while we account for re-exports that may result in higher domestic consumption (e.g., if some of the exported commodities are refined and re-exported to the country of production). Also, given the importance of Brazil, differences may also stem from the fact that we find that 20% of deforestation embodied in Brazilian beef and soy production is exported, while Lawson assumes that the share is 30%.

Two studies exist that quantify deforestation emissions embodied in Brazilian beef and soy exports[50, 51]. Both determine emissions with a land use and deforestation model for the Brazilian Amazon, considering specific regional deforestation drivers, but then differ in the allocation of emissions between domestic consumption and exports. One study splits deforestation emissions equally between domestic consumption and exports[50], while the other uses a MRIO model to trace trade flows to final consumers[51].

Despite substantial conceptual differences between top-down MRIO modeling and bottom-up material-flow approaches like the one used here[52], the results of the study by Karstensen et al. [51] are similar to the findings for Brazil presented here, regarding the trends and main destination countries for deforestation embodied in exports. However, the absolute emissions estimates presented by Karstensen et al. are higher than ours, due to the fact that they attribute all deforestation in Brazil to commercial agriculture, whereas we assume that around 20% of deforestation is caused by other activities such as smallholder farming (consistent with the empirical evidence[53]). Also, the Karstensen study uses higher biomass carbon stocks than we do, as we assume a portion of total biomass to be removed by logging before land clearing. Other differences in absolute numbers stem from the fact that the Karstensen study attributes a much larger share of deforestation to soy, assuming (contrary to empirical evidence[5]) that most of the land cleared in the Amazon forest biome is cropped with soy for the first years, prior to being converted to pastures. This also results in a higher share of Brazilian emissions embodied in exports (30%) compared to our results, given that the export share is higher for soy than for beef.

In addition, it is important to keep in mind that all the above studies face a range of uncertainties. Key challenges to the quantification of deforestation emissions in general are high variations in the description of forest area changes, due to differing underlying forest definitions, and of biomass stocks, which involve uncertainties of up to 60%[46, 54, 55]. Another main limitation stems from a lack of quantified deforestation drivers; i.e., information about land uses replacing forest and the extent to which specific agricultural production systems induce deforestation. A recent attempt to compile this data[18] found that quantitative estimates of direct deforestation drivers were available for only 11 out of 100 tropical countries—and that at a highly aggregated level, distinguishing only between broad classes of proximate drivers, such as subsistence vs. commercial farming—highlighting the urgent need for further research and data collection in this field. Even where there are multiple studies using remote sensing data to quantify land uses replacing forests, as for palm oil and timber plantations is Southeast Asia[29, 40, 56], results still differ widely.

The combined uncertainties in biomass densities of cleared forests and the share of deforestation attributed to different forest-risk commodities was estimated to lead to an overall uncertainty in deforestation footprints for Brazilian beef and Indonesian palm oil of just under 30%, with uncertainties for Brazilian soy being substantially lower[24]. Uncertainties for beef, soy and palm oil footprints calculated here are likely to be in the same range. However, we deem uncertainties to be higher for the emissions associated with wood products, as there is little data on the amount of land cleared both for wood products alone and for timber plantations (compared to, e.g., palm oil plantations[29]). Similarly, there seem to be large uncertainties in the share of forests that have been logged prior to conversion to other land uses, as well as the amount of biomass removed in this process, with different sources providing very different estimates (see Technical Appendix for details).

Policy Discussion: The Potential for Demand-Side Measures in Reducing Forest Loss

Our results illustrate the increasingly important role of forest-risk commodity consumption in promoting tropical deforestation. This indicates that supply-side measures and national-scale conservation policies alone, such as payments for reduced deforestation through an international REDD mechanism, may not be effective in the long-term if the rising demand for forest-risk commodities is not addressed.

Demand-side measures are therefore considered as a necessary complement to successfully reduce global deforestation in general and deforestation footprints of agricultural commodities in particular[2]. A range of different measures has been presented and assessed in the literature lately: Brack & Bailey[1] summarize different demand-side measures that have been used to (successfully) control illegal timber trade in the past, whereas Walker and colleagues[2] provide an analysis of options that might be suitable to control supply chains and reduce deforestation footprints of agricultural forest-risk commodities. The described measures target different actor groups such as governments (through public-procurement policies or legislation), the private sector (through roundtables or industry standards) or civil society (through certification schemes, labeling or information campaigns), see the text box below for a brief summary.

Examples of possible demand-side measures to control illegal wood products trade and reduce deforestation footprints of agricultural forest-risk commodities[1, 2]

- **Public procurement policies:**
  - The public sector is a significant purchaser of food and catering services with high potential to address forest-risk commodity trade and consumption
  - Procurement policies currently used by 13 countries to source legal timber
  - UK has a central government procurement policy for sustainable palm oil in food and catering.
- **Bilateral agreements** between governments:
  - Voluntary Procurement Agreements (VPAs) within the FLEGT Initiative
- **Legislation,** e.g., the US Lacey Act, EU Timber Regulation, Australian Illegal Logging Prohibition Act
  - Consist of a) a legal prohibition, making imported illegal products illegal in the country of import; b) 'due diligence' requirements on domestic industry
- **Private sector initiatives** for sustainable agricultural commodities
  - Commodity roundtables (e.g., soy, palm oil)
  - Voluntary standards by groups of companies: the Consumer Goods Forum, the Soy Moratorium, Zero-Deforestation Policies
  - Corporate Social Responsibility strategies such as those by Wilmar and APP
  - Environmental investment and lending requirements
- **Consumer measures:** usually action-based campaigning, awareness-raising, boycotts, also includes individual consumer choices for specific labels /certification

(i) Which are the most promising demand-side measures for the commodities and countries described in this report?

Which type of intervention is most promising depends strongly on the level of intervention and the initiating actor; is it the government of a consumer country, or individual consumers, or rather the private sector? It seems that a mix of different options at various levels of society has the highest potential for impacts, as shown by the experience from demand-side interventions aimed at controlling illegal timber trade[1]. These include a range of different measures such as public procurement policies, various government regulations (e.g., in the building sector), bilateral agreements between consumer and producer countries to establish licensing systems, the introduction of legislation rendering imported illegitimate wood illegal in the importing country, and due diligence requirements on industry to prove that timber stems from legal sources. In combination with voluntary commitments by the private sector, these measures have succeeded to initiate a visible change in the demand for and consumption of legal and certified timber[1].

A similar case can be made for Brazilian soy and beef production, where a combination of stricter law enforcement, credit access restrictions, expansion of protected areas, and supply chain interventions have contributed to the recent 70% decline in Amazon deforestation rates.[6] However, elsewhere measures to address deforestation from soy, palm oil and beef production are mainly limited to voluntary private sector activities (e.g., commodity roundtables), in some cases supported by consumer action[2]. These initiatives could offer an easily accessible platform for complementary public sector measures such as legislation or bilateral agreements.

These examples highlight the complementarity of public (regulation) and private (voluntary) measures. In most cases voluntary agreements will not alone suffice, as they may not be stringent enough, will most often not cover all market actors and are imperfectly enforced. However, they can help levy support for (or at least reduce resistance to) public policies that are comprehensive, as these will level the playing field among market actors.

Which commodities importing nations should make the priority of demand-side measures depends to a large degree on the perspective taken and the underlying objectives. Brack & Bailey[1] have formulated some general criteria that facilitate the control of supply chains and could help to identify suitable commodities to target:

- Simple supply chains, with few stages at which controls can be applied, and a narrow category of products in which the raw material ends up;
- Strong geographic concentration of production, and a concentration of market power at one or more points along the supply chain (producers, traders, processors or retailers);
- A high ratio of exports to domestic consumption, and a high proportion of exports to sensitive markets;
- Existence of an identification scheme for sustainable products;
- Existence of voluntary private-sector initiatives.

Based on the first two criteria and seen from a global perspective it would make most sense to focus on commodities with high deforestation and climate impacts that could largely be reduced through increasing the productivity of existing systems (in hand with policies that strengthen forest protection, to avoid rebound effects), which is the case for beef from the Amazon.[57] From an institutional perspective, and based on the last three criteria, palm oil and soy would be promising commodities as round-tables and basic agreements are already underway that could be relatively easily complemented by further interventions[1].

In addition to these general considerations, our data can be used as basis for the prioritization of commodities and producer countries, which obviously also has to take into account political realities and other policy aspects. The largest emission flows resulting from our analysis include palm oil from Indonesia to India, the EU and China, wood products from Malaysia to China and the rest of Asia, and Brazilian beef to the EU.

Table 3 provides a top-ten ranking of embodied deforestation emission flows in 2009. Note however that for some countries and commodities, such as beef from Brazil, domestic consumption plays a much larger role than export demand. The table also shows that the ranking changes when looking at the area footprint instead of the emissions. The clearing of comparatively small areas in regions with dense, carbon rich forests (e.g., Indonesia) causes much higher emissions than clearing vast areas of Brazilian Cerrado where biomass and carbon content are much lower. Nevertheless, dry forest ecosystems such as the Cerrado are often biodiversity hotspots, the loss of which is not considered when looking at deforestation emissions only. Whereas in this analysis the focus was on emissions from deforestation due to commodity production, linking area footprints with other impacts, such as biodiversity loss or water use, helps to obtain a broader overview about the impacts of commodity production /can lead to very different results.

Table 3: *Ranking of top-ten embodied deforestation area and emission flows in 2009, by producer country and consumer country / region (MtCO2).*

	Commodity	Producer country	Consumer country/region	Embodied deforestation ('000 ha)	Embodied emissions (MtCO2)
Top ten deforestation area flows:					
1	Beef	Brazil	EU-28	102	29
2	Beef	Brazil	CIS (Former Soviet Union)	81	23
3	Soy	Brazil	EU-28	73	15
4	Soy	Brazil	China	71	14
5	Beef	Brazil	Middle East & North Africa	58	17
6	Soy	Argentina	EU-28	54	10
7	Wood products	Malaysia	China	43	43
8	Soy	Bolivia	Latin America	41	14
9	Beef	Paraguay	Latin America	41	8
10	Wood products	Malaysia	Rest of Asia	39	40
Top ten deforestation emission flows:					
1	Wood products	Malaysia	China	43	43
2	Wood products	Malaysia	Rest of Asia	39	40
3	Palm oil	Indonesia	India	35	39
4	Palm oil	Indonesia	EU-28	33	37
5	Beef	Brazil	EU-28	102	29
6	Pulp & paper	Indonesia	China	21	26
7	Palm oil	Indonesia	China	22	25
8	Beef	Brazil	CIS	81	23
9	Wood products	Papua New Guinea	China	21	19
10	Beef	Brazil	Middle East & North Africa	58	17

(ii) Challenges for effective demand-side approaches

A key obstacle to demand-side measures is the resistance from producers, who will not invest in major changes unless there is are apparent long-term benefits (i.e., in terms of price premiums) or costs (i.e., risk of losing customers) involved. It is often difficult for producers to obtain price premiums from customers, whereas the costs for improved environmental performance are usually borne by producers. This is especially the case in some of the world's major markets where the willingness to pay for sustainable production is lower; e.g., among palm oil consumers in Asia, and Brazilian beef consumers in China, the Middle East and Russia.[2]

Then there is always a risk of advsere indirect effects from any kind of demand-side action. Especially when focusing measures on specific countries or niche-markets it is possible that suppliers simply source their products from elsewhere, creating displacement and leakage effects. The same effect can happen on the demand side: if only some buyers impose demand-side restrictions, then suppliers could shift their sales from 'more concerned' buyers to 'less concerned' buyers. In that context it should be mentioned that the results we present here only refer to the direct contribution of consumer countries to tropical deforestation, which might underestimate the actual role of consumption as our assessment does not consider any indirect market effects, such as indirect land-use changes arising from increased production of biofuels.

Finally, a main challenge lies in the complexity of supply chains that makes it difficult to distribute and trace responsibilities. The demand-side options described here will all rest on the traceability of sustainably produced commodities through identification systems, which in most cases will imply some form of certification. It is therefore essential that monitoring and control can be ensured in all stages of the supply chain, as otherwise demand-side requirements would be rendered useless. Especially in the case of agricultural forest-risk commodities, technological advancements and reduced costs of remote sensing offer opportunities to improve supply chain controls and in the best case allow the tracing of supply chains from field to fork.

A main conclusion from our findings is that supply-side measures alone, e.g. in the form of payments for good forest stewardship and reduced deforestation as in REDD, are not likely to be effective in the long-term due to a growing importance of export production in promoting agricultural expansion and LUC. The design of conservation policies such as REDD has to address the fact that international driving forces for tropical deforestation are gaining importance in addition to domestic drivers. Since international economic factors have the potential to override national policies[58], the effectiveness of supply-side interventions could be increased with complementing demand-side policies that reduce the deforestation footprints of agricultural forest-risk commodities.

References

1. Brack, D. and R. Bauiley. 2013. Ending Global Deforestation: Policy Options for Consumer Countries. London: Chatham House and Forest Trends.
2. Walker, N., et al. 2013. Demand-side interventions to reduce deforestation and forest degradation. International Institute for Environment and Development (IIED), London, UK.
3. Rautner, M., M. Leggett, and F. Davis. 2013. The little book of big deforestation drivers. edited by T.G.C. Programme.
4. Rudorff, B.F.T., et al. 2012. "Remote Sensing Images to Detect Soy Plantations in the Amazon Biome—The Soy Moratorium Initiative." *Sustainability* 4 (5):1074-1088.
5. Macedo, M.N., et al. 2012. "Decoupling of deforestation and soy production in the southern Amazon during the late 2000s." *Proceedings of the National Academy of Sciences* 109 (4):1341-1346.
6. Nepstad, D., et al. 2014. "Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains." *Science* 344 (6188):1118-1123.
7. Rudel, T.K. 2007. "Changing agents of deforestation: From state-initiated to enterprise driven processes, 1970-2000." *Land Use Policy* 24 (1):35-41. doi: DOI: 10.1016/j.landusepol.2005.11.004.
8. Rudel, T.K., et al. 2009. "Changing Drivers of Deforestation and New Opportunities for Conservation." *Conservation Biology* 23 (6):1396-1405. doi: 10.1111/j.1523-1739.2009.01332.x.
9. Lambin, E.F. and P. Meyfroidt. 2011. "Global land use change, economic globalization, and the looming land scarcity." *Proceedings of the National Academy of Sciences* 108 (9):3465-3472. doi: 10.1073/pnas.1100480108.
10. Meyfroidt, P., et al. 2013. "Globalization of land use: distant drivers of land change and geographic displacement of land use." *Current Opinion in Environmental Sustainability* 5 (5):438-444. doi: 10.1016/j.cosust.2013.04.003.
11. Hansen, M.C., et al. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (6160):850-853. doi: 10.1126/science.1244693.
12. Lindquist, E.J., et al. 2012. Global forest land-use change 1990–2005. Rome: Food and Agriculture Organization of the United Nations (FAO) and European Commission Joint Research Centre (JRC).
13. Millenium Ecosystem Assessment. 2005. Ecosystems and human well-being: Biodiversity synthesis. Washington, D.c.: World Resources Institute (WRI).
14. Grace, J., E. Mitchard, and E. Gloor. 2014. "Perturbations in the carbon budget of the tropics." *Global Change Biology*.
15. Harris, N.L., et al. 2012. Progress towards a consensus on carbon emissions from tropical deforestation. Winrock International and Woods Hole Research Center.
16. Geist, H. and E. Lambin. 2001. What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. In *LUCC Report Series*: International Human Dimensions Programme on Global Environmental Change (IHDP) and International Geosphere-Biosphere Programme (IGBP).
17. Boucher, D., et al. 2011. The root of the problem: what's driving tropical deforestation today? Cambridge, MA: Union of Concerned Scientists.
18. Hosonuma, N., et al. 2012. "An assessment of deforestation and forest degradation drivers in developing countries." *Environmental Research Letters* 7 (4):044009.
19. Houghton, R.A. 2012. "Carbon emissions and the drivers of deforestation and forest degradation in the tropics." *Current Opinion in Environmental Sustainability* 4 (6):597-603. doi: DOI 10.1016/j.cosust.2012.06.006.

20. Rademaekers, K., et al. 2010. Study on the evolution of some deforestation drivers and their potential impacts on the costs of an avoiding deforestation scheme. Brussels: European Commission, Directorate-General for Environment.
21. Gibbs, H.K., et al. 2010. "Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s." *Proceedings of the National Academy of Sciences* 107 (38):16732-16737. doi: 10.1073/pnas.0910275107.
22. Lawson, S. 2014. Consumer Goods and Deforestation: An Analysis of the Extent and Nature of Illegality in Forest Conversion for Agriculture and Timber Plantations. edited by F. Trends. Washington, D.C.
23. Kastner, T., M. Kastner, and S. Nonhebel. 2011. "Tracing distant environmental impacts of agricultural products from a consumer perspective." *Ecological Economics* 70 (6):1032-1040. doi: 10.1016/j.ecolecon.2011.01.012.
24. Persson, U.M., S. Henders, and C. Cederberg. 2014. "A method for calculating a land-use change carbon footprint (LUC-CFP) for agricultural commodities – applications to Brazilian beef and soy, Indonesian palm oil." *Global Change Biology*:n/a-n/a. doi: 10.1111/gcb.12635.
25. Klink, C.A. and R.B. Machado. 2005. "Conservation of the Brazilian Cerrado." *Conservation Biology* 19 (3):707-713. doi: 10.1111/j.1523-1739.2005.00702.x.
26. Harris, N.L., et al. 2012. "Baseline Map of Carbon Emissions from Deforestation in Tropical Regions." *Science* 336 (6088):1573-1576. doi: 10.1126/science.1217962.
27. Mueller, C.C. 2003. Expansion and modernization of agriculture in the Cerrado – the case of soybeans in Brazil's Center-West In *University of Brasilia Serie Texto para Discussao*: University of Brasilia.
28. Grau, H.R., N.I. Gasparri, and T.M. Aide. 2005. "Agriculture expansion and deforestation in seasonally dry forests of north-west Argentina." *Environmental Conservation* 32 (02):140-148.
29. Abood, S.A., et al. 2014. "Relative contributions of the logging, fiber, oil palm, and mining industries to forest loss in Indonesia." *Conservation Letters* In press. doi: 10.1111/conl.12103.
30. Miettinen, J., et al. 2012. "Extent of industrial plantations on Southeast Asian peatlands in 2010 with analysis of historical expansion and future projections." *GCB Bioenergy* 4 (6):908-918. doi: 10.1111/j.1757-1707.2012.01172.x.
31. Ernst, C., et al. 2013. "National forest cover change in Congo Basin: deforestation, reforestation, degradation and regeneration for the years 1990, 2000 and 2005." *Global change biology* 19 (4):1173-1187.
32. Fisher, B. 2010. "African exception to drivers of deforestation." *Nature Geosci* 3 (6):375-376.
33. Persson, U.M. 2012. "Conserve or convert? Pan-tropical modeling of REDD–bioenergy competition." *Biological Conservation* 146 (1):81-88. doi: 10.1016/j.biocon.2011.10.038.
34. Pearson, T.R.H., S. Brown, and F.M. Casarim. 2014. "Carbon emissions from tropical forest degradation caused by logging." *Environmental Research Letters* 9 (3):034017.
35. Kastner, T., K.-H. Erb, and H. Haberl. 2014. "Rapid growth in agricultural trade: effects on global area efficiency and the role of management." *Environmental Research Letters* 9 (3):034015.
36. Kastner, T., K.-H. Erb, and S. Nonhebel. 2011. "International wood trade and forest change: A global analysis." *Global Environmental Change* 21 (3):947-956. doi: 10.1016/j.gloenvcha.2011.05.003.
37. Opio, C., et al. 2013. Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment. edited by F.a.A.O.o.t.U.N. (FAO). Rome: Food and Agriculture Organization of the United Nations (FAO).
38. Dalgaard, R., et al. 2008. "LCA of soybean meal." *The International Journal of Life Cycle Assessment* 13 (3):240-254.

39. Prudêncio da Silva, V., et al. 2010. "Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios." *Journal of environmental management* 91 (9):1831-1839.
40. Gunarso, P., et al. 2013. Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. In *Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO)*: RSPO.
41. Page, S., et al. 2011. Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia. In *International Committee on Clean Transportation (ICCT)*.
42. Chevallier, R. and M.-L. du Preez. 2012. Timber Trade in Africa's Great Lakes: The Road From Beni, DRC to Kampala, Uganda. edited by S.A.I.o.I.A. (SAIIA).
43. Lawson, S. 2014. Illegal Logging in the Democratic Republic of the Congo. edited by C. House. London.
44. Defourny, P., C. Delhage, and J.-P.K. Lubamba. 2011. ANALYSE QUANTITATIVE DES CAUSES DE LA DEFORESTATION ET DE LA DEGRADATION DES FORETS EN REPUBLIQUE DEMOCRATIQUE DU CONGO. edited by U.C.d. Louvain. Louvain, Belgium.
45. Obidzinski, K. and M. Chaudhury. 2009. "Transition to timber plantation based forestry in Indonesia: towards a feasible new policy." *International Forestry Review* 11 (1):79-87.
46. Angelsen, A., et al. 2012. *Analysing REDD+: Challenges and choices*. Bogor: Center for International Forestry Research (CIFOR).
47. Grieg-Gran, M., et al. 2007. The Dutch economic contribution to worldwide deforestation and forest degradation. edited by A. IIED. London.
48. INPE. 2014. Projeto PRODES: Monitoramento da floresta Amaônica Brasileira por satélite. edited by I.N.d.P.E. (INPE). São José dos Campos.
49. Cuypers, D., et al. 2013. The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation. edited by E. Commission.
50. Zaks, D.P.M., et al. 2009. "Producer and consumer responsibility for greenhouse gas emissions from agricultural production—a perspective from the Brazilian Amazon." *Environmental Research Letters* 4 (4):044010.
51. Karstensen, J., G.P. Peters, and R.M. Andrew. 2013. "Attribution of CO 2 emissions from Brazilian deforestation to consumers between 1990 and 2010." *Environmental Research Letters* 8 (2):024005.
52. Kastner, T., et al. 2014. "Cropland area embodied in international trade: Contradictory results from different approaches." *Ecological Economics* 104:140-144.
53. Margulis, S. 2004. Causes of deforestation of the Brazilian Amazon. World bank.
54. Ometto, J.P., et al. 2014. "Amazon forest biomass density maps: tackling the uncertainty in carbon emission estimates." *Climatic Change* 124 (3):545-560. doi: 10.1007/s10584-014-1058-7.
55. Houghton, R., et al. 2012. "Carbon emissions from land use and land-cover change." *Biogeosciences* 9 (12):5125-5142.
56. Carlson, K.M., et al. 2012. "Carbon emissions from forest conversion by Kalimantan oil palm plantations." *Nature Climate Change* 3 (3):283-287. doi: http://www.nature.com/nclimate/journal/vaop/ncurrent/abs/nclimate1702.html#supplementary-information.
57. Cohn, A.S., et al. 2014. "Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation." *Proceedings of the National Academy of Sciences* 111 (20):7236-7241.
58. Gasparri, N., H. Grau, and J. Gutierrez Angonese. 2013. "Linkages between soybean and neotropical deforestation: Coupling and transient decoupling dynamics in a multi-decadal analysis." *Global Environmental Change* 23 (6):1605-1614.

Technical Appendix

This appendix provides a brief technical description of the materials used to link deforestation and associated carbon emissions in tropical countries to consumption of forest risk commodities—beef, soybeans, palm oil and wood products—across the world. We first provide references for the methods applied in this analysis, and then discuss the underlying assumptions in terms of deforestation rates and proximate drivers in our case countries: Argentina, Bolivia, Brazil, Paraguay, Democratic Republic of the Congo, Indonesia, Malaysia and Papua New Guinea.

1. Methods – Deforestation Footprints and Trade Analysis

For a description of the technical details and procedures of the applied deforestation footprint methodology and the trade flow analysis, please refer to the following scientific articles by the authors of this report:

- Persson, U.M., S. Henders, and C. Cederberg, *A method for calculating a land-use change carbon footprint (LUC-CFP) for agricultural commodities – applications to Brazilian beef and soy, Indonesian palm oil.* Global Change Biology, 2014: p. n/a-n/a.

- Kastner, T., M. Kastner, and S. Nonhebel, *Tracing distant environmental impacts of agricultural products from a consumer perspective.* Ecological Economics, 2011. **70**(6): p. 1032-1040.

2. Materials – Deforestation Rates, Drivers and Biomass Carbon Stocks in the Case Countries

(a) Argentina

The three major forested ecosystems in Argentina experiencing land use changes are the Gran Chaco (seasonally dry forest/wooded grassland), the Yungas (evergreen and semi-evergreen forest on the Andean foothills), and the Atlantic forest (moist tropical forest that stretches from Brazil in the north to Argentina in the south). The Gran Chaco is by far the biggest biome, and also the one where land use changes have been most rapid, accounting for approximately 90% of total deforestation in 1990-2005 (Gasparri et al. 2008). In total, the Chaco lost about 200 000 ha annually in 1990-2005, constituting a deforestation rate of around 1%/yr (Gasparri et al. 2008), whereas deforestation rates in the Yungas and Atlantic forest biomes averaged 12 000 ha/yr and 17 000 ha/yr, respectively. However, clearing rates in Argentina seem to have accelerated after 2005 (Hansen et al. 2013).

The drivers of land use change in these biomes have shifted over time. Historically agricultural expansion was limited by agronomic and climatic restrictions, leading to cotton being the main driver of deforestation in the Chaco, sugar cane in the Yungas, and yerba mate in the Atlantic forest (Gasparri et al. 2008). In the Atlantic forest, recent deforestation has mainly been driven by the expansion plantations (timber in the west and tea/yerba mate in the east) (Clark et al. 2012), while in the Chaco and Yungas soybean has become the main driver of deforestation since the late 1980s. This is due to a confluence of factors: climatic (i.e., increased rainfall), agronomic (i.e., adoption of herbicide and fertilizer use, as well as transgenic cultivars, increasing yields), and socio-economic (high world market prices, devaluation of the peso, and domestic policies favoring large agribusiness) (Zak et al. 2004, Grau et al. 2005, Gasparri and Grau 2009).

Although the focus in the literature has been on the large-scale, mechanized clearing of the Chaco for soybeans, expansion of cattle ranching has likely also contributed to deforestation in the region. Clark et al. (2010) use remote sensing data to attribute land use changes in the Chaco ecoregion of Argentina, Bolivia and Paraguay in 2002-2006 to the expansion of cropland and pastures, finding that in total over half of deforestation is due to cattle ranching, with just over 40% due cropland expansion. That soybean expansion alone cannot be responsible for clearing in the Chaco is supported by agricultural statistics: the annual expansion of soybean area planted in the provinces of Chaco, Salta, Santiago del Estero, and Tucuman (being where most soy in the Chaco biome is grown and also the provinces where deforestation due to agricultural expansion has been "particularly intense" (Grau et al. 2005)) only amounts to about 40% of total land clearing in the 1990 and just over 70% in the 2000s.[9]

We focus our analysis here on deforestation in the Chaco and Yungas, since it is here that soy and beef expansion has caused land use change. We base our assumptions on deforestation rates on Gasparri et al. (2008) for 1991-2000 and Hansen et al. (2013) for 2001-2010 (assuming that the share of 2001-2010 deforestation that is in the Chaco and Yungas is constant over time). We further assume that 40% of deforestation is attributed to soybeans in 1991-2000, rising to 70% in 2001-2010, while expanding pastures accounts for 50% and 20% of deforestation in each time period, respectively. For the

[9] Data on planted soy area is taken from the Sistema Integrado de Información Agropecuaria, Programa de Servicios Agrícolas Provinciales, Ministerio de Agricultura, Ganadería y Pesca, Argentina (http://www.siia.gob.ar/series, accessed June 2, 2014).

cleared Chaco vegetation, we assume biomass carbon stocks of 50tC/ha, including above-ground and below-ground biomass (Gasparri et al. 2008).

(b) Bolivia

Bolivia has a forest area of around 50 Mha, mainly consisting of Amazon rainforest, Chiquitano Dry forest, the Yungas and Andean mountain forests. 80% of the forest area is located in the lowlands, where also most of the deforestation has taken place. Deforestation was negligible until the 1980s but has been increasing since then, mainly due to agricultural expansion into the Amazon (Müller et al. 2014b). Annual deforestation rates for the period 1990 – 2004 increased from 0.14 Mha/yr in 1987-91 to 0.15 Mha for 1992-2000 and 0.22 Mha for the years 2001-2004 (Killeen et al. 2007). These values have been complemented by data from Hansen et al. (2013) that state annual average deforestation of 0.24 Mha for 2000-2010. For the years 2000-2004 where data of the two sources overlaps we use an average of the two.

In recent decades, the main deforestation drivers have been mechanized agriculture, cattle ranching and small-scale agriculture. Mechanized agriculture contributes 12% of Bolivian exports and is practiced mainly for the cultivation of soya as summer crop, often combined with sunflower or wheat as winter crop. Most of the production occurs in medium and large-scale cultivation (>50ha), with domestic and foreign agribusiness companies as main actors. The lion's share of foreign investment comes from Brazil in the case of soy, but also from Japan, mainly for rice and soy. Another important actor is the group of Mennonites that practice medium-scale farming in mixed systems with cattle.

Small-scale agriculture is practiced on areas smaller than 50 ha and usually consists of manual cultivation for subsistence or local/national markets. The group of small-scale farmers is estimated to comprise around 400,000 person that cultivate mainly rice, maize, and banana. Productivity in small-scale systems is very low. While Bolivian cattle ranching is also practiced in extensive breeding systems on natural pastures in savannah regions, here we focus on the intensive fattening systems on artificial pastures in deforested lowland areas. No official numbers exist but extrapolating municipality numbers yields a total of 1.5 m heads in these systems, which reflects a density of 0.5-2 heads/ha, which is even lower than Brazil. Most of the beef produced in Bolivia is supplied to national or regional markets, as the country is not free from the foot and mouth disease (Müller et al. 2014b).

Quantified deforestation drivers have been described by Müller et al. (2012) for the years 1992 to 2004 and by Müller et al. (2014a) for the period 2000-2010. In the first time period, mechanized agriculture was responsible for 54% of total deforestation (1 Mha), cattle ranching contributed 27% of deforestation (0.52 Mha) and small-scale agriculture 19% (0.36 Mha). In the second period, on average 52% of forest conversion was due to cattle ranching (0.94 Mha), 30% due to the expansion of mechanized agriculture (0.54 Mha), and 18% due to smallholder agriculture (0.33 Mha). The importance of soy decreased and that of cattle increased during the study period, whereas the contribution of smallholder agriculture to deforestacion remained relatively stable over time.

The biomass content of Bolivian lowland forests seems to be much lower than in the Brazilian Amazon. Dauber et al. (2000) combine data from 74 Bolivian forest inventories with allometric equations for tropical rainforest, and derive biomass volumes of 171 Mg/ha; i.e. a carbon stock of 85.5 MgC/ha. Similar ABG biomass values of 139 Mg/ha (69.5 MgC/ha) were obtained by Broadbent et al. (2008) in an exercise linking field and remote sensing measurements. However, a study by Villegas and Mostacedo (2011) that compiles different biomass estimates states an ABG average of 150 MgC/ha over the different predominant forest types (tropical rainforest, tropical decididuous and tropical dry forest, mountain forest). Here we assume a carbon stock of 102 MgC/ha, representing an average of the three forest types.

(c) Brazil

Brazil harbors around a third of the world's tropical rainforest, which covers nearly 60% of its territory. The major part of this is located in the Amazon basin, where also most of the deforestation takes place. Brazil's National Space Institute (INPE) has conducted annual remote sensing assessments of Amazon deforestation since 1988 and describes deforestation rates of around 2 Mha per year for 2000-2006, decreasing to less than 1 Mha between 2007 and 2010 (INPE 2014). The INPE database does not cover the Cerrado biome, where we construct an annual time-series by combining clearing rates from Klink and Moreira (2002) for the period 1980-1995, Machado et al. (2004) and Bustamante et al. (2012) for the period 1996-2002, and Bustamante et al. (2012) for the period 2002-2010 (extending their estimates from 2008 to 2010).

Many studies identify cattle ranching as a major driver of deforestation in the Brazilian Amazon, historically responsible for around 80% of forest conversion in the region (Fearnside et al. 1993, Chomitz and Thomas 2001, Margulis 2004, Börner and Wunder 2008). These results were confirmed by two more recent studies that combined spatial deforestation data with census information to attribute forest clearing in the Brazilian Amazon to pasture expansion (Bustamante et al. 2012) Here we use the results for the 2003-2008 time period from Bustamante et al. (2012) and assume that for other years

80% of forests cleared were replaced by pastures for beef production. For the Cerrado, Klink and Moreira (2002) indicate that 73-88% of clearings in the period 1980-1995 were due to the establishment of pastures, whereas more recently (2003-2008) expansion of cattle operations was only responsible for 57% of total clearings (Bustamante et al. 2012). We interpolate the results from these two studies to construct a continuous time series for the years 1996-2002.

The extent of Amazon deforestation due to soybean expansion is investigated in remote-sensing based studies for the states of Mato Grosso, Pará, and Rondônia (Brown et al. 2005, Morton et al. 2006, Rudorff et al. 2011, Arvor et al. 2012, Macedo et al. 2012). Taken together, these studies provide data that accounts for 99% of the soybean area in the Amazon biome. Macedo et al. (2012), analyze forest clearing in Mato Grosso between 2001-2009, showing a trend of increasing clearing for soy until 2003, followed by a rapid decline to near zero deforestation for soy. Rudorff et al. (2011, 2012) show that deforestation for soy in the period 2007-2011 was negligible also in Pará and Rondônia, something that can be attributed to the implementation of the Soy Moratorium. Our assumptions of the amount of direct deforestation for soy in the Brazilian Amazon are based on the time series from Macedo et al. (2012) in 2001-2009, assuming a linearly increasing trend prior to 2001, and complementing this with data for Pará (Rudorff et al. 2011) and Rondônia (Brown et al. 2005, Rudorff et al. 2011). Where data is missing (Pará prior to 2008 and Rondônia in 2002-2007) we assume that 15% of annual soy expansion comes at the expense of forests (based on a comparison between soy area data from IGBE and deforestation for soy in Mato Grosso and Rondônia).

For the Brazilian Cerrado biome, Galford et al. (2010) show that although the majority (63%) of soy expansion in the Cerrado region of Mato Grosso occurred on previous pasture land, soy expansion still accounted for nearly 70% of all Cerrado clearing between 2001-2006. By assuming a similar relation between soy expansion and Cerrado clearing in the other main Cerrado states (Maranhão, Tocatins, Goiás, Bahia, Minas Gerais, Mato Grosso do Sul, and Piauí), we estimate that 15% of Cerrado clearing in 2002-2008 was due to expanding soy production. With little Cerrado clearing for cropland occurring prior to 1995 (Klink and Moreira 2002), we assume a linearly increasing trend from 0 in 1995 to 15% in 2000 and being stable thereafter, noting the very large uncertainties in this estimate.

Our assumptions on forest biomass values for Brazil are based on the analysis of Aguiar et al. (2012) that uses four different biomass maps to estimate spatially-explicit biomass densities for forests cleared in the Brazilian Amazon since 1990. We take the average above ground biomass (AGB) of forests cleared between 1990-2009 of 215 t/ha and convert it to carbon density of both above and below ground biomass (BGB) using a root-to-shoot ratio of 0.27 (Saatchi et al. 2007, Nogueira et al. 2008, Saatchi et al. 2011)(Saatchi et al. 2007, Nogueira et al. 2008, Saatchi et al. 2011)(Saatchi et al. 2007, Nogueira et al. 2008, Saatchi et al. 2011)(Saatchi et al. 2007, Nogueira et al. 2008, Saatchi et al. 2011)(Saatchi et al. 2007, Nogueira et al. 2008, Saatchi et al. 2011)(Saatchi et al. 2007, Nogueira et al. 2008, Saatchi et al. 2011) and a carbon fraction of 0.47 (IPCC 2006). This yields an average carbon content of 128 tC/ha. The average carbon content of Cerrado is assumed to be 35 tC/ha (AGB + BGB), based on the review by Batlle-Bayer et al. (2010). For allocating a share of the biomass to logging and associated damage, we assume that 23% of the forests in the Brazilian Amazon have been logged prior to clearing (based on Asner et al. 2006) and that logging removes 5.6 tC/ha (including indirect logging damages) based on (Pearson et al. 2014).

(d) Paraguay

Paraguay is dominated by two main biomes, the moist tropical Atlantic forest (part of the bigger forest stretching from Brazil in the north to Argentina in the south) and the Gran Chaco, a major wooded grassland (that extends into Bolivia and Argentina) with a climatic gradient from humid in the east to semi-arid in the west. Both biomes have experienced rapid rates of land use change since the 1990. The Atlantic forest lost approximately 13 500 ha annually between 1990-2000, representing a deforestation rate of nearly 4%/yr (Huang et al. 2009). However, in 2004 Paraguay implemented a 'Zero Deforestation Law', aiming to conserve the remains of the Atlantic forest that reportedly has led to a reduction in deforestation in this biome by 90% in just a few years.[10]

The Chaco biome saw similar absolute rates of land use change as the Atlantic forest in the 1990s, losing 11 900 ha (0.7%) per annum (Huang et al. 2009). This loss of native vegetation seem to have continued unabated into the 2000s, with national deforestation rates averaging 300 000 ha/yr in 2000-2010 (Hansen et al. 2013), despite the drastic reduction of clearing in the Atlantic biome.

The proximate drivers of deforestation have also differed between the two biomes in the 1990-2010 period. With most of the Paraguayan Chaco consisting of marginal cropland not suitable for large-scale farming (Huang et al. 2009), areas devoted to cropland in the Chaco have been falling consistently from 1991-2009 and deforestation has

---

[10] WWF, "Deforestation rates slashed in Paraguay", (August 30, 2006, http://www.wwfca.org/?uNewsID=79260) and "Paraguay extends commitment towards zero net deforestation" (November 27, 2008, http://www.wwf.org.uk/what_we_do/safeguarding_the_natural_world/forests/forest_work/atlantic_forest/atlantic_forest_in_paraguay.cfm?uNewsID=2472).

predominantly been driven by expanding pastures for beef production (Clark et al. 2010, Caldas et al. 2013). In the Atlantic forest biome on the other hand, land clearing has primarily (80%) been caused by expanding cropland by large-scale farmers and to a lesser extent by smallholder settlers (20%) (Huang et al. 2007).

Here we base our assumptions on deforestation rates on Huang et al. (2009) for 1991-2000 and Hansen et al. (2013) for 2001-2010. We assume that the share of total deforestation in 2001-2004 that occurs in the Atlantic forest biome is the same as that in the 1991-2000 period (based on Huang et al. 2009), but that following the 2004 introduction of the 'Zero Deforestation Law' clearing rates fall by close to 90% to 2006[11] and then remains stable. The remaining land use change is then assumed to occur in the Chaco biome, with the resulting clearing rates being consistent with remote sensing data from the Chaco region in that time period (Kalogirou et al. 2013).

All of land use change in the Chaco is attributed to cattle ranching. Because most of the soybean expansion in the Atlantic biome has occurred in the provinces of Alto Parana, Itapua, and Canindeyu[12] that also saw the highest rates of deforestation in the 1990-2000 period (Huang et al. 2009), we assume that all clearing of Atlantic forest for large-scale agriculture (i.e., 80% of total clearing) can be attributed to soy. The respective biomass carbon stocks used were 50tC/ha for Chaco clearing, and 160 tC/ha for Atlantic forest, based on Gasparri et al. (2008).

(e) Democratic Republic of the Congo (DRC)

After the Amazon, the Congo Basin harbors the second largest area of contiguous moist tropical forest left in the world, with historically low deforestation rates compared to Latin America and Asia. The main land uses in the region are logging concessions, protected areas and shifting cultivation. However, the margins of the Congo Basin as well as some regions affected by human conflicts are seeing a rapid increase in deforestation due to agricultural encroachments, whereas others remain almost untouched (de Wasseige et al. 2009).

Of the 251 Mha forest in the Congo Basin, around 150 Mha are found in the Democratic Republic of the Congo, where 0.4-0.7 Mha is being lost every year (Hansen et al. 2008, FCPF and UN-REDD 2013). Deforestation in DRC is principally driven by slash and burn agriculture, followed by semi-industrial artisanal logging for domestic

[11] Ibid.

[12] Minesterio de Agricultura ý Ganaderia, Dirección de Censos y Estadísticas Agropecuarias, "Soja: Superficie, produccion y rendimiento por departemanto" (http://www.mag.gov.py/Censo/temporales/SOJA.pdf, accessed May 28, 2014).

(urban) markets.[13] Other activities contributing to deforestation are fire/fuel wood collection and charcoal making for domestic consumption; and to a lesser degree mining (Ministére de l'Environnement 2012).

Deforestation hotspots are found at the periphery of densely populated areas, which means that the most affected regions are not the ones with highest forest cover and biomass density but those accessible from cities (Ministére de l'Environnement 2012). In addition, deforestation is higher in secondary forests than in primary ones, which suggests a strong correlation between degradation and deforestation (Defourny et al. 2011): logging and related road infrastructure opens up 'impenetrable' forests for smallholder agriculture (FCPF and UN-REDD 2013). In general, deforestation for the production of export commodities seems not to play a major role (yet) in DRC, with the possible exception being timber. However, empirical evidence indicate that commercial timber extraction does not appear as main deforestation driver at the national scale, although it may play a role in certain regions (Defourny et al. 2011, Ministére de l'Environnement 2012).

(f) Indonesia

Indonesia holds the world's third largest area of tropical moist forests, being the largest forest nation in Southeast Asia. However, deforestation in the country has been rampant in the last decades, especially in lowland forests. Wicke et al. (2011) synthesize national and international forestry statistics for Indonesia in the time period 1975-2005, finding that forests were lost at a rate of around 2 Mha per annum in the early 1990s, declining to 0.6-0.7 Mha/yr in the early 2000s. These numbers agree well with results from a number of recent remote sensing analyses for the country (Hansen et al. 2009, Miettinen et al. 2011, Harris et al. 2012), as well as from an earlier World Bank assessment (Holmes, 2002).

Two activities have generally been implicated as driving forest loss in Indonesia: clear-cutting of forests for valuable timber, and the clearance of forest for the establishment of plantations, mainly oil palm, but recently also short-rotation timber (acacia) plantations for the pulp and paper industry. Yet there have been few studies that have tried to quantify the share of deforestation in Indonesia due to different proximate drivers. A couple of studies, however, use remote sensing data to estimate the share of deforestation on subnational level that is due to palm oil expansion in recent years

[13] For a recent investigation into the drivers of deforestation, see the series of studies conducted by various actors, including civil society from the DRC, FAO, Catholic University of Louvain, Belgium and UNEP (http://www.un-redd.org/Newsletter35/DRC_Drivers_of_Deforestation/tabid/105802/Default.aspx, accessed 2014-06-11)

(2000-2010). Carlson et al. (2012) find that close to 60% of deforestation in Kalimantan was due to expanding oil palm plantations and Lee et al. (2014) find that 20% of forest clearing in Sumatra was due to expanding palm oil. Given that 80-85% of recent (2000-2010) deforestation occurred on Sumatra and Kalimantan (Hansen et al. 2009, Miettinen et al. 2011) and that most of the oil palm expansion have also occurred on these islands—in the period 2004-2009 over 90% of oil palm expansion occurred on these islands according to statistics from the Indonesian Directorate General of Estates (Abdullah 2012)—taken together these two studies give a relatively complete picture the share of deforestation due to oil palm expansion.

These figures also correspond with the picture one gets from analyzing the FAO data on oil palm cultivation area. To supplement the remote sensing analysis, and extend the coverage back in time, we take the approach proposed by Koh & Wilcove (2008) to put bounds on the amount of forest conversion for oil palm plantations by assuming either (1) that all oil palm expansion came at the expense of forests (maximum deforestation for oil palm), or (2) that palm oil primarily expanded on already cultivated land and that forest clearing for oil palm only occurred if the aggregate decline in area of other major crop groups (e.g., vegetables, fruits, nuts, beans and pulses, spices, fiber crops, and estate crops) was lower than the total expansion of oil palm area (minimum deforestation for palm oil). The results show that in the periods 1980-1997 and 2004-2009 the bounds put by the maximum and minimum amount of deforestation for oil palm is actually quite narrow and there is a clear trend towards a larger share of deforestation driven by expanding oil palm plantations over time. The average between the minimum and maximum estimate also correspond perfectly with the remote sensing analyses for the period 2000-2010 (Carlson et al. 2012, Lee et al. 2014), and therefore we use these values here. Note, however, that the resulting share of deforestation due to expanding oil palm plantations is substantially higher than what is indicated in two other remote sensing based studies covering the period 2000-2010 (Gunarso et al. 2013, Abood et al. 2014).

To estimate carbon emissions associated with the extraction of wood resources from natural forests we assess the amount of complete clearing of forests solely for wood products, as well as allocate a share of the carbon lost in conversion to oil palm plantation to timber extraction prior to deforestation. The former is based on the remote sensing analysis presented in Agus et al. (2013), taking the changes in land-use classification between forest and 'bare land' as clearing for wood products. For the share of forests being logged prior to conversion to oil palm plantations there is a large span in the literature. Carlson et al. (2012), in their study of Kalimantan, find that 32% of forest had been logged prior to oil palm conversion, while Gunarso et al. (2013) and Margono et al. (2012) find that nearly all forests were degraded prior to clearing. Here we take a conservative estimate, between the numbers found in the literature, of 50% of forests being logged prior to being cleared for oil palm development. Further, based on a recent study by Pearson et al. (2014) we assume that selective logging reduces the forest carbon stock by 50.7 tC/ha (21%) , which includes the carbon loss from logging damages (though their estimate of timber extraction rate seems low compared to other estimates, e.g., Fisher et al. 2011, Carlson et al. 2012). Note however, that this assumption does not affect the total carbon emissions embodied in wood and palm oil products, only its distribution between the different commodities.

Finally, we estimate that 12.8% of deforestation in Indonesia in the 2000s was due to the establishment of short-rotation, pulp-wood plantations, based on the remote sensing analysis by Abood et al. (2014). While their analysis only covers land-use changes occurring within industrial concessions, and therefore can be seen as lower limit (i.e., assuming no conversion of forests outside of fiber concessions to timber plantations), their estimate is still more than double that of another remote sensing study (Gunarso et al. 2013). However, the Abood et al. (2014) data is also consistent with the results from an analysis of deforestation for timber plantations in the Riau province (Uryu et al. 2008), the center of the Indonesian pulp and paper industry (Obidzinski and Dermawan 2012). With no direct data on forest conversion to short-rotation timber plantations prior to 2000, we assume a linearly increasing trend from zero in 1990, based on the fact that little pulp wood came from plantations prior to the early 2000s (Obidzinski and Dermawan 2012), acknowledging the large uncertainties here. Finally, yields of acacia plantations, having a 7 year rotation period, are taken from Pirard and Cossalter (2006).

For Indonesian biomass estimates we differentiate between forest on mineral soil and on peat soils and weigh the respective biomass values according to the distribution of oil palm plantations on these lands (based on Koh *et al.,* 2011). We average mineral soil biomass estimates for Sumatra (540 t/ha; Murdiyarso et al. 2002) and Borneo (430 and 457 t/ha; Paoli et al. 2008, Slik et al. 2010), and peatland forest biomass values from Sumatra (358 t/ha, Murdiyarso *et al.,* 2010) and Kalimantan (228 t/ha; Kronseder et al. 2012). After weighing we arrive at an average ABG content of 457.5 t/ha. The BGB fraction of 0.11 is based on values described for Sulawesi (Hertel et al. 2009) and Sabah, Malaysia (Pinard and Putz 1996). Total average ABG+BGB biomass (508 t/ha) and a carbon fraction of 0.47 (IPCC, 2006) yields a carbon stock of 238.7 tC/ha.

In addition to the carbon emissions from deforestation, we also account for the emissions associated with draining and cultivation carbon rich peat soils, which leads to large losses of soil carbon. Based on Lee et al. (2014) and Page et al. (2011) we assume an annual loss of peat carbon of 22.1 tC/ha/yr for palm oil cultivated on peat soils,. In Indonesia it is assumed that roughly 20% of oil palm cultivation occurs on peat land, based again on the remote sensing data from Agus et al. (2013), and that 35% of deforestation for timber plantations has occurred on peat land, based on the study by Abood et al. (2014).

(g) Malaysia

Malaysia, together with neighboring Indonesia, harbors the majority of the remaining tropical primary forest of Southeast Asia. However, the country has experienced high levels of deforestation throughout the 1990s and 2000s, with signs of an increasing trend in clearing rates. Wicke et al. (2011), compiling forest cover data for Malaysia from a number of sources, found that the country lost on average 92 000 ha of forests annually between 1990-2000, a number somewhat higher than what the country reported to the FAO (FAO 2010). Miettinen et al. (2011) and (Harris et al. 2012), using remote sensing data, both found that the rate of forest loss had increased to 230 000 ha/yr in the 2000s. Gunarso et al. (2013), on the other hand estimate an annual deforestation rate of 150 000 ha/yr in 2001-2010, while Hansen et al. (2013) reports higher—and rapidly increasing—rates, peaking at 620 000 ha in 2009.

Deforestation in Malaysia has historically been driven by logging operations and the expansion of plantation agriculture, in the last two decades mainly oil palm estates. Malaysia is the world's second largest producer of palm, following Indonesia, with 16% of the total land area under oil palm plantations (Gunarso et al. 2013). Analyzing satellite images, Gunarso et al. (2013) have mapped land uses across Malaysia for the years 1990, 2000, 2005, and 2010, allowing them to quantify the contribution of oil palm expansion to land use changes and we base our assumptions on the amount of deforestation for palm oil production on their analysis. They find that in the 1990s oil palm plantations directly replaced forests at a rate of 78 000 ha/yr, implying that over half of the oil palm expansion came at the expense of forests (pristine and disturbed). In the 2000-2005 period the rate of forest clearing for oil palm decreased to 67 000 ha/yr, declining further to 50 000 ha/yr in 2005-2010. Comparing with the land use change data presented above, these results indicate that in the 1990s over 80% of deforestation in Malaysia was due to expanding oil palm plantations, but that this decreased to between 17-39% in the 2000s (depending on if one used the high or low estimates for forest clearing rates).

Other literature sources confirm that nearly all deforestation was driven by expanding oil palm plantations in the 1990s, but that this share was reduced in the 2000s. Grieg-Gran et al. (2007) attribute 46% of Malaysian deforestation in 2000-2005 to oil palm and Lawson (2014) estimate that in the state of Sarawak 43% of deforestation in 2006-2010 was due to oil palm expansion. These numbers are also within the span given by an analysis of FAO data based on the approach by Koh & Wilcove (2008) (i.e., at one extreme, that all oil palm expansion comes at the expense of forests and at the other that oil palm plantations take up all the slack given by reductions in area of other crops and the remainder coming at the expense of forests).

Here we base the amount of deforestation due to logging alone and for palm oil on the remote sensing data presented in Agus et al. (2013) and Gunarso et al. (2013). As for Indonesia, where these studies identify changes in land classified as forest in one time period to 'bare land' in the next, we assume that this forest loss is solely due to logging. The share of deforestation for palm oil is based on the numbers reported above, decreasing from 83% in 1990-2000, to 42% in 2001-2005, and 35% in 2006-2010. We assume biomass carbon contents to be similar as in Indonesia and use the same values of 238.7 tC/ha.

For the wood products assessment, we assume that 80% of forests converted to palm oil had been logged prior to forest clearing (a conservative estimate, given that Bryan et al. (2013) find that 80% of all forest land in Malaysian Borneo had been impacted by logging, and that Gunarso et al. (2013) find that all deforestation for oil palm is in disturbed forests). Based on the field data from Indonesia (Pearson et al. 2014), we assume that selective logging leads to losses of biomass carbon of 50.7 tC/ha. Compared to neighboring Indonesia, there seem to have been little conversion of forests to timber plantations in Malaysia (Miettinen et al. 2012, Gunarso et al. 2013)

Again, as for Indonesia, we also account for the emissions associated with draining and cultivation carbon rich peat soils. We assume an annual loss of peat carbon of 22.1 tC/ha/yr for palm oil cultivated on peat soils, based on Lee et al. (2014) and Page et al. (2011). We further assume that the share of oil palm cultivation occurring on peat soils increase over time, nearly doubling from 7% in 1990 to 13% in 2010 (Agus et al. 2013).

(h) Papua New Guinea

Papua New Guinea constitutes the western half of the island of New Guinea, the world's second largest island (the eastern half being the Indonesian states of Papua and West Papua). Most studies estimate that Papua New Guineas extensive tropical forests have been lost at a rate of about 50 000 ha/yr in the last two decades (Harris et al. 2012, Gunarso et al. 2013, Hansen et al. 2013), based on remote sensing evidence. However, one study (Shearman et al. 2009) estimate a much higher rate of deforestation, averaging 263 000 ha/yr between 1972-2002, but with an increasing trend that would imply twice as large areas cleared in the latter years of this period. However, given the consistence of the estimated clearing rates from the other three remote sensing studies, we base our assumption on deforestation on these.

The primary proximate drivers of forest loss in Papua New Guinea have been, in order of importance, (illegal) logging, subsistence farming, forest fires, and plantation agriculture (primarily palm oil). Shearman et al. (2009), comparing aerial photography based maps from 1972 and satellite imagery from 2002, attribute 48.2% of the forest loss to logging activities, 45.6% to subsistence farming, and 1.2% to oil palm plantations. The latter corresponds to a yearly rate of forest clearing for the establishment of oil palm plantations of 3 200 ha, a number that is roughly consistent with the analysis by Gunarso et al. (2013). The latter study find that in the 1990-2000 period oil palm plantations replaced forests at a rate of 16 200 ha/yr, increasing to 25 400 ha/yr in 2000-2005 and then to 41 500 ha/yr in 2005-2010. Comparing this to the numbers for total deforestation used here, it implies that the role of oil palm plantations in driving land use change increased from 3.4% in the 1990s, to 7.0% in the latter half of the 2000s.

Biomass carbon stocks of forests in PNG are assumed to have the same magnitudes as forests in Indonesia and Malaysia, therefore we use 238.7 tC/ha as underlying assumption. Based on the Shearman et al. (2009) data, we attribute half of deforestation in Papua New Guinea to logging. We further assume that 73% of forest converted to palm oil plantations in the 1990s was logged prior to the land-use change, increasing to 99% in 2000-2005, and the declining to 89% in 2006-2009, based on the remote sensing evidence in Gunarso et al. (2013). As for Indonesia and Malaysia, we assume that selective logging removes 50.7 tC/ha (Pearson et al. 2014).

References

Abdullah, A. 2012. The Economic and Environmental Analysis of Palm Oil Expansion in Indonesia: Export Demand Approach and EIRSAM Model Graduate School ofInternatonal Development, Nagoya University, Japan.

Abood, S. A., J. S. H. Lee, Z. Burivalova, J. Garcia-Ulloa, and L. P. Koh. 2014. Relative contributions of the logging, fiber, oil palm, and mining industries to forest loss in Indonesia. Conservation Letters **In press**.

Aguiar, A. P. D., J. P. Ometto, C. Nobre, D. M. Lapola, C. Almeida, I. C. Vieira, J. V. Soares, R. Alvala, S. Saatchi, D. Valeriano, and J. C. Castilla-Rubio. 2012. Modeling the spatial and temporal heterogeneity of deforestation-driven carbon emissions: the INPE-EM framework applied to the Brazilian Amazon. Global Change Biology **18**:3346-3366.

Agus, F., P. Gunarso, B. Sahardjo, N. Harris, M. van Noordwijk, T. J. Killeen, and J. Goon. 2013. Historical CO2 emissions from land use and land use change from the oil palm industry in Indonesia, Malaysia and Papua New Guinea. Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia.

Arvor, D., M. Meirelles, V. Dubreuil, A. Bégué, and Y. E. Shimabukuro. 2012. Analyzing the agricultural transition in Mato Grosso, Brazil, using satellite-derived indices. Applied Geography **32**:702-713.

Asner, G. P., E. N. Broadbent, P. J. C. Oliveira, M. Keller, D. E. Knapp, and J. N. M. Silva. 2006. Condition and fate of logged forests in the Brazilian Amazon. Proceedings of the National Academy of Sciences **103**:12947-12950.

Batlle-Bayer, L., N. H. Batjes, and P. S. Bindraban. 2010. Changes in organic carbon stocks upon land use conversion in the Brazilian Cerrado: A review. Agriculture, Ecosystems & Environment **137**:47-58.

Broadbent, E. N., G. P. Asner, M. Peña-Claros, M. Palace, and M. Soriano. 2008. Spatial partitioning of biomass and diversity in a lowland Bolivian forest: Linking field and remote sensing measurements. Forest Ecology and Management **255**:2602-2616.

Brown, J. C., M. Koeppe, B. Coles, and K. P. Price. 2005. Soybean Production and Conversion of Tropical Forest in the Brazilian Amazon: The Case of Vilhena, Rondônia. AMBIO: A Journal of the Human Environment **34**:462-469.

Bryan, J. E., P. L. Shearman, G. P. Asner, D. E. Knapp, G. Aoro, and B. Lokes. 2013. Extreme differences in forest degradation in Borneo: Comparing practices in Sarawak, Sabah, and Brunei. PLoS ONE **8**:e69679.

Bustamante, M. C., C. Nobre, R. Smeraldi, A. D. Aguiar, L. Barioni, L. Ferreira, K. Longo, P. May, A. Pinto, and J. H. B. Ometto. 2012. Estimating greenhouse gas emissions from cattle raising in Brazil. Climatic Change **115**:559-577.

Börner, J., and S. Wunder. 2008. Paying for avoided deforestation in the Brazilian Amazon: from cost assessment to scheme design. International Forestry Review **10**:496-511.

Caldas, M. M., D. Goodin, S. Sherwood, J. M. Campos Krauer, and S. M. Wisely. 2013. Land-cover change in the Paraguayan Chaco: 2000–2011. Journal of Land Use Science:1-18.

Carlson, K. M., L. M. Curran, G. P. Asner, A. M. Pittman, S. N. Trigg, and J. Marion Adeney. 2012. Carbon emissions from forest conversion by Kalimantan oil palm plantations. Nature Climate Change **3**:283-287.

Chomitz, K. M., and T. S. Thomas. 2001. Geographic Patterns of Land Use and Land Intensity in the Brazilian Amazon. World Bank, Washington, D.C.

Clark, M. L., T. M. Aide, H. R. Grau, and G. Riner. 2010. A scalable approach to mapping annual land cover at 250 m using MODIS time series data: A case study in the Dry Chaco ecoregion of South America. Remote Sensing of Environment **114**:2816-2832.

Clark, M. L., T. M. Aide, and G. Riner. 2012. Land change for all municipalities in Latin America and the Caribbean assessed from 250-m MODIS imagery (2001–2010). Remote Sensing of Environment **126**:84-103.

Dauber, E., J. Terán, and R. Guzmán. 2000. Estimaciones de biomasa y carbono en bosques naturales de Bolivia. Superintendencia Forestal, Santa Cruz, Bolivia.

de Wasseige, C., D. Devers, P. de Marcken, R. Eba'a Atyi, R. Nasi, and P. Mayaux. 2009. The Forests of the Congo Basin - State of the Forest 2008. Publications Office of the European Union, Luxembourg.

Defourny, P., C. Delhage, and J.-P. K. Lubamba. 2011. ANALYSE QUANTITATIVE DES CAUSES DE LA DEFORESTATION ET DE LA DEGRADATION DES FORETS EN REPUBLIQUE DEMOCRATIQUE DU CONGO. Louvain, Belgium.

FAO. 2010. Global Forest Resources Assessment 2010. FAO Forestry Paper 163, Food and Agriculture Organization of the United Nations (FAO), Rome.

FCPF, and UN-REDD. 2013. Stratégie-cadre nationale REDD de la République Démocratique du Congo.

Fearnside, P. M., N. Leal, and F. M. Fernandes. 1993. Rainforest burning and the global carbon budget: Biomass, combustion efficiency, and charcoal formation in the Brazilian Amazon. Journal of Geophysical Research: Atmospheres **98**:16733-16743.

Fisher, B., D. P. Edwards, T. H. Larsen, F. A. Ansell, W. W. Hsu, C. S. Roberts, and D. S. Wilcove. 2011. Cost-effective conservation: calculating biodiversity and logging trade-offs in Southeast Asia. Conservation Letters **4**:443-450.

Galford, G. L., J. Melillo, J. F. Mustard, C. E. P. Cerri, and C. C. Cerri. 2010. The Amazon Frontier of Land-Use Change: Croplands and Consequences for Greenhouse Gas Emissions. Earth Interactions **14**:1-24.

Gasparri, N. I., and H. R. Grau. 2009. Deforestation and fragmentation of Chaco dry forest in NW Argentina (1972–2007). Forest Ecology and Management **258**:913-921.

Gasparri, N. I., H. R. Grau, and E. Manghi. 2008. Carbon Pools and Emissions from Deforestation in Extra-Tropical Forests of Northern Argentina Between 1900 and 2005. Ecosystems **11**:1247-1261.

Grau, H. R., N. I. Gasparri, and T. M. Aide. 2005. Agriculture expansion and deforestation in seasonally dry forests of north-west Argentina. Environmental Conservation **32**:140-148.

Grieg-Gran, M., M. Haase, J. Kessler, S. Vermeulen, and E. Wakker. 2007. The Dutch economic contribution to worldwide deforestation and forest degradation. London.

Gunarso, P., M. E. Hartoyo, F. Agus, and T. J. Killeen. 2013. Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. RSPO.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science **342**:850-853.

Hansen, M. C., D. P. Roy, E. Lindquist, B. Adusei, C. O. Justice, and A. Altstatt. 2008. A method for integrating MODIS and Landsat data for systematic monitoring of forest cover and change in the Congo Basin. Remote Sensing of Environment **112**:2495-2513.

Hansen, M. C., S. V. Stehman, P. V. Potapov, B. Arunarwati, F. Stolle, and K. Pittman. 2009. Quantifying changes in the rates of forest clearing in Indonesia from 1990 to 2005 using remotely sensed data sets. Environmental Research Letters **4**:034001.

Harris, N. L., S. Brown, S. C. Hagen, S. S. Saatchi, S. Petrova, W. Salas, M. C. Hansen, P. V. Potapov, and A. Lotsch. 2012. Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. Science **336**:1573-1576.

Hertel, D., G. Moser, H. Culmsee, S. Erasmi, V. Horna, B. Schuldt, and C. Leuschner. 2009. Below- and above-ground biomass and net primary production in a paleotropical natural forest (Sulawesi, Indonesia) as compared to neotropical forests. Forest Ecology and Management **258**:1904-1912.

Huang, C., S. Kim, A. Altstatt, J. R. G. Townshend, P. Davis, K. Song, C. J. Tucker, O. Rodas, A. Yanosky, R. Clay, and J. Musinsky. 2007. Rapid loss of Paraguay's Atlantic forest and the status of protected areas — A Landsat assessment. Remote Sensing of Environment **106**:460-466.

Huang, C., S. Kim, K. Song, J. R. G. Townshend, P. Davis, A. Altstatt, O. Rodas, A. Yanosky, R. Clay, C. J. Tucker, and J. Musinsky. 2009. Assessment of Paraguay's forest cover change using Landsat observations. Global and Planetary Change **67**:1-12.

INPE. 2014. Projeto PRODES: Monitoramento da floresta Amaônica Brasileira por satélite.*in* I. N. d. P. E. (INPE), editor., São José dos Campos.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change.

Kalogirou, V., C. Solimini, M. Paganini, and O. Arino. 2013. Deforestation Mapping using the Google Earth Engine: First Experiments in Boqueron, Paraguay.*in* ESA Living Planet Symposium 2013, Edinburgh, UK.

Killeen, T. J., V. Calderon, L. Soria, B. Quezada, M. K. Steininger, G. Harper, L. A. Solórzano, and C. J. Tucker. 2007. Thirty years of land-cover change in Bolivia. AMBIO: A Journal of the Human Environment **36**:600-606.

Klink, C. A., and A. G. Moreira. 2002. Past and current human occupation, and land use. Pages 69–88 *in* P. S. Oliveira and R. J. Marquis, editors. The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna. Columbia University Press, New York.

Koh, L. P., and D. S. Wilcove. 2008. Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters **1**:60-64.

Kronseder, K., U. Ballhorn, V. Böhm, and F. Siegert. 2012. Above ground biomass estimation across forest types at different degradation levels in Central Kalimantan using LiDAR data. International Journal of Applied Earth Observation and Geoinformation **18**:37-48.

Lawson, S. 2014. Consumer Goods and Deforestation: An Analysis of the Extent and Nature of Illegality in Forest Conversion for Agriculture and Timber Plantations. Washington, D.C.

Lee, J. S. H., S. Abood, J. Ghazoul, B. Barus, K. Obidzinski, and L. P. Koh. 2014. Environmental Impacts of Large-Scale Oil Palm Enterprises Exceed that of Smallholdings in Indonesia. Conservation Letters **7**:25-33.

Macedo, M. N., R. S. DeFries, D. C. Morton, C. M. Stickler, G. L. Galford, and Y. E. Shimabukuro. 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. Proceedings of the National Academy of Sciences **109**:1341-1346.

Machado, R. B., M. B. R. Neto, P. G. P. Pereira, E. F. Caldas, D. A. Gonçalves, N. S. Santos, K. Tabor, and M. Steininger. 2004. Estimativas de perda da área do Cerrado brasileiro. Relatório técnico não publicado. Brasília.

Margono, B. A., S. Turubanova, I. Zhuravleva, P. Potapov, A. Tyukavina, A. Baccini, S. Goetz, and M. C. Hansen. 2012. Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. Environmental Research Letters **7**:034010.

Margulis, S. 2004. Causes of deforestation of the Brazilian Amazon. World bank.

Miettinen, J., A. Hooijer, C. Shi, D. Tollenaar, R. Vernimmen, S. C. Liew, C. Malins, and S. E. Page. 2012. Extent of industrial plantations on Southeast Asian peatlands in 2010 with analysis of historical expansion and future projections. GCB Bioenergy **4**:908-918.

Miettinen, J., C. Shi, and S. C. Liew. 2011. Deforestation rates in insular Southeast Asia between 2000 and 2010. Global Change Biology **17**:2261-2270.

Ministére de l'Environnement. 2012. Synthèse des études sur les causes de la déforestation et de la dégradation des forêts en République Démocratique du Congo.

Morton, D. C., R. S. DeFries, Y. E. Shimabukuro, L. O. Anderson, E. Arai, E.-S. Fernando del Bon, F. Ramon, and J. Morisette. 2006. Cropland Expansion Changes Deforestation Dynamics in the Southern Brazilian Amazon. Proceedings of the National Academy of Sciences of the United States of America **103**:14637-14641.

Murdiyarso, D., M. Van Noordwijk, U. R. Wasrin, T. P. Tomich, and A. N. Gillison. 2002. Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra. Journal of Vegetation Science **13**:429-438.
Müller, R., D. M. Larrea-Alcázar, S. Cuéllar, and S. Espinoza. 2014a. Causas directas de la deforestación reciente (2000-2010) y modelado de dos escenarios futuros en las tierras bajas de Bolivia. Ecología en Bolivia **49**:20-34.
Müller, R., D. Müller, F. Schierhorn, G. Gerold, and P. Pacheco. 2012. Proximate causes of deforestation in the Bolivian lowlands: an analysis of spatial dynamics. Regional Environmental Change **12**:445-459.
Müller, R., P. Pacheco, and J. C. Montero. 2014b. El contexto de la deforestación y degradación de los bosques en Bolivia. Center for International Forestry Research (CIFOR), Bogor, Indonesia.
Nogueira, E. M., P. M. Fearnside, B. W. Nelson, R. I. Barbosa, and E. W. H. Keizer. 2008. Estimates of forest biomass in the Brazilian Amazon: New allometric equations and adjustments to biomass from wood-volume inventories. Forest Ecology and Management **256**:1853-1867.
Obidzinski, K., and A. Dermawan. 2012. Pulp industry and environment in Indonesia: is there sustainable future? Regional Environmental Change **12**:961-966.
Page, S., R. Morrison, C. Malins, A. Hooijer, J. Rieley, and J. Jauhiainen. 2011. Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia.
Paoli, G., L. Curran, and J. W. F. Slik. 2008. Soil nutrients affect spatial patterns of aboveground biomass and emergent tree density in southwestern Borneo. Oecologia **155**:287-299.
Pearson, T. R. H., S. Brown, and F. M. Casarim. 2014. Carbon emissions from tropical forest degradation caused by logging. Environmental Research Letters **9**:034017.
Pinard, M. A., and F. E. Putz. 1996. Retaining forest biomass by reducing logging damage. Biotropica:278-295.
Pirard, R., and C. Cossalter. 2006. The Revival of industrial forest plantations in Indonesia's Kalimantan Provinces: Will they help eliminate fiber shortfalls at Sumatran pulp mills or feed the China market. CIFOR, Bogor, Indonesia.
Rudorff, B. F. T., M. Adami, D. A. Aguiar, M. A. Moreira, M. P. Mello, L. Fabiani, D. F. Amaral, and B. M. Pires. 2011. The Soy Moratorium in the Amazon Biome Monitored by Remote Sensing Images. Remote Sensing **3**:185-202.
Rudorff, B. F. T., M. Adami, J. Risso, D. A. de Aguiar, B. Pires, D. Amaral, L. Fabiani, and I. Cecarelli. 2012. Remote Sensing Images to Detect Soy Plantations in the Amazon Biome—The Soy Moratorium Initiative. Sustainability **4**:1074-1088.
Saatchi, S. S., N. L. Harris, S. Brown, M. Lefsky, E. T. A. Mitchard, W. Salas, B. R. Zutta, W. Buermann, S. L. Lewis, S. Hagen, S. Petrova, L. White, M. Silman, and A. Morel. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. Proceedings of the National Academy of Sciences **108**:9899-9904.
Saatchi, S. S., R. A. Houghton, R. C. Dos Santos AlvalÁ, J. V. Soares, and Y. Yu. 2007. Distribution of aboveground live biomass in the Amazon basin. Global Change Biology **13**:816-837.
Shearman, P. L., J. Ash, B. Mackey, J. E. Bryan, and B. Lokes. 2009. Forest Conversion and Degradation in Papua New Guinea 1972–2002. Biotropica **41**:379-390.
Slik, J. W. F., S.-I. Aiba, F. Q. Brearley, C. H. Cannon, O. Forshed, K. Kitayama, H. Nagamasu, R. Nilus, J. Payne, G. Paoli, A. D. Poulsen, N. Raes, D. Sheil, K. Sidiyasa, E. Suzuki, and J. L. C. H. van Valkenburg. 2010. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. Global Ecology and Biogeography **19**:50-60.
Uryu, Y., C. Mott, N. Foead, K. Yulianto, A. Budiman, F. Takakai, E. Purastuti, N. Fadhli, C. M. B. Hutajulu, J. Jaenicke, R. Hatano, F. Siegert, and M. Stüwe. 2008. Deforestation, forest degradation, biodiversity loss and CO2 emissions in Riau, Sumatra, Indonesia. WWF-Indonesia, Jakarta.

Wicke, B., R. Sikkema, V. Dornburg, and A. Faaij. 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy **28**:193-206.

Villegas, Z., and B. Mostacedo. 2011. Diagnóstico de la situación actual sobre políticas, información, avances y necesidades futuras sobre MRV en Bolivia. CIFOR.

Zak, M. R., M. Cabido, and J. G. Hodgson. 2004. Do subtropical seasonal forests in the Gran Chaco, Argentina, have a future? Biological Conservation **120**:589-598.