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A new accounting framework for assessing forest footprint of nations

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ABSTRACT

In a tele-coupled and globalized World, understanding the links between demand for wood products and land use is becoming challenging. World's economies are increasingly open and interconnected, and international trade flows of wood products are continuously growing. The increasing resource consumption of humanity is increasingly dependent on international trade. In this context, the study of forest products demand from a global-multi-regional perspective emerges as a critical issue to achieve the goal of sustainable consumption and production. In this paper, we introduce a novel accounting framework for assessing the forest footprint of nations. The method combines Multi-regional Input-Output techniques and detailed data from the Food and Agriculture Organization of the United Nations on production, consumption and bilateral trade of primary, intermediate and final wood products, advancing with respect to existing approaches with these practical distinctions for more accurate computations. The approach tracks resource flows along the global supply chain and provides detailed information on the production, transformation, international trade, and final use of 20 forest products in 223 countries, having also much wider coverage than most previous studies. We test this framework to analyse forest footprint of nations in the year 2014, showing that 22 Million hectares (Mha) of forest were harvested for the extraction of roundwood for global demand, being 9.1 Mha to satisfy the foreign demand of wood products (42% of the total forestland harvested area). Harvested forestland is concentrated in America (32%), Asia (29%) and Europe (28%), representing Africa (7%) and Oceania (4%). More than 50% of the reported forest area harvested worldwide is located in USA (15%), China (14%); Russia (11%) and Canada (8%). In terms of forest footprint, Asia shows the highest share of the total forest footprint (44%), followed by America (25%), Europe (21%), Africa (7%) and Oceania (2%). Country-wise, half is concentrated in China (24%), USA (16%), India (5%), and Russia (5%).

1. Introduction

Humanity depends on the multiple goods and services provided by earth's land (IPBES, 2019; TEEB, 2010; Reid et al., 2005). Land encompasses a primary source of food, fibre, energy, water, and medicines (FAO, 2017a). It provides other non-tangible benefits like cultural or spiritual services and plays a fundamental role in biodiversity conservation (IPBES, 2019). Land is also key in natural processes such as water cycling, soil formation, nutrient cycling and decomposition, among others (EEA, 2016; Smith et al., 2013; Thompson et al., 2011). However, while available land for all these goods and services is limited, anthropogenic needs have remarkably increased, resulting in a growing competition for land (Marques et al., 2019; Lambin and Meyfroidt, 2011; Meyfroidt and Lambin, 2011; Smith et al., 2010).

Of particular concern are the effects of forest use for the provision of roundwood, which is in many cases linked to changes in forest area (Curtis et al., 2018). The increasing demand for wood and agriculture products can threaten the remaining natural and semi-natural forest worldwide, in particular in tropical regions, if it leads to forest degradation or forest loss (Pendrill et al., 2019; IPBES., 2019; IPCC, 2019; Meyfroidt et al., 2014; Geist and Lambin, 2002). Natural forests support an exceptional confluence of globally significant environmental values compared to degraded forests, including imperilled biodiversity, carbon sequestration and storage, water provision, indigenous culture, and

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human health (Watson et al., 2018). It is therefore important that the extraction of forest biomass is done in accordance with sustainable practices (Innes and Tikina, 2017; MacDicken et al., 2015) and avoiding progressive declines of carbon stocks and decreased forest's functionality that might lead to deforestation events (FAO, 2017b; Sanz et al., 2017).

In a tele-coupled and globalized world (Liu et al., 2015; Liu et al., 2015; Rethinking Global Land Use in an Urban Era, 2014; Meyfroidt et al., 2013; Liu, 2013), understanding the links between demand for wood products and land use is becoming challenging (Lambin and Meyfroidt, 2011; Liu, 2013; Meyfroidt et al., 2010). The growing resource consumption of humanity is increasingly dependent on international trade (Giljum et al., 2014; Kastner et al., 2014; Schaffartzik et al., 2014; Warren Hertel and Villoria, 2011; Wiedmann et al., 2015; Erb et al., 2009; NBIP, 2020). International trade of wood products is likewise growing. In fact, according to the Food and Agriculture Organization of the United Nations (FAO) dataset (FAOSTAT), international trade in primary and manufactured wood products doubled between 1997 and 2014.

In this context, there is a growing interest to analyse and quantify the forest land embodied in international trade, and the forest area harvested worldwide to satisfy the final uses of forest products of a specific country (i.e. forest footprint). For example, consumption-based accounting for biomass products, in general, has been recently analyzed by Bhan et al. (2021), with the focus on land use-induced carbon emissions, Ortiz et al. (2021), Marques et al. (2019) on biodiversity and carbon sequestration, Kalt et al. (2021) or Dorninger et al. (2021) with a global resource footprint perspective; and forest products, in particular, in Bruckner et al. (2019), Pendrill et al. (2019) who also include agricultural products.

Chaudhary et al. (2017) was more focused on the biodiversity and ecosystem service losses, or e.g. Zhang et al. (2020) based on a monetary MRIO database linked to the timber harvest FAO database as satellite account existing a broad array of methodological and empirical contributions among the several cited works.

In this paper, we present a novel accounting and analytical framework for assessing the forest footprint of nations and the forest area embodied in international trade. This framework is based on physical Multi-regional Input-Output (MRIO) techniques and FAOSTAT datasets. Kastner et al. (2011a, 2011b) and O'Brien and Bringezu (2018), among others, have previously used FAO data to assess the forest footprint of nations and forest land embodied in international trade. Building upon the contribution of these authors, our novel framework aims to overcome some of the critical shortcomings that they point out. For instance, as Kastner et al. (2011b): 1038) acknowledge, their approach "*can only give results at the apparent consumption level, considering trade in processed products (as opposed to the consistent differentiation between intermediate and final consumption in Input-Output models)*".

MRIO models have been also used to trace trade in biomass (and wood) products, dealing better with the above issue and increasing the system boundaries. These models typically work in monetary units and have lower granularity in terms of the number of forest products and countries than FAO data (e.g. Zhang et al., 2020). Hence, a trade-off exists between the MRIOs and FAO data based studies. A very interesting advance is the combination of both approaches in a hybrid form linking a biophysical model based on FAO data with a monetary MRIO model (Bruckner et al., 2019).

The relevant features of our new accounting framework, in comparison to previous studies, can be summarized as follows. First, it allows the analysis of forest harvests from a supply chain perspective, since it traces the links among primary, intermediate and final products. Second, it includes multilateral trade links in a consistent balancing framework with FAO data and, therefore, can be used to assess to what extend the demand of wood products in one country relies on the imports of wood products and on the extraction of roundwood from others. Third, the framework integrates data from production and trade statistics from FAO, information on the input rates of different forest products and on their input-output (I-O) linkages which is used to develop a new physical MRIO. Finally, the dataset is complemented with a set of land accounts quantifying the area harvested to extract roundwood and wood fuel which can be used to calculate the forest footprint of nations and products. The result of this novel accounting consist of a physical MRIO table of forest products (MRIO-forest) with detailed information on the production, transformation, trade and final use of 20 products, the area harvested for the extraction of roundwood and wood fuel, and covering 223 countries.

This paper focuses on the presentation of the new database and the methods used in its construction. The paper also illustrates how the database can be used to investigate the global supply chain of forest products and to calculate indicators such as the forest area required for the production and consumption (footprint) of wood products, and the forest area embodied in traded products, establishing clear bilateral links and dependencies. We also show how the database can be used to analyse specific clusters or groups of countries which have relevant interregional flows such as the Mekong area, a region which shows a net loss of natural forest of 0.3 Million hectares (Mha) between 2010 and 2017.[1]

The rest of the article is organized as follows. Section 2 presents the novel accounting framework for assessing land use and global supply chains of forest products. Section 3 contains the results of forest land footprint and forest land embodied in trade obtained from testing our framework. Section 4 summarises the main conclusions.

2. Methodology

Our study combines data from the FAOSTAT database and MRIO techniques to build a type of global physical (in cubic meters and metric tonnes) MRIO database of forest products (MRIO-forest). The end goal is to benefit from the detailed information from different FAOSTAT datasets (such as the forest production and trade statistics or the bilateral trade datasets) and the structure of intermediate and final products of input output (I-O) models in order to develop a global MRIO database that can be used to assess the global supply-chain of forest products. The different datasets are integrated into a single MRIO database using different adjusting methods, while keeping as close as possible to the original figures on production and trade reported in the FAOSTAT database. The database is also complemented by a set of land accounts, which report the area harvested (in hectares) for the extraction of primary wood products.

FAOSTAT provides free access to historical data on food, agriculture, forestry, trade, and land use for over 200 countries. These data have been extensively used to analyse issues related to land use, production, consumption, and trade (Alexander et al., 2015; FAOSTAT, 2018a; Kastner et al., 2014; Kastner et al., 2012; Kastner et al., 2011b; Lambin and Meyfroidt, 2011; van Vliet et al., 2016; Weinzettel et al., 2013). For our specific purposes, the FAOSTAT database, developed and compiled by the Statistics Division of FAO, provides relevant information for understanding the complex interactions that determine the flow of forest products around the world (223 countries). In particular, FAOSTAT database provides detailed information on *i)* extraction and trade of wood fuel and roundwood, *ii)* the production of wood products by country, and *iii)* exports and imports by country and partner of wood products (primary and processed products). In order to get full advantage of these datasets, this information has to be processed, reconciled and assembled in a comprehensive accounting framework. Using FAOSTAT's data, our methodological approach contributes to better understand the links between land use for harvesting forest products,

[1] Note that wood extraction does not necessarily translate into deforestation. However, it is well known that lodging is one of the main drivers and in some countries (Curtis et al., 2018).

primary extraction, transformation, and final uses. With this purpose, it integrates a global-multi-regional perspective taking into account bilateral trade linkages.

The accounting method presented in this paper is mostly based on I-O techniques, developed in the mid-20th century by the Nobel Prize Wassily Leontief (Leontief, 1936, 1937). The central element of the I-O framework is the I-O table, which describes the flows of goods and services between all industries of an economy, and the goods and services delivered to final users. The I-O framework is part of the System of National Accounts (SNA 2008) and National Statists Institutes elaborate it on a regular basis. Standard I-O tables represent national economies and are reported in monetary terms. However, the same approach can be used to represent a sub-system of an economy (e.g. the extraction-transformation-consumption of forest products) and can be reported in other units such as tonnes or cubic meters. Furthermore, I-O tables can also include information on the use of primary inputs such as land, in order to expand the scope of the I-O analysis.

In recent years, the increase in data availability and the support of different institutions (e.g. OECD, European Commission), has favoured the development of global MRIO tables (Tukker and Dietzenbacher, 2013; Stadler et al., 2016; Lenzen et al., 2013; OECD, 2018; Dietzenbacher et al., 2013; Eurostat, 2016). These tables use information from bilateral trade statistics to link national I-O tables of countries and, consequently, provide a more comprehensive vision of the flows of goods services in a globalized world. In our case, we will use the information of the FAOSTAT database and the principles of I-O accounting to develop the physical MRIO of forest products (MRIO-forest). Section 2.1 describes the structure of I-O tables and Section 2.2 shows the methodology for the constructing of these I-O tables.

2.1. Structure of input-output tables

Fig. 1 shows the typical structure of the I-O table of a national economy, adapted to show the flows of forest products.[2] Matrices $\mathbf{Z^D}$ and $\mathbf{Z^M}$ represent the intermediate inputs and their element z_{ij} denotes the physical amount of domestically produced (denoted by superscript **D**) or imported (denoted by superscript **M**) commodity i (e.g. wood chips) used to produce commodity j (e.g. pulp). Similarly, $\mathbf{Y^D}$ and $\mathbf{Y^M}$ are the matrices of final uses (wood products or fuel wood) and their element y_{if} indicates the final demand for commodity i to satisfy final use f. $\mathbf{e}$ is the column vector of sectoral exports to other countries, $\mathbf{x}$ is the column vector of total output by commodity, and $\mathbf{m}$ is the vector of total imports from other countries. Finally, the I-O table also includes a matrix of land use accounts $\mathbf{L}$ and its element l_{hj} denotes the physical amount of land use of type h (forest land used for the extraction of roundwood or for wood fuel) used to harvest primary commodity i.

MRIO tables represent the economic structure of two or more countries/regions. In addition to the information reported by national I-O tables, they also show the flows of commodities between the countries/regions covered by the MRIO table. MRIO tables can be constructed by the regionalisation of a single-region I-O table into several sub-regions, or by putting together information from various national I-O tables using bilateral trade data. The latter is the method followed in this framework, and the resulting MRIO table has the structure shown in Fig. 2. The interpretation of the components of the MRIO tables is similar to the national I-O ones. The scripts r, s, and t denote countries. Note that in the case of the global MRIO table, the vectors of total exports and imports are now replaced by bilateral trade matrices. Therefore, for a specific country r, we have that the vectors of total exports and imports are equal to $\mathbf{e^r} = \mathbf{Z^{rs}u} + \mathbf{Z^{rt}u} + \mathbf{Y^{rs}v} + \mathbf{Y^{rt}v}$ and $\mathbf{m^r} = \mathbf{Z^{sr}u} + \mathbf{Z^{tr}u} + \mathbf{Y^{sr}v} + \mathbf{Y^{tr}v}$, where and $\mathbf{u}$ and $\mathbf{v}$ are summation vectors of appropriate dimension (i.e. column vectors with ones).

2.2. Construction of global multi-regional input-output tables for forest products

The transformation of FAO datasets into MRIO tables constitutes a complex processes where different datasets, accounting balances, algorithms for adjusting inconsistent data sources, and classifications are combined, while preserving as much as possible the structures and figures of the original data.

More precisely, the construction of the MRIO-forest is divided into three steps (see Fig. 3).

First, we use information from “Forest production and trade” statistics to construct national I-O tables for forest products. Then, we use the information reported by the “Forestry trade flows” statistics (hereafter “Detailed trade”) to link the national I-O tables of forest products. As a result of this second step, we get the MRIO-forest table. Finally, we construct the land accounts that will be linked to the MRIO-forest table.

2.2.1. First step: From forest production and trade statistics to national input-output tables of forest products

In a first step, we construct the national I-O tables of forest products using statistics on production and trade in combination with information input rates and data on the level of processing of the different forest products (see Fig. 3).

The main data sources used to construct the national I-O tables of forest products are the production and trade statistics of FAO (FAOSTAT, 2018b). On the one hand, the “Forestry production and trade” statistics report for each country and year, the primary/raw extraction and the production of final and intermediate products. On the other hand, “Forestry production and trade” report the total amount of forest products exported/imported by country and year (hereafter “Country trade” statistics).

The trade statistics are reported in a more aggregated classification than the production statistics, creating mismatches for some products. To overcome this issue when linking both datasets into the I-O tables, we have used a simplified classification covering 20 forest products (see Table 1). For those commodities showing mismatches we proceeded as follows:

1. Production of “Sawlogs and veneer logs, coniferous”, “Pulpwood, round and split, coniferous (production)”, and “Other industrial roundwood, coniferous (production)” where aggregated into the category “Industrial roundwood, coniferous (export/import)”.
2. Production of “Sawlogs and veneer logs, non-coniferous”, “Pulpwood, round and split, non-coniferous (production)”, and “Other industrial roundwood, non-coniferous (production)” where aggregated and allocated proportionally to the amount of exports to “Industrial roundwood, non-coniferous tropical (export/import)” and “Industrial roundwood, non-coniferous non-tropical (export/import)”.

In addition, “Detailed trade” statistics report data for China mainland, Hong Kong, Macao and Taiwan aggregated under the epigraph China. Thus, production statistics were aggregated accordingly. Similarly, production data for Belgium and Luxemburg were aggregated under the region Belgium-Luxemburg.

Once we have the production and trade statistics in the same classification, we link the information of these two datasets to the national I-O tables. The exports and imports by product are directly linked to the

[2] Bold-faced lower-case letters are used to indicate vectors, bold-faced capital letters indicate matrices, and italic lower-case letters indicate scalars (including elements of a vector or matrix). Subscripts indicate industries and superscripts indicate countries. Vectors are columns by definition, row vectors are obtained by transposition, denoted by a prime (e.g. $\mathbf{x}'$). Diagonal matrices are denoted $\widehat{}$ (e.g. $\widehat{\mathbf{x}}$).

		Intermediate use	Final use		Total
			National	Exports	
Intermediate input	Domestic	$\mathbf{Z^D}$	$\mathbf{Y^D}$	**e**	**x**
	Imported	$\mathbf{Z^M}$	$\mathbf{Y^M}$		**m**

Land use	**L**

Fig. 1. Simplified structure of a national I-O table for forest products.
Source: Own elaboration.

		Intermediate use			Final use			Total
		Country *r*	Country *s*	Country *t*	Country *r*	Country *s*	Country *t*	
Intermediate input	Country *r*	$\mathbf{Z^{rr}}$	$\mathbf{Z^{rs}}$	$\mathbf{Z^{rt}}$	$\mathbf{Y^{rr}}$	$\mathbf{Y^{rs}}$	$\mathbf{Y^{rt}}$	$\mathbf{x^r}$
	Country *s*	$\mathbf{Z^{sr}}$	$\mathbf{Z^{ss}}$	$\mathbf{Z^{st}}$	$\mathbf{Y^{sr}}$	$\mathbf{Y^{ss}}$	$\mathbf{Y^{st}}$	$\mathbf{x^s}$
	Country *t*	$\mathbf{Z^{tr}}$	$\mathbf{Z^{ts}}$	$\mathbf{Z^{tt}}$	$\mathbf{Y^{tr}}$	$\mathbf{Y^{ts}}$	$\mathbf{Y^{tt}}$	$\mathbf{x^t}$

Land use	$\mathbf{L^r}$	$\mathbf{L^s}$	$\mathbf{L^t}$

Fig. 2. Simplified structure of a MRIO table for forest products.
Source: Own elaboration.

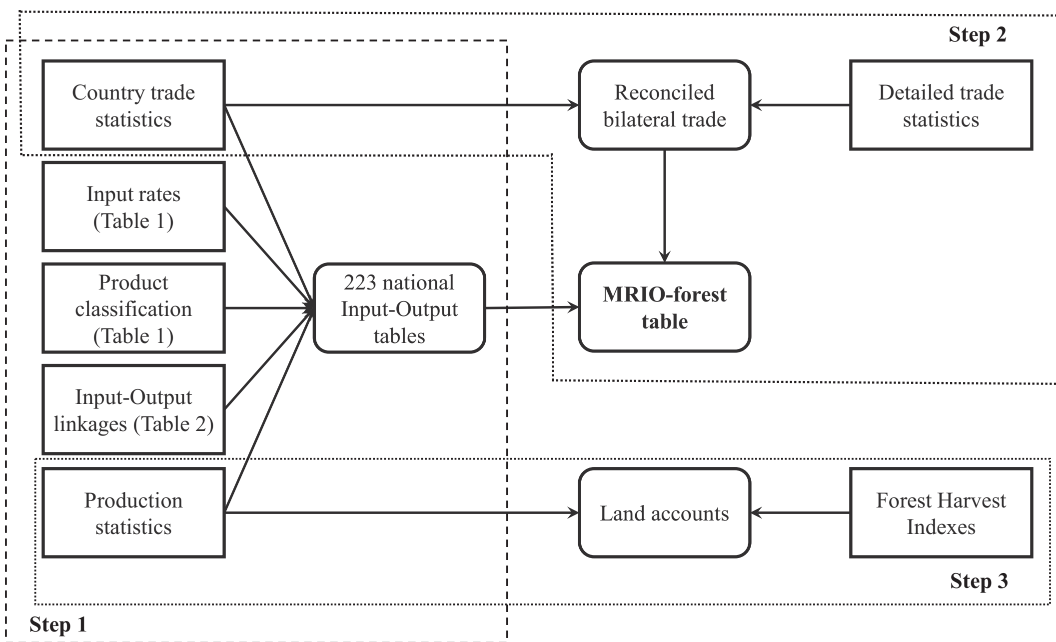

Fig. 3. Procedure in 3 steps for the construction of global MRIO tables for forest products and land accounts.
Source: Own elaboration.

column and row vectors of the I-O table respectively.[3] The procedure for translating the information on production statistics to the I-O tables is as follows:

1. Classify the products according to the level of processing, distinguishing between raw materials, intermediate products, and final products (see the third column in Table 1). Wood fuel constitute a special case since it can be used as raw material for the production of charcoal, or as final product.
2. Allocate domestic production and imports of final products to the categories of domestic final use of fuel wood (in the cases of wood charcoal and wood pellets) and domestic final use of wood products (rest of the final products, yellow cells in Table 2). It should be noted that we have two types of final products: wood products and fuel wood (not to misunderstand with wood fuel, which is a fuel such as firewood, charcoal, chips, sheets, pellets, sawdust, etc. and is indeed barely traded compared to more processed final products). In the case of wood fuel, the final use is calculated as the difference between the total production and the intermediate use for the production of "Wood charcoal" calculated in step 4 below.
3. Assign intermediate production to the different production processes using information on the available for intermediate use, the estimated input requirements, and the production structures. After this step, the available supply for intermediate uses is computed as:
Available for intermediate use = *Production* + *Imports* – *Domestic final uses* – *Exports*
4. Estimate the input requirements for the production of the different intermediate and final products by multiplying the production of

[3] We also adjusted total exports by commodity in order to ensure that exports are lower than production.

Table 1
Classification of forest products and input rates.

Item code	Item	Type of product	Input rates (Roundwood equivalent)
1619	Wood chips and particles	Intermediate	1
1620	Wood residues	Intermediate	1
1630	Wood charcoal	Final: Wood fuel	6
1632	Sawnwood, coniferous	Final: Wood products	1.6
1633	Sawnwood, non-coniferous all	Final: Wood products	1.6
1634	Veneer sheets	Final: Wood products	1.6
1640	Plywood	Final: Wood products	1.6
1646	Particle board and OSB	Final: Wood products	1.6
1651	Industrial roundwood, coniferous (export/import)	Raw material	
1657	Industrial roundwood, non-coniferous tropical (export/import)	Raw material	
1670	Industrial roundwood, non-coniferous non-tropical (export/import)	Raw material	
1668	Pulp from fibres other than wood	Intermediate	
1669	Recovered paper	Intermediate	
1671	Newsprint	Final: Wood products	
1693	Wood pellets	Final: Wood fuel	1.6
1694	Other agglomerates	Final: Wood products	1.6
1860	Paper+-Board Ex Newsprint	Final: Wood products	
1864	Wood Fuel	Raw material/ Final Final: Wood fuel	
1874	Fibreboard	Final: Wood products	1.6
1875	Wood Pulp	Intermediate	3.37

Source: Own elaboration from FAOSTAT statistics.

each commodity times the input rate (i.e. volume of roundwood per unit of product) obtained from the Joint Forest Sector Questionnaire Conversion Factors as reported in (UNECE and FAO, 2010) (fourth column in Table 1):

$$Estimated\ input\ requirements = Production \times Input\ rate$$

5. Identify the I-O relations on the basis of the flow of raw materials and intermediate products in the forest processing sector (see Fig. 27 in UNECE and FAO, 2005: 43, reproduced here as Fig. A1). As a result, we get the matrix of I-O linkages reported in Table 2.
6. Reconcile *Available for intermediate use* and *Estimated input requirements* using the information of the I-O linkages (Table 2). In the case of wood fuel, the difference between available supply and estimated input requirements is allocated to final uses (yellow cell in Table 2). In the case of the newsprint and paper and board, the available for intermediate use of pulp, recovered paper and wood pulp is allocated proportionally to the estimated input requirements (blue cells in Table 2). Finally, we use a bi-proportional adjustment method to match available supply and input requirements of the rest of commodities (green cells in Table 2).

The final result of this step is a set of 223 national Input-Output tables of forest products.

2.2.2. *Second step: From national I-O tables to multi-regional I-O tables of forest products*

Once we have built the national I-O tables for forest products, the next step consists on linking the different national I-O tables using bilateral trade data reported by FAO in the "Detailed trade" statistics (see Fig. 3). FAOSTAT periodically publishes "Detailed trade" data, yet these data are unreconciled. That is, a user may find that for a given commodity in a given year (in terms of quantity and/or value), what country A officially declares as imports from country B, it does not correspond to what country B, officially and reciprocally, declares as its exports to country A.[4] Hence, although FAO does adjust/modify some official figures when there are evident inconsistencies, the total World exports and imports by commodity are not reconciled. Finally, for some years, the figures reported by the "Detailed trade" and "Country trade" statistics are also different at the country and commodity level (e.g. the exports of Newsprint of the USA are not always the same in both datasets).

In this context, one of the key steps for the development of the MRIO framework consists on the estimation of a set of reconciled detailed trade matrices consistent with the exports and imports vectors reported in the "Country trade" statistics, which can be used to bilaterally link the exports and imports of the different countries covered by FAOSTAT. In general, the attempt is to preserve, as much as possible, the official trade figures in the "Country trade" statistics while using the detailed bilateral trade structure provided by the "Detailed trade" statistics to build new bilateral trade matrices. The step-by-step method to reconcile bilateral trade statics is described below:

1. Reconcile "Detailed trade". As mentioned before, the exports and imports in the "Detailed trade" do not always match. In order to reconcile these figures, we have replaced the exports/imports by the maximum flow reported There are certainly alternatives to this choice, given the common asymmetry in values from the reported bilateral exports and imports. For example, one could trust more in the imports or in the exports. Also, it is possible to argue that the trade flows reported by some countries is more relivable than that reported by its partners. An alternative could also be the use, for each bilateral trade flow, the average trade reported by the exporter and the importer. An interesting solution is the one of (Ferreira, 2018), using the asymmetry in value to allocate non-specified exports. Our choice (maximum flow) is grounded on the fact that we expect more incentives or biases (due to lack of reporting or misreporting) towards undervaluing than overvaluing the flows, especially when they are in physical units, as it is our case. It should be taken into account that, ultimately, we do not modify the absolute exports and imports values obtained from the official figures in the "Country trade" statistics, so this bilateral trade reconciliation affects only the trade structure. A sensitivity analysis to this choice is performed in section 2.2.4.
2. Fill data gaps in "Country trade". For some countries, the "Country trade" does not report any value while the "Detailed trade" reports a non-zero value. In these cases, we replace the zeroes in the "Country trade" by the value reported in the "Detailed trade" after the reconciliation (see step 1). This information is used to recalculate new total exports and imports for the World.
3. Reconcile World values in "Country trade" after filling data gaps. Once the data gaps of "Country trade" have been filled we proceed to reconcile World's exports and imports by replacing the World's exports/imports by the maximum flow reported.
4. Adjust country values in "Country trade" after reconciliation of World values. The differences between the total "Country trade" (step 2) and the World totals (step 2) are allocated to "Statistical Difference".
5. Additional adjustment to "Detailed trade" calculated in step 1 before the reconciliation with "Country trade". This adjustment consists of replacing those flows with zero total exports/imports in the

[4] For further information on the Detailed trade matrices seehttp://fenixservices.fao.org/faostat/static/documents/TM/TM_e.pdf

Table 2
Input-Output linkages of forest products.

		1619	1620	1630	1632	1633	1634	1640	1646	1651	1657	1670	1668	1669	1671	1693	1694	1860	1864	1874	1875	Fuel wood	Wood prod.
Wood chips and particles	1619								X											X	X		
Wood residues	1620								X							X	X			X	X		
Wood charcoal	1630																					X	
Sawnwood, coniferous	1632																						X
Sawnwood, non-coniferous all	1633																						X
Veneer sheets	1634																						X
Plywood	1640																						X
Particle board and OSB	1646																						X
Industrial roundwood, coniferous	1651	X	X		X		X	X													X		
Industrial roundwood, non-coniferous tropical	1657	X	X			X	X	X													X		
Industrial roundwood, non-coniferous non-tropical	1670	X	X			X	X	X													X		
Pulp from fibres other than wood	1668														X			X					
Recovered paper	1669														X			X					
Newsprint	1671																						X
Wood pellets	1693																					X	
Other agglomerates	1694																						X
Paper+-Board Ex Newsprint	1860																						X
Wood Fuel	1864			X																		X	
Fibreboard	1874																						X
Wood Pulp	1875														X			X					

Source: Own elaboration from FAOSTAT statistics.

Table 3
World total Input-Output table of forest products, 2014 (Million cubic meters, Million metric tonnes, Million hectares).

Units	Code	1619	1620	1630	1632	1633	1634	1640	1646	1651	1657	1668	1669	1670	1671	1693	1694	1860	1864	1874	1875	WFUE	WPRD	DIFF	TOTAL
Mm3	1619								80.99											69.55	90.52		0.05	0.11	241.22
Mm3	1620								50.65							36.99	8.53			74.48	49.37		0.04	1.16	221.21
Mt	1630																					52.40		0.00	52.40
Mm3	1632																						312.55	0.00	312.55
Mm3	1633																						126.99	0.00	126.99
Mm3	1634																						13.90	0.00	13.90
Mm3	1640																						147.34	0.00	147.34
Mm3	1646																						111.07	0.00	111.07
Mm3	1651	124.44	85.12		498.23		6.47	53.05													251.82			0.04	1019.17
Mm3	1657	17.54	28.73			109.98	9.01	62.49													72.10		0.00	-0.08	299.78
Mt	1668														0.60			12.52					0.00	0.00	13.12
Mt	1669														13.42			210.30					0.02	0.19	223.94
Mm3	1670	76.36	69.34			116.41	8.14	56.95													171.73			0.04	498.97
Mt	1671																						26.96	0.00	26.96
Mt	1693																					25.96			25.96
Mt	1694																						5.61		5.61
Mt	1860																						377.08	0.00	377.08
Mt	1864			314.42																		1548.00		-0.51	1861.90
Mm3	1874																						115.60	0.00	115.60
Mt	1875														12.86			162.39						0.01	175.27
Mha	LHRW									11.02	4.15			6.46											22.00
Mha	LHWF																		84.84						84.84

Note: 1619: Wood chips and particles; 1620: Wood residues; 1630: Wood charcoal; 1632: Sawnwood, coniferous; 1633: Sawnwood, non-coniferous all; 1634: Veneer sheets; 1640: Plywood; 1646: Particle board and OSB; 1651: Industrial roundwood, coniferous (export/import); 1657: Industrial roundwood, non-coniferous tropical (export/import); 1670: Industrial roundwood, non-coniferous non-tropical (export/import); 1668: Pulp from fibres other than wood; 1669: Recovered paper; 1671: Newsprint; 1693: Wood pellets; 1694: Other agglomerates; 1860: Paper+-Board Ex Newsprint; 1864: Wood Fuel; 1874: Fibreboard; 1875: Wood Pulp; WFUE: Fuel wood; WPRD: Wood products; DIFF: Statistical difference; LHRW: Land harvested roundwood; LHWF: Land harvested wood fuel.
Note: Mm3: million cubic meters; Mt.: million metric tonnes; Mha: million hectares.
Source: Own elaboration from FAOSTAT statistics.

Table 4
WRPD resulting from comparing the forest MRIO tables calculated with different methods for the reconciliation of trade data.

	Average	Export	Import
Maximum	0.9910	0.9909	0.9896
Average		0.9892	0.9867
Export			0.9869

"Detailed trade" and non-zero values in the "Country trade" by the weighted average World bilateral trade patterns of the "Detailed trade".

6. Reconciliation of the "Detailed trade" and the "Country trade". In this step, we reconcile the "Detailed trade" resulting from step 5 and the "Country trade" from step 2. The idea is to keep as close as possible the vectors of exports and imports of the reconciled "Country trade" (step 2) and use the structure of the "Detailed trade" (step 5) to calculate a new reconciled "Detailed trade" matrix consistent with these two vectors. This is done by applying a bi-proportional iterative adjustment method (also known as RAS in Input-Output literature, see (Miller and Blair, 2009: 313–36) with just the 2 constraints of the vectors of exports and imports by country and product.
7. Final adjustment of the reconciled "Detailed trade". The resulting reconciled "Detailed trade" matrix in step 7 will be consistent with the reconciled "Country trade" vectors. However, for some specific flows differences could exist. In such a case, the difference between the total trade of a country and the detailed trade will be allocated to "Statistical Difference", which captures the mismatches between the trade matrix after the bi-proportional adjustment and the official figures in the "Country trade" statistics (for the footprint analysis we have assumed that the statistical difference is part of the domestic demand, guaranteeing that all the forest area harvested is allocated to the footprint of a specific country).

Once we have a set of bilateral trade matrices consistent with the data of forest statistics, we proceed to develop the MRIO. For that, we use the trade structure from the reconciled trade statistics, splitting the import and the export vectors of the different national I-O tables and integrating the resulting trade matrices into a unique MRIO table. As a result, we get the MRIO-forest table.

Table 3 shows the total World Input-Output table of forest products for the year 2014. Note that Table 3 is a country-wise aggregation of the fully-fledged MRIO-forest table, which covers 20 forest products, 223 countries, two categories of final use and a column of statistical difference, and has 127,015 non-zero values. The MRIO-forest table of the year 2014 can be found in list format in the *Supplementary material*.

2.2.3. *Third step: Construction of land accounts*

Although timber is a key resource in the bioeconomy context, the calculation of land demand related to timber consumption is challenged by limited data availability regarding actual harvested forest areas, in contrast to overall forest areas (Bruckner et al., 2015; Kurniawan, 2017). The FAO dataset does not report how much forestland is harvested to extract primary forest products. For the construction of the land accounts, we use the concept of forest land "harvested" to extract primary forest products (i.e. industrial roundwood and wood fuel). Thus, the link between forest supply chains and harvested forestland is not straightforward. In order to establish this link, we used a set of forest harvest indexes (FHI) (Furukawa et al., 2015), which link the production volume of roundwood and wood fuel reported by FAO to the harvested forest area (see Table A1 in the Annex). Furukawa et al. (2015: 151) define the FHI as follows: "[…] *the gross loss of forest area reflecting the demand for wood products. Since the index does not consider whether forest cover returns after harvest, it represents expected global forest cover loss as a result of logging. Wood products can be categorized into industrial roundwood (including derived products) and wood fuel. The majority of industrial roundwood is harvested through large-scale operations, while household-level harvests are common for wood fuel especially in developing countries* […].". The FHI then calculates the expected gross forest cover loss (GFCL) reflecting the demand for timber and wood products at the global scale. The FHI was constructed making use of the FAOSTAT data on volume of industrial roundwood and wood fuel produced, the ratio between wood volume, and the aboveground biomass of an entire tree and the growing stock density.[5] The accuracy and precision of the index was established in that work by investigating the relationship between the FHI and actual GFCL measured through remote sensing. Following this approach, the area harvested for industrial roundwood and wood fuel extraction is calculated multiplying the FHI by the roundwood extraction, and the wood fuel reported by the production statistics of FAO.

In our accounting framework, two different types of forestland are considered: forest harvested for the extraction of roundwood and forest harvested for the extraction of wood fuel. This distinction is important since the extraction of roundwood is a stronger indicator of forest cover loss (Furukawa et al., 2015).

Finally, it is worth to mention that Furukawa et al. (2015) do not clarify whether they are including or not "other wooded land" or just forest areas.[6] However, comparing the figures of area harvested for wood fuel and the total "forest area" from the Forest Assessment Report (FRA) of 2010 (FAO, 2010), which is used by Furukawa et al. (2015), we can conclude that, at least, for wood fuel they are considering both forest area and other wood land. For example, for 11 countries the forest area harvested for wood fuel is greater that the forest area reported in the FRA.

The land accounts for the year 2014 can be found in list format in the *Supplementary material* and include data on the forest area harvested for 197 countries,[7] four primary products (Industrial roundwood, coniferous; Industrial roundwood, non-coniferous tropical; Industrial roundwood, non-coniferous non-tropical; Wood fuel) and two types of forestland.

[5] In particular, making use of the expression $FHI_i = \sum_{jk}(V_{i,j,k} \cdot BEF_{k\cdot}/D_{i,j})$, where V is the volume of wood produced (either industrial roundwood or wood fuel; m^3) and D is growing stock density ($m^3\ ha^{-1}$). $BEF_{k\cdot}$ is the biomass expansion factor (unitless), it is the ratio between roundwood volume and the aboveground biomass of an entire tree, including its branches and leaves, and is usually calculated from volume-yield relationships using proposed equations (Schroeder et al., 1997). Subscripts j and k depict year (from FY2000 to FY2004) and wood type (i.e., conifer and non-conifer) under each climatic zone (i.e., boreal, temperate, and tropics), respectively. The BEFs did not vary much across Climatic zones and wood types (mostly around 1.3–1.4) except for the non-conifer wood fuel found in the tropical zones (3.4). Also an exception was made for the BEF of tropical non-conifer industrial roundwood, in which the value of eucalyptus plantations was adopted for its significant and growing share in tropical forest plantations. To obtain a rough estimate of the share of wood produced from each climatic zone, it was calculated the proportion of forest under each climate in each country based on terrestrial ecoregions of the world (Olson et al., 2001). Among the 139 countries analyzed, 116 (83%) had forests belonging to a single climatic zone; China and the US had forests under all three zones, but they were predominantly temperate forests (69% and 91%, respectively).

[6] According to FAO, "Forests" refer to the land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. "Other wooded land" is the land not classified as "Forest", spanning more than 0.5 ha; with trees higher than 5 m and a canopy cover of 5–10%, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10%. It does not include land that is predominantly under agricultural or urban land use.

[7] Note that for 26 countries FAO database does not report primary extraction and, therefore, the harvested area is zero.

2.2.4. Sensitivity analysis

One of the critical assumptions in the construction of the MRIO tables is the method for the reconciliation of the "Detailed trade" statistics. The issue is that "Detailed trade" statistics report, for each bilateral trade flow, the exports reported by the exporting country and the imports reported by the imported, and in most cases these figures are different. As already argued in section 2.2.2, we have decided to trust in the maximum trade flow reported, but there are other options. In this section, we test how different would be the final MRIO-forest table if, instead of using as reconciliation criteria he maximum flow, we used: *i)* the exports, *ii)* the imports, or *iii)* the average value.

In order to perform this comparison, we have constructed three additional MRIO tables following these three alternative reconciliation criteria. Then, we have proceeded to compare the cell-by-cell differences between the four matrices. The comparison between matrices has been widely addressed in the IO literature using different indicators such as the so-called weighted relative percentage difference (WRPD) (e.g. Arto et al., 2014). The WRPD is defined as a weighted average of the relative percentage difference rate of the (i,j)-th element with respect to the same (i,j)-th element of the other matrix. The mathematical expression of the WRPD would therefore be as follows:

$$\mathrm{WRPD} = \sum_i \sum_j \left(\frac{\left| z_{ij}^A + z_{ij}^B \right| / 2}{\sum_k \sum_l \left| z_{kl}^A + z_{kl}^B \right| / 2} \right) \times \mathrm{RPD}_{ij}$$

being

$$\mathrm{RPD}_{ij} = \frac{\left| z_{ij}^B - z_{ij}^A \right|}{\left| z_{ij}^B + z_{ij}^A \right|} \times 100,$$

where $z_{ij}{}^A$ and $z_{ij}{}^B$ and represent each of the elements of one of the two different matrices (denoted by A and B). In our case, compare all the four matrices calculated under the different assumptions aforementioned (maximum, average, export, import) with each other. In order to compare the different matrices we will use the ρ-likelihood coefficient which is ranged between 0 (when the matrices are likely to be very different) and 1 (when they are likely to be very similar). The ρ-likelihood coefficient which is defined as:

$$\rho - \mathrm{likelihood} = 1 - \frac{WRPD}{200}$$

The results show that the criterion used for selecting the initial bilateral trade matrix barely affects the final MRIO. The ρ-likelihood coefficients when comparing each of the four MRIO tables with the other three range from 0.9867 to 0.9910, showing that the four matrices are ~99% similar (see Table 4). Furthermore, the MRIO matrix calculated with the maximum criterion is the one that is more similar to the other three matrices (i.e. it reports the highest ρ-likelihood coefficients).

2.3. Analysis of multi-regional input-output tables for forest products

In this section, we explain how the MRIO-forest database can be used to analyse land footprints and land embedded in international trade.

We can make use of the Leontief (Leontief, 1936, 1937) demand-driven model in combination with the MRIO tables to analyse land used, directly and indirectly, to satisfy the final demand of a country (e.g. forestland the land harvested in Uruguay to support paper consumption in France).

The departing point of the Leontief demand-driven model is the accounting equation $\mathbf{x} = \mathbf{Zu} + \mathbf{Yv}$, where $\mathbf{x}$, $\mathbf{Z}$, and $\mathbf{Y}$ refer to the components of the MRIO table (see Fig. 2), and $\mathbf{u}$ and $\mathbf{v}$ are summation vectors of appropriate dimension. This equation can be transformed into the Leontief demand-driven model represented by the following expression:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Yv} = \mathbf{BYv} \tag{1}$$

Where $\mathbf{A} = \mathbf{Z}(\widehat{\mathbf{x}})^{-1}$ is the matrix of technical coefficients of the multi-regional table indicated above, and the element $a_{ij}{}^{rs}$ of $\mathbf{A}$ represents the amount of commodity i from country r required to produce one unit of commodity j in country s; and $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix and the element $b_{ij}{}^{rs}$ represents the total (direct and indirect) output of commodity i from country r that is required to satisfy one unit of final demand of commodity j produced in country s.

Finally, being $\mathbf{w}$ a vector of unitary land use coefficients of land use of type h (forest land used for the extraction of roundwood or for wood fuel) per unit of output, with element $w_j{}^s = l_{hj}{}^s / x_j{}^s$ denoting the forest-land area land in country s that is required to harvest one unit of commodity i, and using Eq. (1) we can express the vector of harvested forestland as:

$$\mathbf{l} = \widehat{\mathbf{w}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Yv} = \mathbf{MYv} \tag{2}$$

Where the element $m_{ij}{}^{rs}$ of $\mathbf{M}$ represents the land used in country r to harvest the total amount of commodity i required to satisfying one unit of final demand of commodity j produced in country s. With this information, we can calculate the forestland[8] footprint, which refers to the land required worldwide to satisfy the final uses of one country. This indicator can be reported at different levels of aggregation, e.g. the forest harvested in Uruguay to extract roundwood that ends up in the newsprint consumption of France, or the forest harvested worldwide to satisfy the total demand of wood products of France. The land used in region r to satisfy the final uses of country t (land footprint of country t in country r) is calculated using the following expression:

$$\mathbf{l}^{\mathbf{r(t)}} = \sum_{\mathbf{s}} \mathbf{M}^{\mathbf{rs}}\mathbf{Y}^{\mathbf{st}}\mathbf{v} \tag{3}$$

Note that we can distinguish between the domestic (i.e. French forestland harvested to satisfy French consumption, or Eq. (3) when $t = r$) and the foreign footprints (i.e. foreign forest harvested to satisfy French consumption, or Eq. (3) when $t \neq r$). The latter is also referenced as land embodied in trade (i.e. land "exported" from country r to country t or land "imported" by t from r).

3. Results: Forest area harvested, footprint and forest area embodied in trade

By combining the information of the MRIO-forest table and the analytical framework, we compute the forest area harvested, the forest footprint of nations, and the forest land embodied in international trade.

Fig. 4a shows, for the year 2014, the distribution of the total forestland harvested around the World resulting from the land accounts developed in Section 2.2.3. Fig. 4b depicts the total area of forestland harvested by country. The results shown in this section refer to forest-land harvested for wood products (i.e. for fuel wood is not reported). Fig. 4c shows the per capita forestland harvested by country.

In the year 2014, 22 Mha of forest were harvested in the world for the extraction of the roundwood required to satisfy the global demand of wood product. The largest share of forestland harvested worldwide is concentrated in America (32% out of 22 Mha of forestland harvested worldwide), followed by Asia (29%), Europe (28%), Africa (7%) and Oceania (4%). At the country level, more than 50% of the reported forest area harvested worldwide is located in just four countries (darkest areas in the map). In particular, 3.3 Mha of forestland is harvested in the USA (15% of total), 3.1 Mha in China (14%), 2.5 Mha in Russia (11%), and 1.8 Mha in Canada (8%). Additionally, six countries have a forestland harvested area ranging between 0.5 and 1 Mha: India (0.9 Mha), Sweden (0.8 Mha), Brazil (0.7 Mha), Finland (0.7 Mha), Indonesia (0.6 Mha), and Australia (0.6 Mha).

Fig. 4c shows the top 60 countries in terms of forest area harvested

[8] We distinguish between forestland harvested for wood products and for wood fuel.

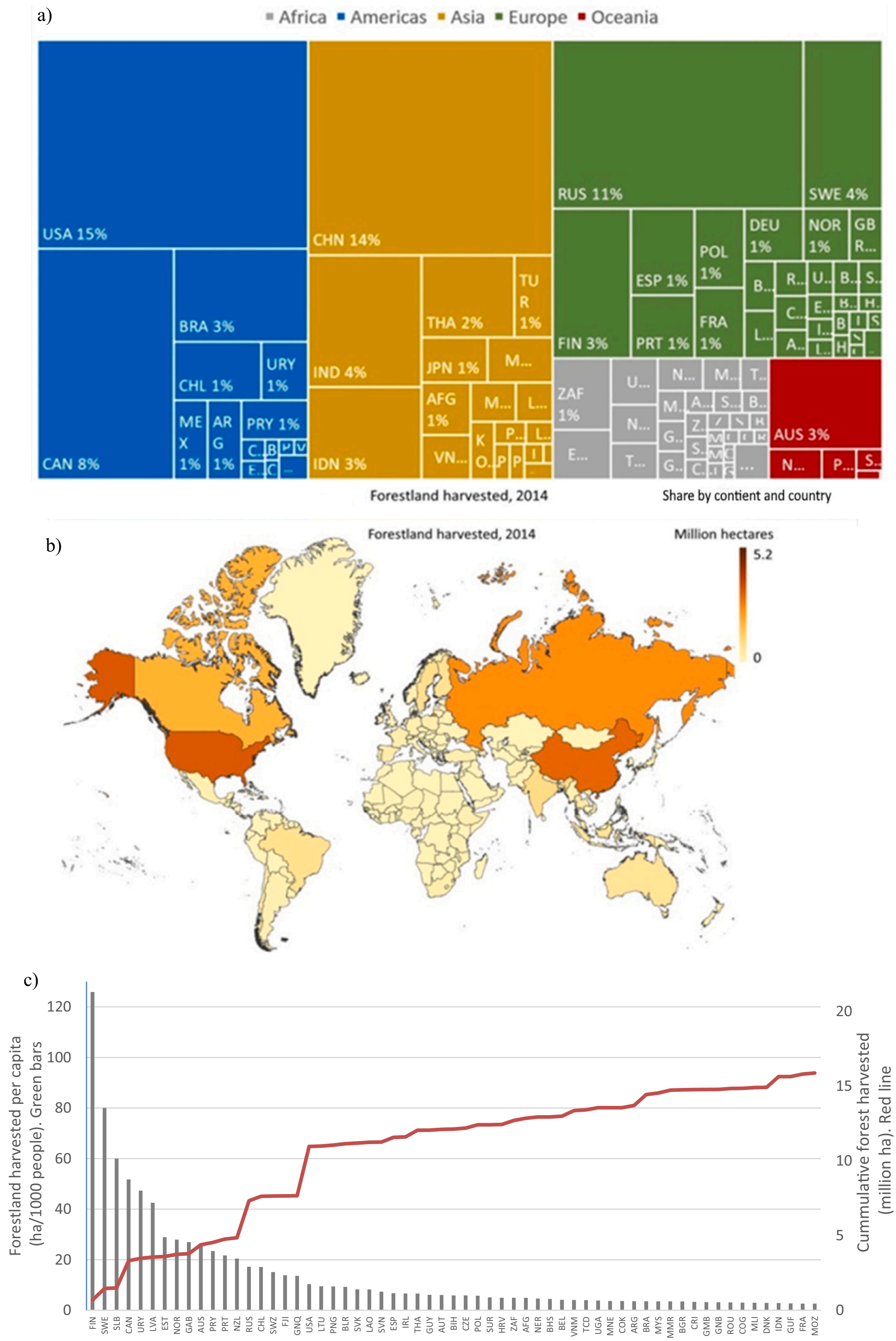

Fig. 4. Forestland harvested, 2014. (a) Million hectares distribution in % of the total forestland harvested around the World. Colours represent continents and areas represent countries. (b) Million hectares of total area of forestland harvested by country. (c) Per capita forestland harvested by country in ha/1000 people.
Source: Own elaboration from FAOSTAT statistics and population data (UN, 2021).

per capita (ha/1000 people), representing 73% of the total forest area harvested worldwide (up to China, ranked 67th, it would be 89%). Within these countries, the top 20 countries with the highest values represent 55% of the total of the total forest area harvested, standing out the Nordic countries (Finland, Sweden, Norway), Canada, the Baltic republics (Latvia and Estonia, to a lesser extent Lithuania), some Latin-American (Uruguay, Paraguay and Chile), African (especially Gabon, also Swaziland, Equatorial Guinea), a few other European (Portugal, Belarus, to a lesser extent Slovakia, Slovenia, Spain, Ireland) and Oceania (especially Australia and New Zealand, also Papua New Guinea),

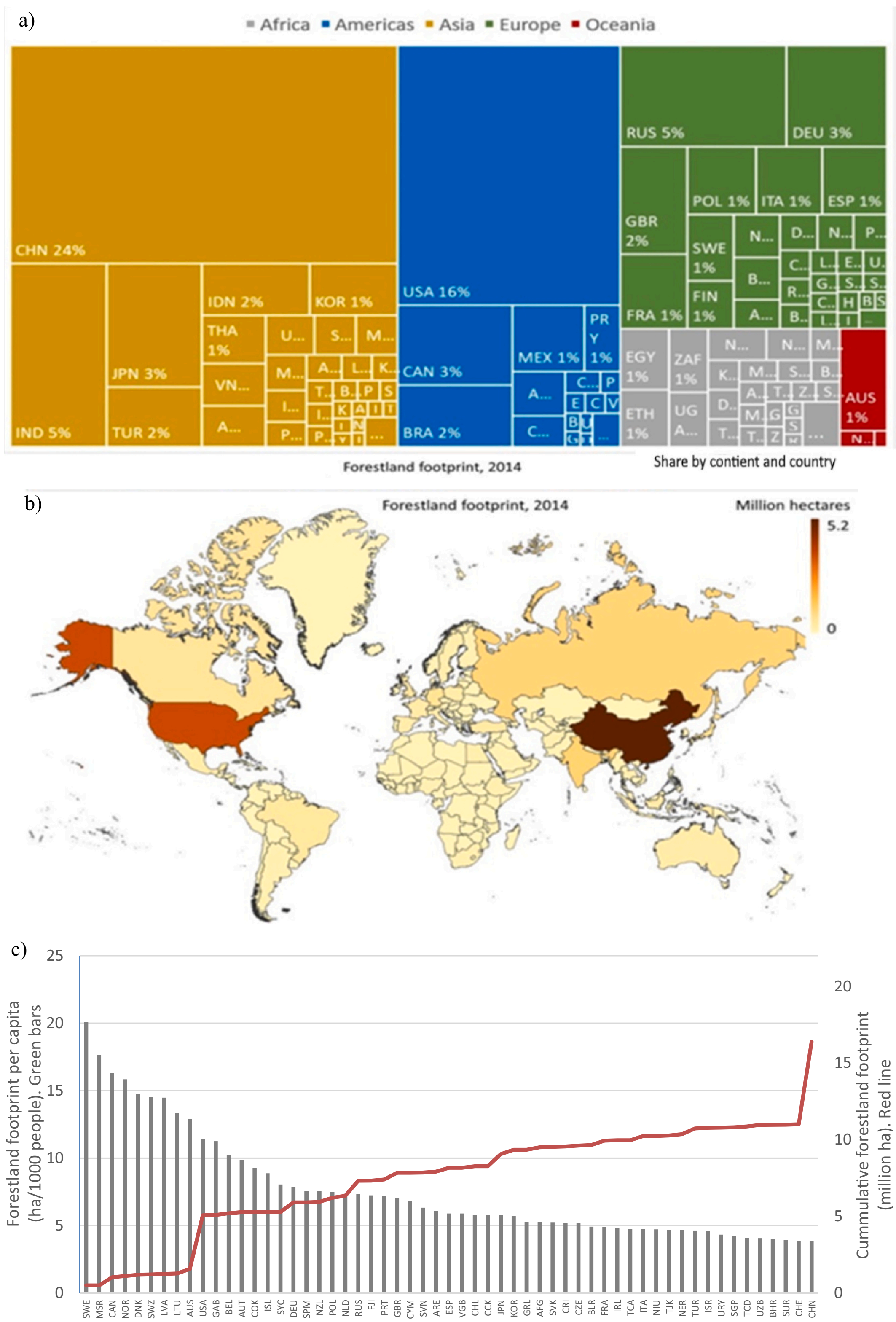

Fig. 5. Forestland footprint, 2014. (a) Million hectares distribution in % of the total forestland footprint around the World. Colours represent continents and areas represent countries. (b) Million hectares of total area of forestland footprint by country. (c) Per capita forestland footprint by country in ha/1000 people.
Source: Own elaboration from FAOSTAT statistics and population data (UN, 2021).

being also high numbers those of Russia and the USA (above 10 ha/1000 people, ranking respectively 14th and 19th). Brazil ranks 47th, Indonesia 58th, China 67th and India 106th.

The forest footprint reflects the area harvested worldwide (i.e. domestic and foreign forest harvested) to satisfy the final use of wood products of a specific country. At the global level, the forest harvested area is equal to the forest footprint (i.e. 22 Mha in 2014). However, at the country level, there can be significant variations since international trade enables differences between the area harvested of a country and its forest footprint. The difference between the harvested area and the forest footprint corresponds to the forestland trade balance.

Fig. 5a,b,c shows the distribution of the forest footprint around the world in 2014. From this perspective, we find a different landscape than the one discussed above when assessing the geographical distribution of the forestland harvests. Looking at the footprint, Asia shows the highest share of the total forest footprint (44%), followed by America (25%), Europe (21%), Africa (7%) and Oceania (2%).

Country-wise, half of the forestland footprint is concentrated in four countries: China (5.2 Mha, 24%), USA (3.6 Mha, 16%), India (1.1 Mha, 5%), and Russia (1 Mha, 5%). Three more countries have a forestland footprint of over 0.5 Mha: Japan (0.7 Mha), Germany (0.6 Mha), and Canada (0.6 Mha).

In per capita terms, despite the fact that on the one hand the comparison is probably fairer across countries in this form, it is also more subject to stressing outliers with negligible effects in the absolute values. In this sense, we exclude from the graph the very large (probably unrealistic) values found for some small countries, islands, etc. (e.g. Pitcairn Islands, Norfolk Island) with more uncertain values both in terms of forestland harvested and population. Fig. 5c shows the top 60 countries in terms of forest footprint per capita, representing 75% of the total forest area harvested worldwide. Within these countries, the top 25 countries (up to Russia) with the highest values represent 33% of the total of the total forest area harvested (then in absolute terms there are not very large footprints, until the 60th, China), standing out again the Baltic republics (Estonia, Latvia and, also now in the top 10, Lithuania), the Nordic ones (Finland, Sweden, Norway and also now Denmark), Canada and Oceania (Australia mainly, to a lesser extent New Zealand), while in general Latin-American ones appear with smaller footprints per capita than harvested (except for Paraguay, ranking 3rd here), in the same fashion than some cited African and European countries, ranking much higher now those with higher income per capita (Belgium-Luxembourg, Austria, Germany, the Netherlands, and interestingly also Poland). The USA now ranks 13th (vs. 19th in harvested per capita, above 10 ha/1000 people), Russia 25th (vs. 14th in harvested per capita), China 60th (vs. 67th in harvested per capita), Brazil 103th, Indonesia 134th, and India 166th. It is noteworthy how some of these last four large countries, with high figures in absolute terms, do have much smaller forest footprints in per capita terms than many developed countries.

Finally, we may highlight that for the year 2014, 51% of the global forestland footprint of wood products is linked to the extraction of coniferous, 27% to non-coniferous non-tropical, and the remaining 22% to of non-coniferous tropical. From a final product perspective, 32% of the forest footprint is linked to the demand of “Paper+-Board Ex Newsprint”, 26% to “Sawnwood, coniferous”, 16% to “Sawnwood, non-coniferous”, 11% to “Plywood” and 9% to “Fibreboard”.

In order to unveil the land use implications of international trade, i.e. the mismatch between forest product consumption and production, it is essential to understand the trade flows across the countries taking part in the global wood products supply chain. In the year 2014, more than 9.1 Mha of forest were harvested worldwide to satisfy the foreign demand of wood products (42% of the total forestland harvested area). In this regard, the analysis of forestland trade balances reveals that trade-related patterns are not equally distributed across the World. While some countries could be considered “land exporting countries” (or land self-sufficient), others could be categorized as “land importing” countries (or land dependent) in terms of forest. In 2014, Russia, Canada, Sweden, Finland, Australia, Brazil, Indonesia, and Thailand were the top net forestland exporters in the World. China, Japan, Germany, the UK and the USA were the top net importers (see Fig. 6).

A closest look at the forestland embodied in international trade, reveals that trade often occurs among nearby countries. For example, in 2014, China —the largest forestland importer in the World— mainly imported forestland from Russia, Canada, USA (these last two certainly cannot be called nearby China, but several others can be), Australia, Indonesia, and Thailand. Likewise, European countries (e.g. Germany, the UK, and Italy) mainly imported from other European nearby partners such as Russia, Sweden, or Finland. In the case of the USA, Canada was the main origin of its imports, while Japan mostly imported from Russia, Canada, the USA, and Australia. Fig. A2 provides this detail in the Appendix, while Fig. 7 below shows the main flows across continents, in which the largest flows occur from Europe and America to Asia, as well as interregional trade between European countries. Some flows from America to Europe are also relevant, as well as some of those between American countries (Canada to USA mainly) and among Asian ones (being relatively marginal the exports from Asia). Interestingly, a dominant role of Europe is much clearer in the bilateral trade of wood products (so the real physical trade flows, shown in Fig. A3 in the Appendix) than in the “forest harvested area” (the Fig. 7 below discussed).

The MRIO-forest can be also used to develop assessments at the regional level. We have illustrated this with the case study of the Southeast Asia’s Mekong region. More than 70 million people live in the Mekong area, where trees and forests have multiple benefits for people and biodiversity. Mekong basing countries signed in 2014 at the United Nations Climate Summit, the New York Declaration on Forests (NYDF) that is a voluntary and non-binding agreement to end deforestation globally by 2030. Since its inception, the NYDF has expanded to include more than 200 endorsers spanning national and subnational governments, non-governmental organizations, multinational corporations, and groups representing Indigenous peoples and local communities. The NYDF report published in 2020 (NYFD Report, 2020) concludes that the vast power disparity between large-scale actors like corporations and governments versus small-scale players like Indigenous peoples and local communities restricts fair and equitable development pathways. A recent pilot study that focused on the three main tropical basins, including the Mekong region by partners of the NYFD, found that, despite restauration taking place, there is an overall net loss of natural forest (2010–17 0.3 Mha net forest lost, with a gross loss of forest of 5.5 Mha) and the restauration is mostly taking place outside the forest (World Resources Institute WRI, 2019). This means that valuable natural and primary forests were lost, and restoration rates are not reaching levels to keep the overall forest area stable, the study also shows that rates of net deforestation are higher in Viet Nam (1.5%) and Lao (1.1%) followed by Cambodia (1%).

Our database shows that the total harvested forestland in the Mekong region reached 832,000 ha in 2014 and was distributed as follows: Thailand 54%; Myanmar 21%; Viet Nam 15%; Lao 10%; Cambodia 0.5% (Table 5, column (a)). Results also show that 467,000 ha (56%) of the forestland harvested in the Mekong region was devoted to satisfying the final use outside the region (Table 5, column (e)). The remaining 309,000 ha of forestland harvested (44%) was linked to the final demand within the region, of which 7% was embedded in intra-Mekong trade (Table 5, columns (d) and (f)), and 37% was linked to the final demand of the countries harvesting the resources (Table 5, column (c)).

The forestland footprint of the region reached 464,000 ha in 2014 with the following distribution: Thailand 41%; Viet Nam 36%; Myanmar 21%; Cambodia 1.0%; Lao 1.0% (Table 5, column (b)). Most of the forestland footprint of the Mekong area was satisfied with domestic resources (Table 5, column (c)), being the intra-regional (Table 5, column (f)) and the foreign imports (Table 5, column (g)) a small share of the total footprint.

When comparing the forestland harvested and the footprint of the

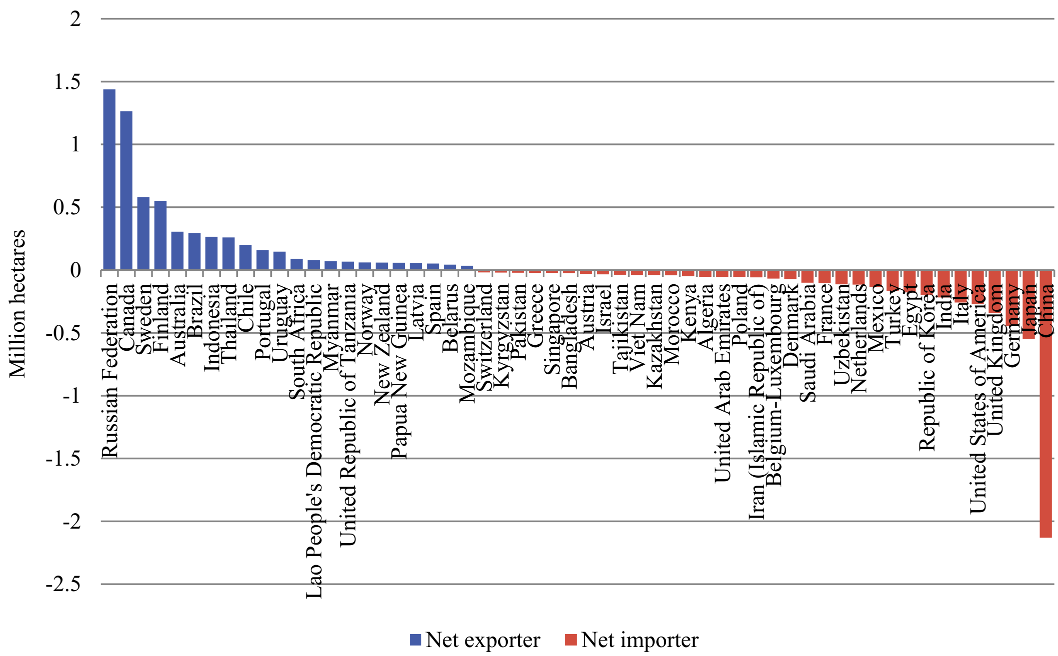

Fig. 6. Top net forestland exporting (blue) and importing (red) countries, 2014 (Million hectares).
Source: Own elaboration from FAOSTAT statistics. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

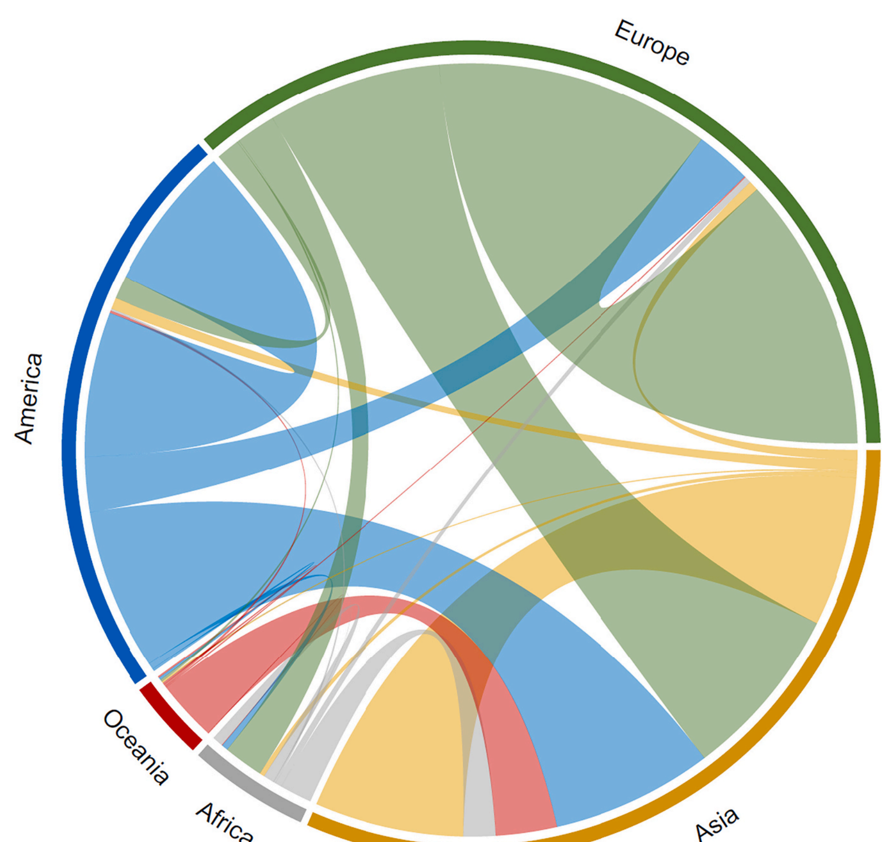

Fig. 7. Forestland embodied in bilateral trade (ha) flows between continents, 2014.
Note: The colour of the flow represents the exporting country (whose colour is given by the ribbon).
Source: Own elaboration from FAOSTAT statistics and Gu et al. (2014).

Table 5
Forest land harvested, forestland footprint and forestland embodied in trade flows, Mekong region, 2014 (hectares).

	Harvested (a)	Footprint (b)	Domestic (c)	Exports		Imports	
				Intra region (d)	Extra region (e)	Intra region (f)	Extra region (g)
Cambodia	3773	4747	1093	1168	1512	1450	2204
Lao	84,373	4862	4311	39,367	40,695	451	100
Myanmar	170,237	99,614	94,484	2013	73,740	1037	4092
Thailand	447,612	188,470	136,873	11,486	299,253	6449	45,147
Viet Nam	126,367	165,917	72,445	433	53,489	45,079	48,394
Total	**832,362**	**463,611**	**309,207**	**54,467**	**468,689**	**54,467**	**99,937**

Note: intra-region refers to trade flows between Mekong countries and extra-region refers to trade flows with countries outside the Mekong region.
Source: Own elaboration from FAOSTAT statistics.

	Viet Nam	Thailand	Myanmar	Cambodia	Lao	China	India	Republic of Korea	Japan	Iran	Indonesia	Malaysia
Thailand	8,695		1,014	1,338	439	179,370	4,200	21,597	19,482	12,940	11,138	8,575
Lao	34,968	4,381	4	14		35,836	227	866	851	20	21	199
Myanmar	261	1,735		16	2	19,161	49,472	169	332	175	61	659
Viet Nam		321	19	82	11	34,685	1,794	6,118	5,529	59	118	1,333
Cambodia	1,155	13	0	0	0	1,180	1	3	6	1	0	1
Indonesia	8,300	2,605	1,680	271	4							
United States of America	5,987	4,670	256	441	13							
Canada	2,560	5,861	554	162	22							
China	3,405	3,672	476	524	2							
South Africa	1,704	4,722	199	103	22							
Chile	2,515	3,904	119	69	14							
Russian Federation	2,941	2,805	233	92	6							
Australia	1,910	2,954	59	65	1							
Brazil	2,726	1,565	87	48	3							
Finland	2,253	1,760	30	31	2							
Sweden	889	2,801	67	170	2							
Malaysia	826	2,278	16	13	0							
Uruguay	1,782	335	62	19	0							
New Zealand	738	1,091	25	15	2							

Fig. 8. Top forestland exporting/importing flows, Mekong region, 2014 (hectares).
Source: Own elaboration from FAOSTAT statistics.

Mekong area, it can be observed that the region was, as a whole, self-sufficient. However, at the country level, while Lao, Myanmar, and Thailand were self-sufficient, Viet Nam and Cambodia were forestland-dependent. Fig. 8 shows the main forestland trade flows of the Mekong countries, both within and outside the region. As already mentioned, the intra-Mekong trade represents a small share of the total forestland embodied in the exports and imports of the Mekong (dark green and dark red areas in the lower charts of Fig. 8). Viet Nam was the main importer of the region, followed by Thailand and Myanmar. The main exporters were Thailand, Lao, and Myanmar. In terms of extra-Mekong exports, the main trade partner for most countries was China (in the case of Myanmar the main trade partner was India), followed by India, the Republic of Korea and Japan. In the case of imports, the main trade partners outside the Mekong region were Indonesia, the USA, and Canada.

4. Discussion

We have highlighted the relevant methodological contributions of the article, but it goes beyond that. This novel approach represents a powerful toolkit that can potentially be used for different purposes such as better understanding past, present, and future forest use; accounting for the environmental (land, water, carbon, etc.) footprint of wood products; or analysing the global supply chains of forest products at multiple levels (i.e. global, regional, national, commodity). This framework can also be used for scenario analysis and modelling purposes. In this regard, the results obtained through this methodological framework can provide relevant insights into how projected changes in social and/or economic conditions are likely to affect future land demand for forest products globally and on different countries or regions (e.g. in the context of Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services-IPBES and the United Nations Framework Convention on Climate Change-UNFCCC).

- Our database can be also used to inform how international trade could contribute to sustainable forestry and the preservation of World's forests through unilateral, bilateral and multilateral agreements/measures. For example, this information can be useful to support the introduction of sustainability standards in forest management, inform consumers on the environmental impacts of their consumption decision, analyse issues related to "impact-shifting" (i.e. prevention of wood extraction in some regions can shift lodging activities to other regions and cause deforestation) or study the drivers of forestland use from a global multiregional perspective.

Up to our knowledge, the closest exercise of this type has been done by Kastner et al. (2011a, 2011b). These authors follow a "process analysis" approach, inspired in the standard method of calculation of ecological footprints (Weinzettel et al., 2014) that is further explained on Kastner et al. (2011b). Despite the pioneering contribution of these authors, their approach can only give results at the apparent consumption level and, in contrast to MRIO approaches, can hardly deal with chains with multiple interconnections between inputs and outputs. In addition, in order to implement the approach suggested by Kastner et al. (2011b), a set of "Equivalence factors" for converting every processed product into primary products is required. As pointed by Kastner et al. (2011b: 1033), "*these conversion factors have to be chosen carefully to avoid double counting*". Conversely, our approach only requires a set of input rates (Table 1) and a matrix representing the flows of raw materials and intermediate products in the forest processing sector (Table 2). These two pieces of information are used to link production and trade data of primary, intermediate, and final products in a consistent way and guaranteeing no double-counting.

The method recently suggested by (O'Brien and Bringezu, 2018) to account for timber flows and footprint of the European Union, also represents a relevant contribution to the literature. This method is based on economy-wide material flow analysis (Schütz et al., 2003), which also combines the concept of apparent consumption and a set of factors to convert processed products into volume of primary equivalent. Although the method may have similar shortcomings to the ones pointed for Kastner et al. (2011b), it covers some key final products such as furniture. However, FAO database does not include information on furniture and, therefore, it is no possible to track the full supply chain of these products up to this point in our case.

Using monetary MRIO tables, or on the contrary physical supply chains or even a type of MRIO with physical data (as the MRIO-forest presented here) may imply trade-offs. On the one hand, the system boundaries are larger in the first case, reaching up to final products such as furniture. On the other hand, the product and country detail is typically larger in the second case, plus there is no interference of the monetary weights in the allocation of physical units. Using the example of China's trade in cropland products and embodied cropland, (Kastner et al., 2014) highlighted contradictory results from different approaches: analyses based on physical trade matrices showed that China is a major net importer of cropland products and embodied cropland, while MRIO- based results suggested exactly the opposite, apparently without finding convincing arguments that could explain these large differences.

We have explored how the results of the forest footprint of nations would be by using the vector of forestland harvested of our database in combination with the EXIOBASE monetary MRIO table (i.e. with more coverage of final products). We have compared the matrix of transactions of forestland (which elements represent the land harvested in country *i* that is embedded in the final demand of country *j*) and the footprint per capita. The results of Fig. 9 show that the matrices of transactions of forestland are quite different, with a similarity of just 64% according to the ρ-likelihood coefficient. The Standard deviation of the per capita footprint from EXIOBASE is almost three times greater than that from the MRIO-forest (18.5 vs. 6.5). In particular, EXIOBASE shows very high per capita footprints for wood exporting countries such as Finland (100.3 ha/ 1000 hab), Sweden (61.5) or Canada (44.5), compared with those resulting from our MRIO (25.5, 20.5 and 16.4 respectively).

According to (Hubacek and Feng, 2016) "the gap between physical trade flows and MRIO is largely due to the system boundary selection and truncation errors from the boundary cut-off. But, as indicated above, there are additional considerations and these two approaches should be used for different research purposes. When focusing on the flows of a particular product (especially a primary product such as rice, wheat or other grains) among countries, the higher level of detail of physical flow model is more suited. Whereas when accounting for the total embodied land in trade and consumption-based land use by recipient countries to analyse drivers of land use, MRIO may be more suitable.

Notwithstanding the important contributions of our novel approach, it is worth noting the limitations of this analysis, which could benefit from further research in order to reduce uncertainty. For example, in the case of FAOSTAT data, we found that some figures are kept fixed for several years or are not officially reported by countries but estimated. Various issues in the production and trade of wood products data of FAOSTAT in several countries have been found due to a lack of reliable official data from some regions (Kallio and Solberg, 2018). These authors found that if wood input coefficients and demand functions for forest industry products employed in a forest sector model are calibrated to match these data while ignoring the inconsistencies in the data, the model results are doomed to carry on these errors in projections of future supply, demand, and prices of forest products. Also, inconsistencies between the roundwood supply and its industrial use were found both in the form of deficits and surpluses of wood. Data problems related to relationships of reported regional wood supply versus wood needed by the industry were found. Kallio and Solberg also found in several countries too low wood supply with respect to the forest industry production or too high exports with respect to wood harvests Those inconsistencies in the data may refer to illegal logging and non-documented (illegal) imports of wood. In this regard, it would be desirable to find ways to deal with illegal harvest, which might be substantial in some countries. Illegal logging accounts for 50–90% of all forestry activities in key producer tropical forests, such as those of the Amazon Basin, Central Africa and Southeast Asia, and 15–30% of all

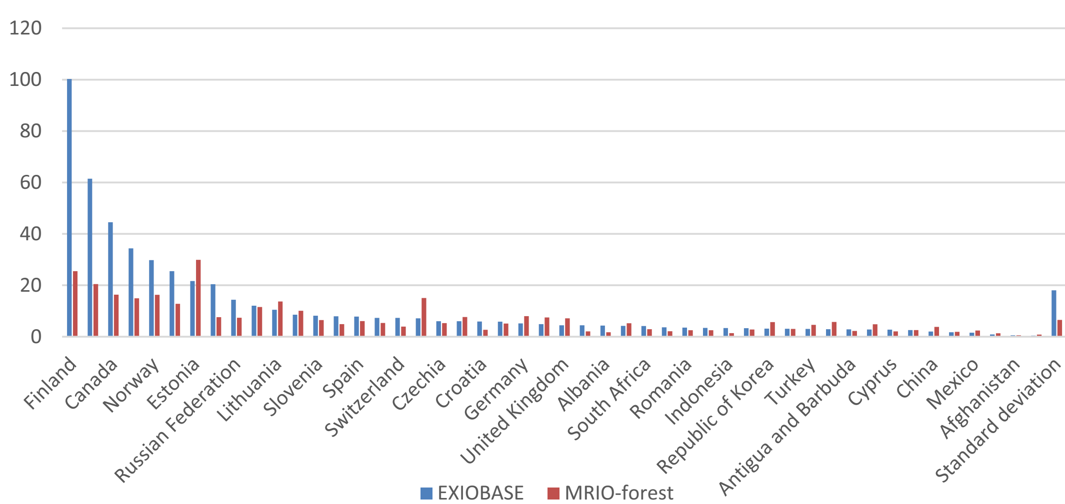

Fig. 9. Forestland footprint calculated with EXIOBASE in blue and the MRIO-forest in red per country, for the year 2014 in ha/1000 people.
Source: Own elaboration from FAOSTAT statistics, EXIOBASE (Stadler et al., 2016). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

wood traded globally. Since the 1950s, the vast tropical forests of Southeast Asia have been steadily depleted by a growing demand for wood in the giant economies of Japan, the United States, Europe, and China. Companies involved in commercial agricultural and hydroelectric dams in the region are facilitating the illegal trade of timber species such as red sandalwood, teak and rosewood through timber laundering. Money laundering, corruption, drug trafficking and other types of organized crime are proven to be linked with illegal logging operations in this region (INTERPOL, 2019).

Regarding the land accounts, there are also some uncertainties on the FHI used in our calculations (see Table 2 in Furukawa et al., 2015). Also the land use quantified in this study is not spatially explicit at a site level and, therefore, we are not able to link land use with land cover. Accordingly, it would be interesting to explore possible ways to link the type of data presented in this study with geospatial information.

We have already discussed that some choices had to be made regarding the reconciliation of bilateral. We have shown that this is not apparently a source of uncertainty. However, we think that it is necessary to further explore this issue and improve the reconciliation process. We have highlighted the important limitation of the data limits as regards supply chain coverage (closer boundaries than pure IO studies). This particularly affects the lack of traceability of the whole supply chain for some forest products such as furniture. In connection to the treatment of some finished products, further integration of the MRIO-forest with other global databases (e.g. detailed trade statistics and EXIOBASE) may be desirable to expand the boundaries of the system studied. This could be done by incorporating longer and additional supply chains that would allow for further tracking of forest-related products and footprints. Further research could be oriented then towards broadening the scope of the forest product coverage to furniture, packaging and other manufactured goods using wood products as intermediate input. In this regard and in line with the hybrid approach of Bruckner et al. (2019), it would be interesting to explore the possibility of merging the MRIO-forest with a monetary MRIO like EXIOBASE, in order to get the best from both worlds.

5. Conclusions

This paper shows a new accounting framework to improve our understanding of forest footprints of nations and global supply chains of forest products across multiple scales. On the one hand, we have developed a MRIO accounting framework to track resource flows of forest products worldwide and to link forestland harvested with extraction, transformation, and final use of forest products, taking into account international trade. On the other hand, we have shown how the combination of I-O techniques with the MRIO-forest database can be used to quantify the global forest land requirements embedded on the final uses of wood products of each country, including the land embedded in internationally traded goods (i.e. the so-called “forest footprint”). With this methodology we analyzed to what extent the demand for wood products of each country relay on forest areas located in other countries, and quantified the amount of land devoted in each country to satisfy domestic and foreign demands.

We have illustrated the usefulness of the MRIO-forest database to assess the forest footprint of nations and the forestland embodied in traded products. The results show that harvested forestland is concentrated in America (32% out of 22 Mha of forestland harvested worldwide), followed by Asia (29%), Europe (28%), Africa (7%) and Oceania (4%). At the country level, more than 50% of the reported forest area harvested worldwide is located in just four countries (USA 15% of total; China 14%; Russia 11% and Canada 8%) (see Fig. 4). In terms of forest footprint (Fig. 5), Asia shows the highest share of the total forest footprint (44%), followed by America (25%), Europe (21%), Africa (7%) and Oceania (2%). Country-wise, half of the forestland footprint is concentrated in four countries: China (5.2 Mha, 24%), USA (3.6 Mha, 16%), India (1.1 Mha, 5%), and Russia (1 Mha, 5%). These differences between harvested forest area and footprints can be explained looking at the forestland embodied in international trade which often occurs across nearby countries (e.g. China and Russia; Australia, Indonesia and Thailand; EU countries and, USA and Canada, among others).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

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Appendix A. Annex

Table A1
Forest harvest index for industrial roundwood (RW) and wood fuel (WF) (m^3 ha^{-1} yr^{-1}).

	RW	WF		RW	WF		RW	WF
Afghanistan	0.086	0.088	French Polynesia	0.015	0.034	Pakistan	0.014	0.021
Albania	0.014	0.014	Gabon	0.020	0.071	Palau	0.015	0.034
Algeria	0.018	0.017	Gambia	0.034	0.091	Panama	0.006	0.017
American Samoa	0.015	0.034	Georgia	0.011	0.011	Papua New Guinea	0.015	0.034
Andorra	0.011	0.011	Germany	0.004	0.004	Paraguay	0.037	0.100
Angola	0.033	0.088	Ghana	0.022	0.059	Peru	0.011	0.028
Anguilla	0.008	0.025	Gibraltar	0.011	0.011	Philippines	0.007	0.019
Antigua and Barbuda	0.008	0.025	Greece	0.028	0.029	Pitcairn Islands	0.015	0.034
Argentina	0.014	0.021	Greenland	0.010	0.010	Poland	0.007	0.007
Armenia	0.032	0.022	Grenada	0.008	0.025	Portugal	0.024	0.024
Aruba	0.008	0.025	Guadeloupe	0.008	0.025	Puerto Rico	0.008	0.025

(continued on next page)

Table A1 (*continued*)

	RW	WF		RW	WF		RW	WF
Australia	0.024	0.045	Guam	0.015	0.034	Qatar	0.032	0.022
Austria	0.005	0.005	Guatemala	0.008	0.013	Reunion	0.020	0.071
Azerbaijan	0.010	0.010	Guinea	0.016	0.044	Republic of Korea	0.019	0.019
Bahamas	0.100	0.262	Guinea-Bissau	0.042	0.113	Republic of Moldova	0.011	0.011
Bahrain	0.032	0.022	Guyana	0.009	0.023	Romania	0.006	0.007
Bangladesh	0.026	0.070	Haiti	0.020	0.050	Russian Federation	0.013	0.013
Barbados	0.008	0.025	Holy See	0.011	0.011	Rwanda	0.010	0.026
Belarus	0.008	0.008	Honduras	0.011	0.022	Saint Helena	0.020	0.071
Belgium	0.006	0.006	Hungary	0.008	0.008	Saint Kitts and Nevis	0.008	0.025
Belgium-Luxembourg	0.011	0.011	Iceland	0.011	0.011	Saint Lucia	0.008	0.025
Belize	0.008	0.021	India	0.018	0.044	Saint Pierre and Miquelon	0.010	0.010
Benin	0.036	0.096	Indonesia	0.010	0.026	Saint Vincent	0.008	0.025
Bermuda	0.010	0.010	Iran	0.030	0.030	Saint-Martin	0.008	0.025
Bhutan	0.007	0.009	Iraq	0.048	0.048	Samoa	0.015	0.034
Bolivia (Plurinational State of)	0.017	0.046	Ireland	0.012	0.013	San Marino	0.011	0.011
Bosnia and Herzegovina	0.008	0.009	Isle of Man	0.011	0.011	Sao Tome and Principe	0.008	0.020
Botswana	0.020	0.071	Israel	0.036	0.036	Saudi Arabia	0.032	0.022
Brazil	0.005	0.013	Italy	0.010	0.010	Senegal	0.034	0.091
British Indian Ocean Territory	0.020	0.071	Jamaica	0.008	0.022	Serbia	0.011	0.011
British Virgin Islands	0.008	0.025	Japan	0.008	0.009	Serbia and Montenegro	0.011	0.011
Brunei Darussalam	0.007	0.018	Jordan	0.047	0.047	Seychelles	0.020	0.071
Bulgaria	0.009	0.009	Kazakhstan	0.012	0.012	Sierra Leone	0.032	0.085
Burkina Faso	0.030	0.081	Kenya	0.007	0.018	Singapore	0.015	0.034
Burundi	0.011	0.029	Kiribati	0.015	0.034	Slovakia	0.005	0.005
Cabo Verde	0.020	0.071	Kuwait	0.032	0.022	Slovenia	0.005	0.005
Cambodia	0.013	0.035	Kyrgyzstan	0.042	0.042	Solomon Islands	0.014	0.036
Cameroon	0.004	0.011	Lao PRD	0.021	0.057	Somalia	0.051	0.136
Canada	0.013	0.013	Latvia	0.008	0.008	South Africa	0.018	0.038
Cayman Islands	0.008	0.025	Lebanon	0.036	0.038	South Sudan	0.020	0.071
Central African Republic	0.008	0.020	Lesotho	0.020	0.071	Spain	0.027	0.028
Chad	0.070	0.186	Liberia	0.008	0.022	Sri Lanka	0.058	0.153
Channel Islands	0.011	0.011	Libya	0.039	0.039	Sudan	0.032	0.022
Chile	0.007	0.007	Liechtenstein	0.011	0.011	Sudan (former)	0.032	0.022
China	0.019	0.025	Lithuania	0.006	0.006	Suriname	0.006	0.015
China, Hong Kong SAR	0.015	0.034	Luxembourg	0.011	0.011	Svalbard and Jan Mayen	0.011	0.011
China, Macao SAR	0.015	0.034	Madagascar	0.008	0.020	Swaziland	0.020	0.071
China, mainland	0.015	0.034	Malawi	0.012	0.031	Sweden	0.012	0.012
China, Taiwan Province of	0.015	0.034	Malaysia	0.006	0.016	Switzerland	0.004	0.004
Christmas Island	0.015	0.034	Maldives	0.022	0.045	Syrian Arab Republic	0.047	0.045
Cocos (Keeling) Islands	0.015	0.034	Mali	0.065	0.172	Tajikistan	0.011	0.011
Colombia	0.009	0.021	Malta	0.011	0.011	Thailand	0.031	0.082
Comoros	0.020	0.071	Marshall Islands	0.015	0.034	The former Yugoslav RoM	0.011	0.011
Congo	0.006	0.017	Martinique	0.008	0.025	Timor-Leste	0.015	0.034
Cook Islands	0.015	0.034	Mauritania	0.064	0.170	Togo	0.014	0.037
Costa Rica	0.012	0.033	Mauritius	0.020	0.071	Tokelau	0.015	0.034
Côte d'Ivoire	0.005	0.013	Mayotte	0.020	0.071	Tonga	0.015	0.034
Croatia	0.007	0.007	Mexico	0.029	0.062	Trinidad and Tobago	0.012	0.032
Cuba	0.015	0.039	Micronesia	0.015	0.034	Tunisia	0.053	0.053
Curacao	0.008	0.025	Monaco	0.011	0.011	Turkey	0.010	0.010
Cyprus	0.028	0.028	Mongolia	0.010	0.010	Turkmenistan	0.011	0.011
Czech Republic	0.005	0.005	Montenegro	0.011	0.011	Turks and Caicos Islands	0.008	0.025
Czechoslovakia	0.011	0.011	Montserrat	0.008	0.025	Tuvalu	0.015	0.034
DPR Korea	0.021	0.021	Morocco	0.037	0.038	Uganda	0.029	0.078
DR Congo	0.006	0.015	Mozambique	0.035	0.094	Ukraine	0.007	0.007
Denmark	0.008	0.008	Myanmar	0.028	0.075	United Arab Emirates	0.032	0.022
Djibouti	0.020	0.071	Namibia	0.020	0.071	United Kingdom	0.011	0.012
Dominica	0.008	0.025	Nauru	0.015	0.034	United Republic of Tanzania	0.035	0.092
Dominican Republic	0.021	0.055	Nepal	0.007	0.015	United States of America	0.009	0.010
Ecuador	0.011	0.025	Netherlands	0.008	0.008	United States Virgin Islands	0.008	0.025
Egypt	0.012	0.012	Netherlands Antilles	0.008	0.025	Uruguay	0.017	0.044
El Salvador	0.006	0.015	New Caledonia	0.020	0.053	USSR	0.011	0.011
Equatorial Guinea	0.020	0.071	New Zealand	0.003	0.034	Uzbekistan	0.223	0.224
Eritrea	0.055	0.148	Nicaragua	0.009	0.021	Vanuatu	0.015	0.034
Estonia	0.007	0.007	Niger	0.122	0.325	Venezuela	0.010	0.025
Ethiopia	0.058	0.147	Nigeria	0.010	0.028	Viet Nam	0.019	0.051
Ethiopia PDR	0.020	0.071	Niue	0.015	0.034	Wake Island	0.015	0.034
Falkland Islands (Malvinas)	0.008	0.025	Norfolk Island	0.015	0.034	Wallis and Futuna Islands	0.015	0.034
Faroe Islands	0.011	0.011	Northern Mariana Islands	0.015	0.034	Western Sahara	0.032	0.022
Fiji	0.015	0.034	Norway	0.015	0.015	Yemen	0.032	0.022
Finland	0.014	0.014	Occupied Palestinian T.	0.032	0.022	Yugoslav SFR	0.011	0.011
France	0.009	0.011	Oman	0.032	0.022	Zambia	0.023	0.061
French Guiana	0.008	0.025	Pacific Islands Trust Territory	0.015	0.034	Zimbabwe	0.034	0.089

Source: own elaboration based on (Furukawa et al., 2015).

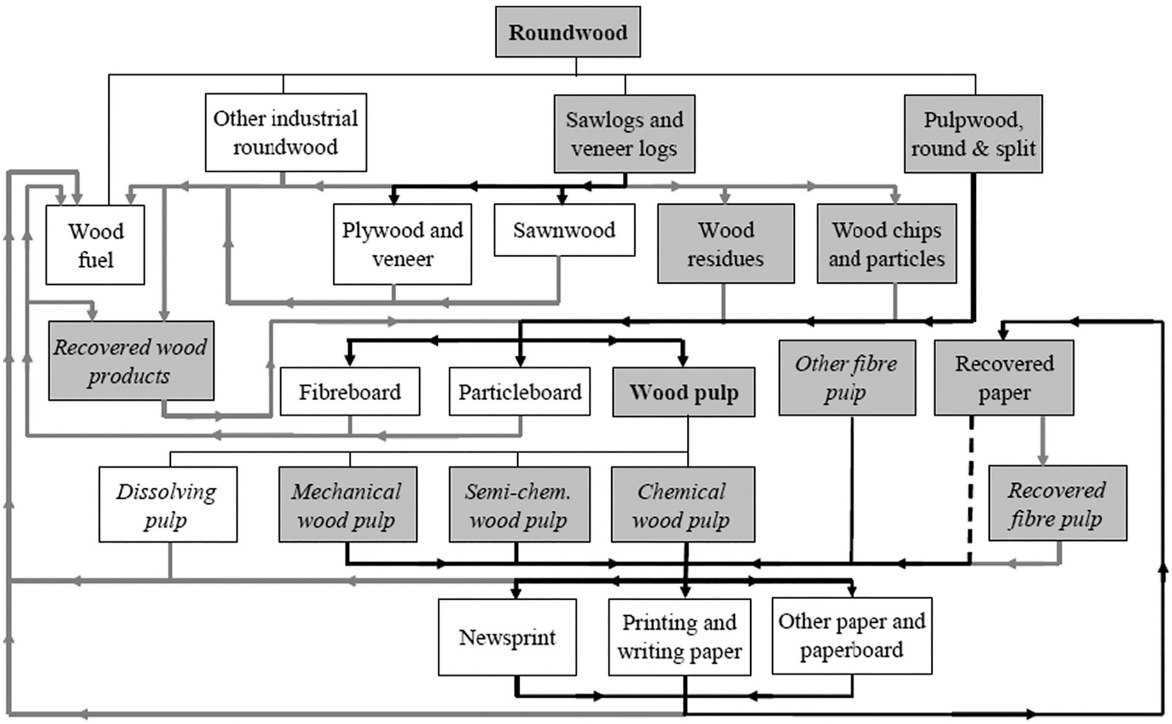

Fig. A1. The flow of raw materials and intermediate products in the forest processing sector.
Note: raw materials and intermediate products are shown in shaded boxes. The thin lines represent disaggregation of a broader product category (shown in bold) into its components (e.g. wood pulp is further subdivided into four different types of wood pulp). The thick lines represent flows of materials through the system. The black lines represent flows where data is readily available, while the grey lines represent flows where information is less reliable. Product categories shown in italics are products that will not be included in the analysis due to lack of information or their relatively low importance. The flow of recovered paper back into the papermaking process is shown as a broken line, because this product is not used directly in the production of paper, but the statistics on recovered fibre pulp production are weak. It should also be noted that all of these products are traded internationally and that the flows into each box reflect the production of each product, while the flows out of each box represent consumption of each product. Thus, for example, it is possible for a country that imports a lot of paper, to produce more recovered paper than original paper production in that country.
Source: Fig. 27 in UNECE and FAO (2005: 43).

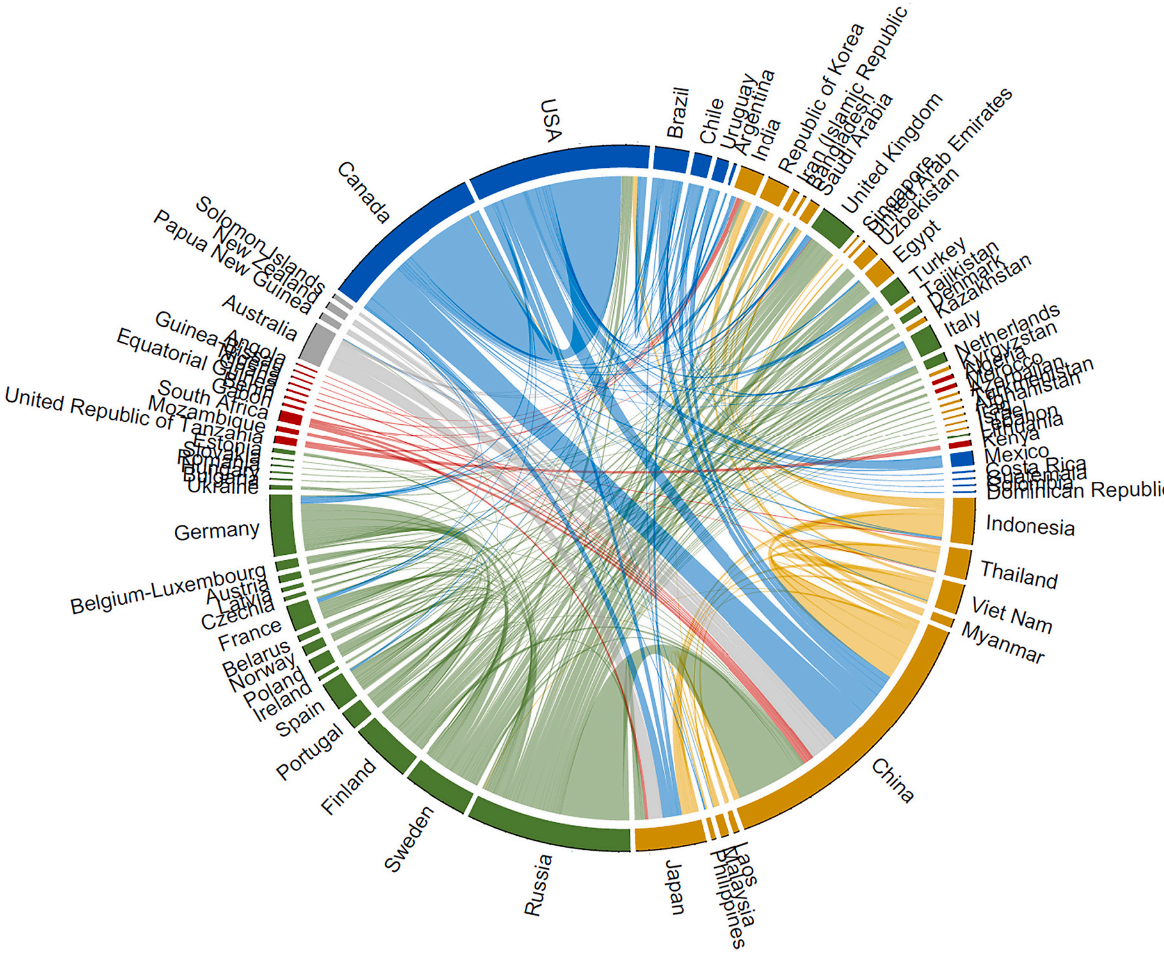

Fig. A2. Forestland embodied in bilateral trade (ha) flows between countries, 2014.
Source: Own elaboration from FAOSTAT statistics and Gu et al. (2014).

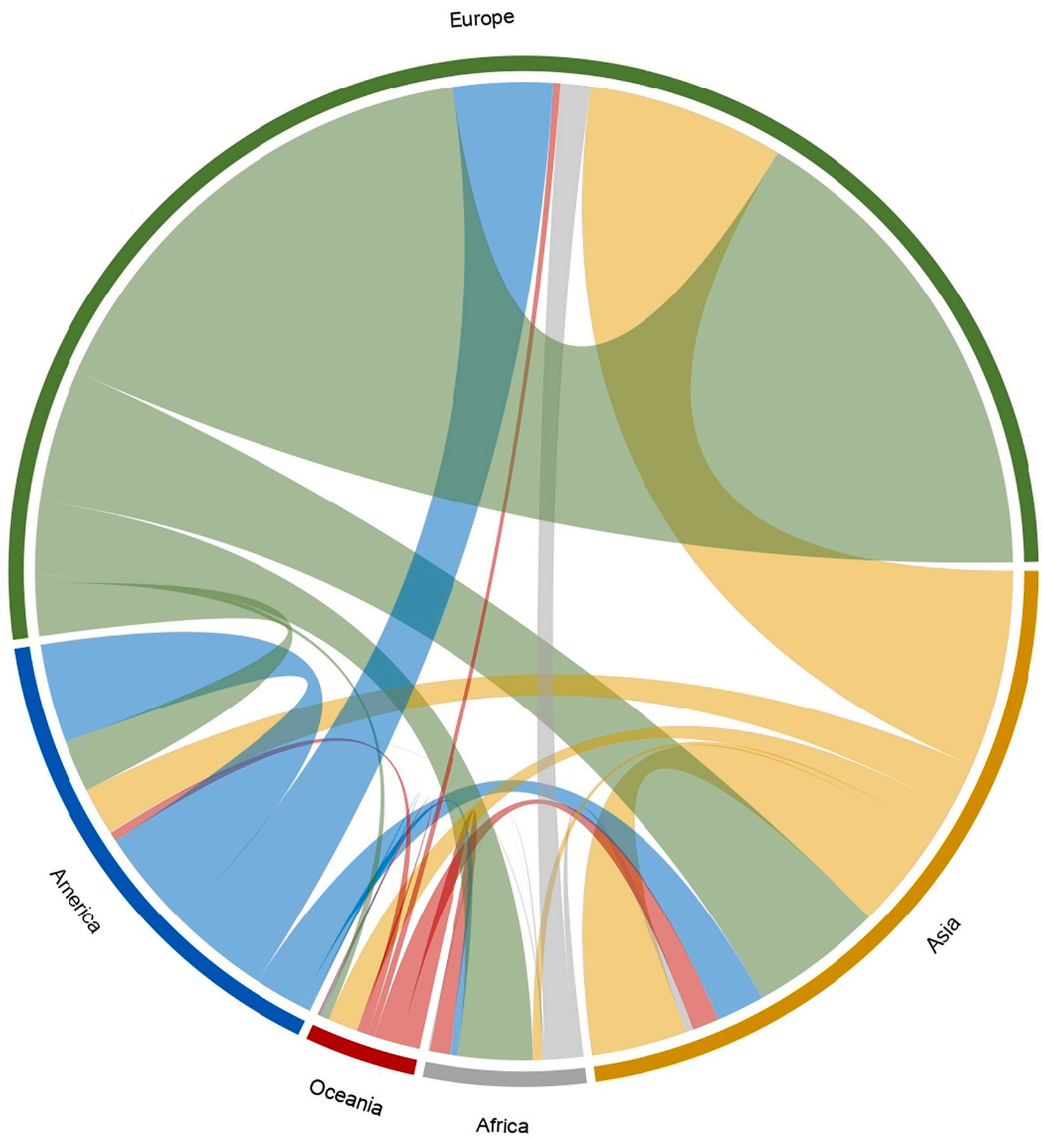

Fig. A3. Bilateral trade flows (tons) between continents, 2014.
Source: Own elaboration from FAOSTAT statistics and Gu et al. (2014).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2021.107337.

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