

# Rise (and Fall?) of China's Demand for Imported Timber: A Network Analysis of the International Roundwood Trade

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## Abstract

The international trade of wood products is an increasingly complex and interdependent component of the global economy, deeply linked to environmental issues, geopolitical shifts, changing competitive landscape, and macroeconomic trends. While the literature offers comprehensive studies on the international timber trade, few to date consider the physical structure of the trade network in their analyses, leaving its structural evolution poorly understood. To address this gap, we employ a network-theoretic approach to model global roundwood trade flows between countries, providing a unique diagnosis of the trade's key structural properties and their temporal evolution from 1996 to 2023. The analysis reveals that the network has developed short-term resilience while becoming consistently more interconnected and structurally concentrated over the long term. Crucially, the structure is highly polarized around China's market dominance, which rapidly grew to concentrate over 56% of total trade value by 2021, due to its import demand. This centralization, coupled with the structural withdrawal of major exporter Russia, created a single point of vulnerability in the global supply chain. The recent decline in China's contribution post-2021—a result of geopolitical shocks, domestic self-sufficiency policies, and structural economic shifts—signals a fundamental shift in the international roundwood trade. These findings underscore the need for exporters to implement market diversification strategies to mitigate policy risks in the global roundwood value chain.

*Keywords:* Globalization, Trade, Wood products, Network theory, Structural resilience, Market concentration, Forest policy

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## 1. Introduction

The international wood products trade stands as an increasingly complex and interdependent component of the global economy, intricately tied to environmental concerns, geopolitical shifts, evolving competition

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schemes, and macroeconomic trends. The uneven global distribution of forest resources, concentrated in a few countries (*e.g.*, Russia, Brazil, Canada, the United States, and China) (FAO, 2024b), necessitates international trade to balance supply and demand to satisfy domestic consumption (Long et al., 2019; Huang et al., 2024).

The 21st century has witnessed significant acceleration in international wood product trade, driven by convergent economic and technological determinants. Primary drivers include sustained global economic growth, escalating demand for construction materials fueled by urbanization, trade liberalization, and technological innovations enhancing forestry value chain operational efficiency<sup>1</sup> (Prestemon et al., 2003; UNECE/FAO, 2022b). Furthermore, global value chains (GVC) proliferation has restructured production paradigms through the spatial fragmentation of manufacturing processes, leading to new market dynamics and more complex supply chain configurations (Amador and Cabral, 2017).

This trade intensification has precipitated systematic displacement of deforestation pressures, characterized by distinct geographic redistribution patterns. Resource accumulation occurs in nations with predominantly non-indigenous, plantation-based forest systems — typically developed economies with established silviculture infrastructure — while simultaneously exerting extractive pressure on regions where indigenous forest ecosystems face depletion, predominantly within developing nations (Prestemon et al., 2003; Leblois et al., 2017; Pendrill et al., 2019; Abman and Lundberg, 2020). This spatial divergence highlights how trade-mediated demand drives forest degradation. In particular, illegal logging and associated trade represent significant drivers of deforestation and forest degradation globally, exacerbating climate change (Lawson and MacFaul, 2010).<sup>2</sup>

This acceleration of the international wood trade has also coincided with growing environmental consciousness and a rising preference for “green” materials with carbon storage capacity, driven by climate change mitigation goals, leading to various environmental regulations and sustainability initiatives (Prestemon et al., 2003). The emerging forest-based bioeconomy, exemplified by strategies like the European Bioeconomy Strategy, aims to replace non-renewable resources with high-value-added products from woody biomass (Wolfslehner et al., 2016; Winkel and European Forest Institute, 2017). This creates a paradox: while increased wood demand can support decarbonization and sustainable development, unsustainable and illegally sourcing risks exacerbating deforestation and forest degradation. Consequently, market-based tools like forest certification schemes<sup>3</sup>

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<sup>1</sup>These innovations encompass advancements in plantation management systems, forest harvesting operations, and manufacturing processes.

<sup>2</sup>Illegal logging and its associated trade also extensively contribute to wider environmental damage, such as global anthropogenic carbon dioxide emissions, loss of biodiversity, deprive governments of billions of dollars in vital revenues, foster corruption, undermine the rule of law, and can fuel conflict (Lawson and MacFaul, 2010).

<sup>3</sup>Such as the Forest Stewardship Council (FSC) and the Program for the Endorsement of Forest Certification (PEFC).

promote sustainable practices, sometimes restricting wood products trade (Guan and Ip Ping Sheong, 2019; Chen et al., 2020; Boubacar and Sissoko, 2025). Furthermore, timber trade regulations, primarily enforced by developed countries, aim to exclude illegal timber from domestic markets, hindering trade volumes (Moral-Pajares et al., 2020; Rougieux and Jonsson, 2021; Apeti and N'Doua, 2023; Kim et al., 2024).<sup>4</sup>

While tariff barriers have declined due to international trade agreements, these trade regulations demonstrate that non-tariff barriers (NTBs) increasingly influence wood product trade (UNECE/FAO, 2022b). NTBs include quotas, embargoes, economic sanctions, export bans, stringent environmental policies, and phytosanitary controls (Li et al., 2007; Sun et al., 2010; Buongiorno and Johnston, 2018; UNECE/FAO, 2022a; FAO, 2024a). Notable trade disputes over wood products, such as those between China and the U.S. (Muhammad and Jones, 2021; Pan et al., 2021), Russian roundwood export restrictions (Turner et al., 2008; Solberg et al., 2010; Lin and Zhang, 2017; Guan and Yang, 2024), and the Canada-U.S. softwood lumber dispute (Van Kooten and Johnston, 2014; Johnston and Van Kooten, 2017), underscore a tension between free trade principles and national policy objectives. Such measures, while often aiming for sustainability or industry protection, can disrupt trade, raise prices, and shift production and consumption patterns.

In recent years, significant economic and geopolitical disruptions have affected the global supply chain for wood products, leading to volatility in timber prices and shipping costs (FAO, 2024a; UNECE/FAO, 2022a). The COVID-19 pandemic initially introduced considerable uncertainty into forest product markets but was swiftly followed by a robust economic rebound in 2021, indicating strong underlying demand and inherent resilience (UNECE/FAO, 2022a). However, the war in Ukraine from mid-2022 exacerbated supply chain disruptions, intensified inflation, and eroded consumer confidence, leading to a demand decline (UNECE/FAO, 2022a). Climate change impact on forests ecosystems worsens such instability, increasing the frequency and severity of natural disturbances like storms, wildfires, and pest outbreaks (Seidl et al., 2011; Seidl and Rammer, 2017; Curtis et al., 2018; Tyukavina et al., 2022; Patacca et al., 2023), directly disrupting timber supply chains and market stability and deteriorating wood quality (García-Jácome et al., 2025). This apparent vulnerability to external shocks suggests that trade resilience is not absolute but contingent on global economic, environmental, and political stability (García-Jácome et al., 2025; Ma et al., 2025).

Understanding the intricate web of these relationships and trade flows is paramount for policy formulation and strategic planning. The literature extensively studies the international timber market and trade, spanning from global to subnational scales and various wood products (*e.g.*, Müller et al., 2004; Raunikar et al., 2010; Caurla et al., 2013; Van Kooten and Johnston, 2014; Buongiorno, 2015; Rougieux, 2017; Rougieux and

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<sup>4</sup>Examples are the European Union's Action Plan for Forest Law Enforcement, Governance and Trade (FLEGT), the European Union Timber Regulation (EUTR), the US Lacey Act, the Australia Illegal Logging Prohibition Act, or the Japan Clean Wood Act.

Jonsson, 2021; Shen and Lovrić, 2022). These studies employ three primary perspectives: trade mechanism analysis, forecasting, and policy analysis (Buongiorno, 2016; Rivière and Caurla, 2020; Mathieu and Roda, 2023).

Overall, the literature on international wood trade draws on models. Traditional approaches, primarily forest sector models and econometric models (including gravity models) rooted in economic theory (Buongiorno, 1996; Kallio et al., 2004; Latta et al., 2013; Northway et al., 2013; Buongiorno, 2015), rely on nationally reported data and treat countries as the main unit of analysis, focusing on discrete bilateral trade relationships (Amador and Cabral, 2017; Shen and Lovrić, 2022).

However, these approaches face significant limitations in accounting for multilateral network effects, indirect trade linkages, and cascading interdependencies inherent in modern international trade and contemporary global value chain structures (De Benedictis and Tajoli, 2011; Amador and Cabral, 2017; Liu et al., 2025). Consequently, traditional approaches offer limited structural insights and may systematically underestimate critical systemic vulnerabilities such as supply chain fragility, contagion effects, and network resilience, while simultaneously overlooking strategic opportunities revealed by comprehensive network topology analysis (Fèvre et al., 2006; Huang et al., 2024). Furthermore, the existing literature exhibits considerable heterogeneity in analytical frameworks, temporal specifications, and spatial delimitations, hindering systematic meta-analysis and comprehensive understanding of global trade network dynamics.

We address this gap by adopting a network theoretic approach that considers the trade flows between countries as the unit of analysis (De Benedictis and Tajoli, 2011; Amador and Cabral, 2017). This perspective offers a deeper, holistic view of wood product trade inherent structure, providing insights into its underlying organization and evolution (Long et al., 2019; Shen and Lovrić, 2022). Indeed, network analysis has been a powerful tool for studying complex global interactions.<sup>5</sup>

Network analysis has significantly advanced the understanding of global wood forest product trade dynamics, moving beyond traditional economic models to reveal structural characteristics, intricate relationships, competitive dynamics, evolutionary trends, network resilience to external shocks, and vulnerabilities (Lovrić et al., 2018; Long et al., 2019; Gao et al., 2024; Huang et al., 2024). Previous research indicates these trade networks have significantly evolved and expanded in the 21st century, showing increased complexity and interdependence, broader participation, and enhanced overall trade efficiency and resilience (Wang et al., 2020; Gao et al., 2024; Huang et al., 2024; Liu et al., 2024). While network density remains stable, average trade value has risen (Zhou et al., 2021).

Network analysis has also identified key players and their evolving roles. Historically, North American and

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<sup>5</sup>See, for example, (Fèvre et al., 2006), who construct networks of the live animal trade to explain the spread of disease.

European countries were central, but emerging economies like China have become dominant importers and increasingly central players across the supply chain, with their influence growing annually (Zhou et al., 2021; Gao et al., 2024; Huang et al., 2024; Liu et al., 2024). Russia and Canada remain major timber exporters, and New Zealand is a significant raw material exporter (Zhou et al., 2021). Despite dynamic changes, these networks maintain a relatively stable core-periphery structure, with China and India now prominent in the core (Wang et al., 2020). While core countries boost network resilience, their dominance introduces vulnerabilities (Huang et al., 2024).

Beyond structural descriptions, the literature has also investigated factors influencing network evolution, including economic scale, geographical distance, cultural differences, and forest resource endowment (Gao et al., 2024), internal trade effects (reciprocity and transitivity) (Shen and Lovrić, 2022), and policy changes (Huang et al., 2024).

Current research on forest product trade networks, while foundational, needs deeper methodological and empirical exploration. Most studies take a broad, macroscopic view, often combining different wood product types, potentially distorting network understanding and leading to less effective trade policies (Gao et al., 2024; Liu et al., 2024). A significant gap exists in comprehensively characterizing the structure and temporal evolution of international roundwood trade networks. This gap is critical because roundwood — unprocessed timber directly harvested from forests — represents the primary commodity in global forest product supply chains, directly linked to sustainable forest management and deforestation issues. As the second most traded wood product by volume over the last decade,<sup>6</sup> roundwood forms the foundational stratum of international forest product trade, linking forest resource extraction with processing industries through complex international trade relationships. The lack of detailed analysis on roundwood trade patterns, both structurally and over time, is a major gap in forest economics research, limiting policy insights for sustainable forest governance.

The present work addresses this gap through a comprehensive network analysis of global roundwood trade dynamics spanning the period 1996–2023. First, we conduct a multidimensional network topology analysis using complementary quantitative metrics to systematically characterize roundwood trade network structural properties and their temporal evolution. This employs graph theory-based methodologies alongside traditional trade analysis metrics for comprehensive structural characterization. Second, we use information of past market behaviour to explain changes in network structure. We hypothesise that global roundwood trade networks demonstrate systematic concentration in exports (due to concentrated forest endowments) while exhibiting structural sensitivity to exogenous disruption events, including economic crises, geopolitical instabilities, and natural disasters. This hypothesis framework incorporates three propositions: (1) network

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<sup>6</sup>According to FAOSTAT data.

concentration in exports remains moderately high over the study period; (2) trade network demonstrates systematic vulnerability to major disruption events; and (3) trade network demonstrates short-term structural recovery patterns following disruption events.

## 2. Material and methods

### 2.1. Bilateral trade data collection

We extracted trade data from the UN Comtrade database in Python 3.12.2 using the Python package “comtradeapicall” 1.2.1 ([untradestats, 2024](#)).<sup>7</sup> The UN Comtrade data provides detailed information on bilateral trade flows by recording the trade reports from more than 200 countries. National statistical reports of trade may be produced on an annual or monthly basis. They cover a wide range of traded commodities, including wood products. Traded commodities are commonly classified under the Harmonized System (HS) nomenclature ([World Customs Organization, 1983](#)). The HS nomenclature encodes each commodity under a 6-digit code, classifying them into chapters (2 digits), headings (4 digits), and subheadings (6 digits). Each trade flow is described through a set of information, including:

- the reporter, *i.e.*, the country that reports the trade flow;
- the partner, *i.e.*, the country with which the reporter trades;
- the period of reporting, *i.e.*, year of trade and, if reported monthly, month of trade;
- the type of trade flow, *i.e.*, import, export, re-import, re-export
- the product HS code and description
- the trade flow’s net weight and traded value (in current US dollars)

Since its creation, the HS nomenclature has been updated approximately every five years. It currently comprises six editions (1996, 2002, 2007, 2012, 2017 and 2022). Each update to the HS nomenclature may result in changes to commodity codes. For instance, new products may be added, some products may be removed due to, for example, low trade volume, or a product may be specified more precisely and divided into several products.<sup>8</sup> Although there are corresponding tables between different editions of the HS nomenclature, tracking its evolution is difficult, and changes in product nomenclature can result in gaps in time series.

Furthermore, although the HS nomenclature provides a common language for trade in all commodities between more than 200 countries, it can lack relevance to industry sectors. Wood products, for example, may

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<sup>7</sup>The Python package “comtradeapicall” extracts and downloads UN Comtrade data through API calls.

<sup>8</sup>For instance, between the 2007 and the 2012 HS nomenclature editions, the product “Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms” (code 440130) was subdivided into “Wood pellets” (code 440131) and “Other sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms” (code 440139).

be grouped together with bamboo materials or plastic furniture in a single chapter. To ensure consistency, we base our extraction on the sector-specific 2022 FAO Classification of Forest Products (FAO, 2022), which provides corresponding tables between the FAO classification and the 2017 and 2022 HS nomenclatures. We extract the corresponding HS product codes for FAO code 012, “Wood in the rough other than wood fuel” (hereafter referred to as “roundwood”), and we ensure consistency between different HS codes across the successive editions of the HS nomenclature.<sup>9</sup> The correspondence between FAO product code 012 and HS product codes across successive HS nomenclature editions is provided in supplementary material X. All trade flows are then aggregated by FAO product code, enabling the analysis to focus on roundwood trade flows as defined by the FAO’s Classification of Forest Products. This approach ensures the sectorial relevance and continuity of the time series for the analysis.

As country reports in the UN Comtrade database can be updated or corrected within two years, we collect trade data from 1996 to 2023 to base our analysis on consolidated data. We only extract data on imports and exports. We also remove poorly specified trade flows, *e.g.*, those with a “non-elsewhere specified” (NES) partners. Finally, to reduce the noise in the data and remove unrealistic trade flows,<sup>10</sup> we remove the 5% of trade flows with the lowest net weight or value from the dataset.

## 2.2. Trade network building from bilateral trade data

Based on this data, we define the roundwood trade network for each year by computing edge lists. In network theory, an edge list is a mathematical representation of a network, which is made up of nodes (*e.g.*, countries, individuals, or entities such as banks or websites) and edges or vertices (*e.g.*, the movement of goods or people between countries, physical interactions between people, or the exchange of information or money) (Albert and Barabási, 2002; Newman, 2003). An example of an edge list for a simple network is provided in Figure 1. In our case, the edge lists are  $N \times 2$  matrices that correspond to a roundwood trade network with  $N$  edges in year  $t$ . Each edge represents a trade flow (either export or import) between nodes (countries), from the country of origin (*i.e.*, the exporter, indexed  $o$ ), to the country of destination, (*i.e.*, the importer, indexed  $d$ ), in year  $t \in 1996, 1998, \dots, 2023$ . The elements of the edge list are nodes that represent countries that engaged in either the export or import of roundwood, in a given year  $t$ .

We take the roundwood trade network for each year of the data as a weighted and directed network, *i.e.*, we consider whether or not two countries are connected by trade, the direction of the trade flows, and the “weight” (or quantity/value) of the trade flows. In our case, we consider the traded value to be the “weight” of the trade flow. This is in contrast to using the net weight in metric tons, which is not an appropriate

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<sup>9</sup>Data were extracted on October 2025.

<sup>10</sup>For example, unrealistic trade flows typically correspond to trade flows with a net weight of a few kilograms.

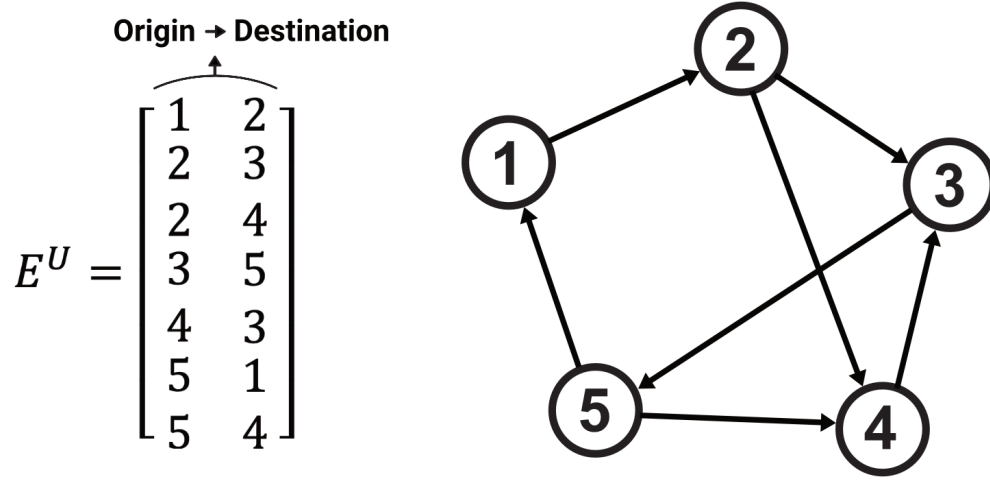


Figure 1: Illustration of an edge list,  $E^U$ , and its corresponding network graph for an *unweighted* and *directed* network of 5 nodes. In the edge list, each row corresponds to an edge from an origin (first column) to a destination (second column). In the network graph, circles indicate nodes and arrows the edges between them.

unit of volume for roundwood as the mass of the roundwood depends on its moisture content.<sup>11</sup> Due to data discrepancies, the reported trade value from the exporter and importer of the same trade flow may differ for at least two reasons: (1) import reports are expressed as “cost, insurance and freight” (CIF), while export reports are expressed as “free on board” (FOB), which excludes CIF costs from trade value, leading to bilateral asymmetries; (2) one of the trading partners may not report the trade (Gaulier and Zignago, 2010; Rougieux et al., 2017; Kallio and Solberg, 2018; Chen et al., 2022; Mitikj and Kaushik, 2024). To minimise the bias that such inconsistencies may cause, we consider both the exporter’s and importer’s reports of trade:  $a_{o,d}$  and  $a_{d,o}$ , respectively. The edge list corresponding to the weighted, directed trade network is now a matrix of size  $N \times 4$ .<sup>12</sup> Each row represents a trade flow for a given year  $t$ , including the country of origin, the country of destination, and the trade values reported by the exporter and importer, as shown in Figure 2.<sup>13</sup> We therefore define 28 edge lists to describe the roundwood trade network for each year of trade.

### 2.3. Trade network properties assessment

Edge lists and any other network objects or raw visualisations are often difficult to read and interpret. Alone, they do not enable a thorough analysis of the structure of a trade network. In order to assess the structural characteristics of trade networks, we computed a series of network metrics for each year, differentiating

<sup>11</sup>UN Comtrade data provides an alternative “quantity” variable (encoded *qty*) to the net weight of the trade flows. However, this variable is poorly reported: (i) units may differ depending on the reporter and range from cubic metres to metres to kilograms, and so on; (ii) the “quantity” variable is not recorded in 7.8% of the dataset.

<sup>12</sup>In fact, edge lists are close to mirror flows that can be derived from bilateral trade data, such as that provided by the UN Comtrade database.

<sup>13</sup>See Rayfield et al. (2011) and Thompson et al. (2017) for examples of this approach in ecological networks.



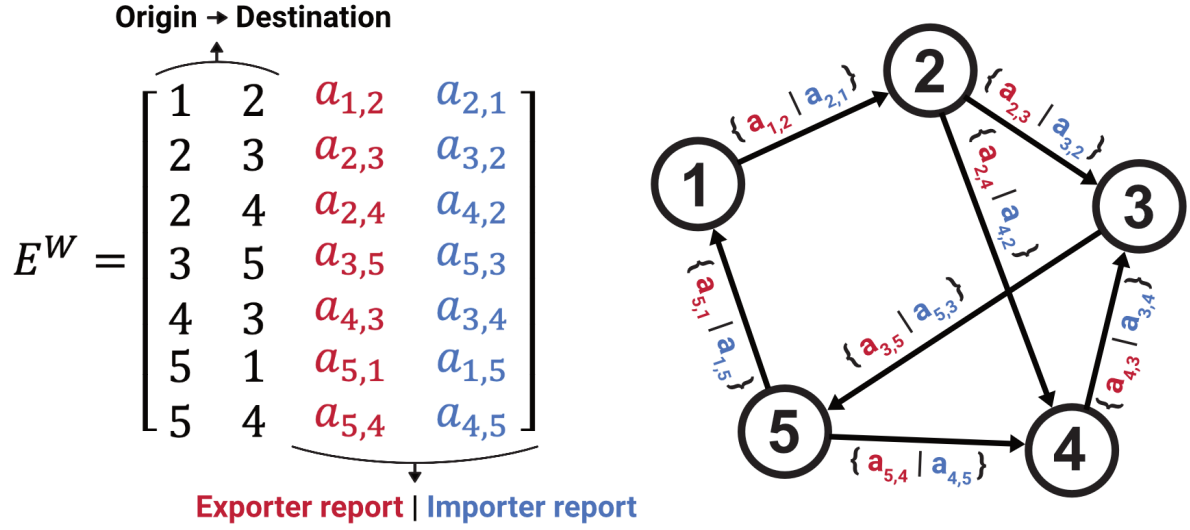


Figure 2: Illustration of an edge list,  $E^W$ , and its corresponding network graph for a *weighted* and *directed* trade network of 5 nodes. In the edge list, each row corresponds to an edge from an origin (first column) to a destination (second column) and include trade values reported by the country of origin (third column, red) and the country of destination (fourth column, blue). In the network graph, circles indicate nodes and arrows the edges between them.

between exports and imports.<sup>14</sup> The Python package “networkx” 3.4.2 (Hagberg et al., 2008) is used to facilitate the measurement network metrics.

First, we assess the composition of the trade network. For each year, we compute the total number of nodes in the network, *i.e.*, the total number of trading countries. These countries are then divided into three more detailed groups: pure exporters (countries that only export roundwood), pure importers (countries that only import roundwood) and mixed countries (countries that both export and import roundwood). To obtain more detailed information on the composition of the network, we then cross-reference the export and import values of each trading country accounting for at least 1% of to the global export or import value with the number of its export and import trading partners. This provides country trade profiles for each year, allowing trade behaviours and groups to be inferred and their evolution observed over time. This set of metrics provides a general overview of the roundwood trade network.

Secondly, to understand the finer details of the network structure, we then computed a set of metrics that assess the connectivity of the trade network, *i.e.*, the mean, variance, skewness, and kurtosis of the number of connections per node (Albert and Barabási, 2002; Newman, 2003). Again, we assess network connectivity differentiating exports and imports. The mean number of connections per node, or node degree,

<sup>14</sup>Considering directed networks enables analysis from either the origin (exporter) or destination (importer) country perspective, allowing exporter or importer trade behaviour to be inferred.

is an average indicator of the degree of connectedness of the network. A high mean number of connections per node means that each country in the network has, on average, a high number of trading partners. The variance of the number of connections per node provides additional information about the dispersion of the number of connections. If the variance is close to zero, then the nodes in the network have more or less the same degree. A high variance indicates that the degree of connectivity of countries largely deviates from the mean. Skewness provides information about the proportion of low to highly connected nodes in the network. If the skewness is negative, the network consists of a higher proportion of highly connected nodes. Conversely, if the skewness is positive, then the network has a higher proportion of lowly connected nodes. Zero skewness implies an equal ratio of low to high connected nodes. Kurtosis provides information on how the degree distribution compares with a normal distribution in terms of its “tailedness” or “flatness”. A positive kurtosis<sup>15</sup> indicates that tailed outliers are more prevalent than in a normal distribution, meaning countries that diverge from the mean are rare. Conversely, negative kurtosis corresponds to a situation in which outliers are common, *i.e.*, where most countries diverge from the mean.

Lastly, we assess market concentration by combining our network approach with a traditional Herfindahl-Hirschman market concentration index (HHI). The HHI is defined as follows:

$$HHI = \sum_{i=1}^N (MS_i)^2 \quad (1)$$

where  $N$  is the number of countries involved in trade and  $MS_i$  the market share of the country  $i$ , that is, the ratio of the value traded by country  $i$  to the global value traded. We computed two  $HHI$ , one for exports and one for imports. The  $HHI$  values can range from  $1/N$  to 1. According to the  $HHI$  value, the US Federal Trade Commission differentiates three types of markets ([U.S. Department of Justice and the Federal Trade Commission, 2010](#)):

- An  $HHI$  between 0.01 and 0.15 corresponds to an unconcentrated market, *i.e.*, a market with no anti-competitive effects presumed;
- An  $HHI$  between 0.15 and 0.25 indicates a moderately concentrated market, *i.e.*, a market with potential or significant anti-competitive effects;
- An  $HHI$  greater than 0.25 indicates a highly concentrated market, *i.e.*, a market with presumption of anti-competitive effects.

To obtain a more detailed understanding of market concentration, we calculated each country’s annual contribution to the global trade value, *i.e.*, the reduction in total trade value if a given country were removed

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<sup>15</sup>We consider Fisher’s definition of kurtosis. A Pearson’s definition would have necessitated the comparison of kurtosis values with 3 instead of 0.

from the network. This is equivalent to estimating the share of total trade value that “flows” through a given country in a particular year. Consequently, the sum of all countries’ contributions does not add up to 100%, due to the bilateral nature of trade flows. This approach allows us to identify dominant countries in the roundwood trade. In cases of high market concentration, the removal of a dominant country is expected to result in a substantial loss in trade value.

Combining multiple complementary metrics offers a more comprehensive understanding of the network’s structure than any single metric alone can provide (Shanafelt et al., 2017; Salau et al., 2022). For example, networks may have the same average number of connections but exhibit vastly different variances, resulting in markedly different topologies. Moreover, we consider our selected set of metrics sufficient for analyzing trade network structure, as many network metrics tend to be correlated (Baggio et al., 2011). The metrics used and their interpretations are summarized in Table 1.

Table 1: List of the metrics used to describe the trade network and their interpretation.

Network metrics	Interpretation
<b>Trade network composition</b>	
Number of nodes	Number of countries involved in trade.
Number of pure exporter	Number of countries that only export roundwood.
Number of pure importer	Number of countries that only import roundwood.
Number of mixed countries	Number of countries that both export and import roundwood.
Country profiles	Trade behaviour of countries in relation to exports and imports.
<b>Trade network connectivity</b>	
Mean number of connections per node	Average number of trading partners per country; indicator of the overall connected-ness of the network.
Variance in the number of connections per node	Variation in the number of trading partners relative to the mean.
Skewness in the number of connections per node	Proportion of low to highly connected countries in the network.
Kurtosis in the number of connections per node	Scarcity or abundance of countries that diverge from the mean connectivity.
<b>Market concentration</b>	
Herfindahl-Hirschman index	Market concentration in the trade of roundwood.

Network metrics	Interpretation
Country contributions to trade value	Share of total trade value that ‘flows’ through a given country.

#### 2.4. Computational workflow and reproducibility

A sustainable data analysis workflow was undertaken using Snakemake 9.6.0 (Mölder et al., 2025). Snakemake is a workflow management system that ensures the reproducibility, adaptability, and transparency of the data analysis. This workflow is available on a GitHub repository,<sup>16</sup> which provides access to the analysis and version control (Braga et al., 2023).

### 3. Results

#### 3.1. Composition of the trade network over time

Over the study period, the number of countries involved in the roundwood trade fluctuated slightly, ranging from 189 in 1997 to 214 in 2008 (Figure 3). On average, 206 countries were involved in roundwood trade from 1996 to 2023. After a moderate increase in the number of countries involved in trade between 1996 and 2008 (an increase of 11.5%, from 192 to 214 countries), the number of countries stabilised until 2015. From 2015 to 2022, the number of trading countries decreased slightly from 213 to 198 (an 7% decrease) before increasing to 209 in 2023 (an increase of 5.3%). Aside from these trends, we found short-term slight decreases in the number of trading countries after 2008, 2015, 2019, and 2021, which, as we will discuss later, can likely be attributed to major global events.

In addition, we can observe several trends in the share of pure exporters, pure importers, and countries that both export and import roundwood. The number of pure exporters has decreased markedly since 1996, falling from 17 to 11 (a decline of around 35.3%). In 2023, pure exporters represented only 5.3% of trading countries compared to an average of 6.3% over the studied period. In contrast, the number of pure importers decreased from 52 to 39 between 1996 and 2007 (a decline of 25%), before rising again to 60 between 2007 and 2015 (an increase of 53.8%). Since 2015, the number of pure importers has stabilised around 55 countries on average. In 2023, pure importers represented a larger share (28.7%, 60 countries) of trading countries than pure exporters (23.5% on average over the study period). Throughout the years, there were consistently more pure importers than pure exporters engaged in the international trade of roundwood, with an average difference of 36 countries. The number of countries that both export and import roundwood

<sup>16</sup>GitHub repository address: [https://github.com/vlmathieu/trade\\_network\\_analysis](https://github.com/vlmathieu/trade_network_analysis)

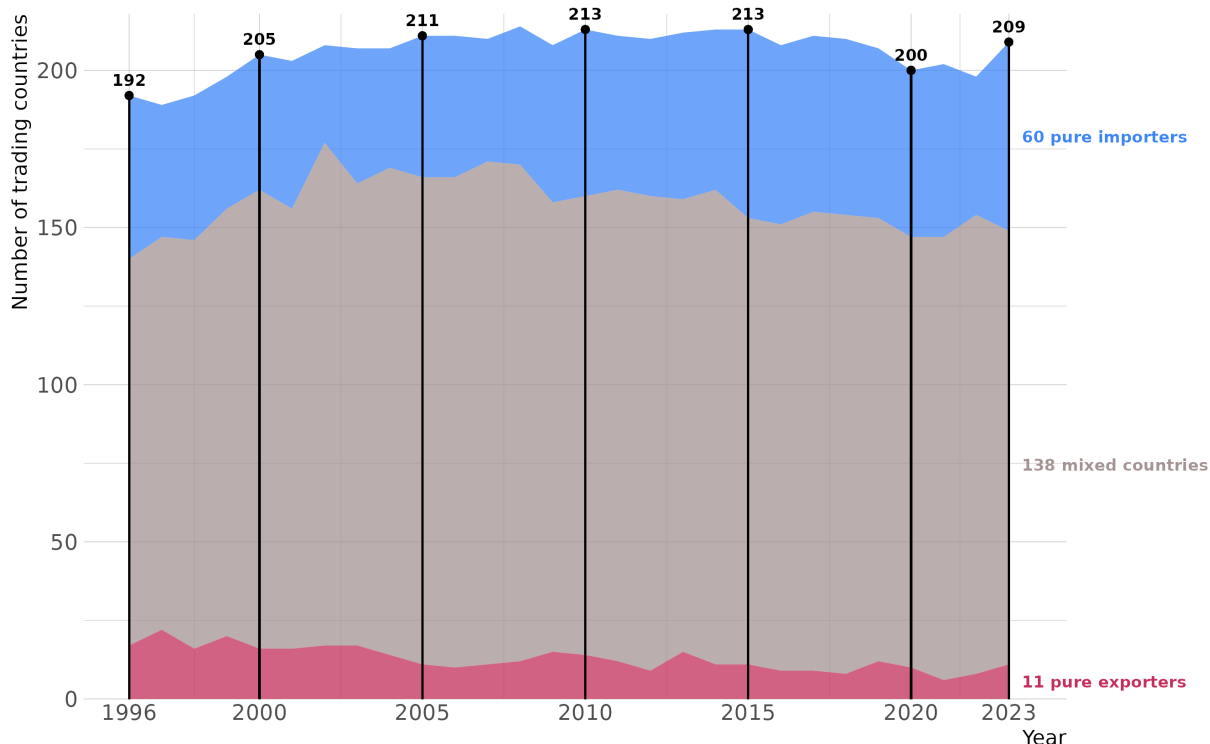


Figure 3: Number of trading countries in total and per group: pure exporters (red), pure importers (blue), mixed countries (grey); for each year of trade.

(“mixed countries”) constituted the vast majority of trading countries (70.2% on average over the studied period, 66% in 2023). The number of mixed countries has increased moderately since 1996, rising from 123 to 138 (an increase of around 12.2%). As for the total number of trading countries, we noticed short terms drops in the number of pure exporters, pure importers, and mixed countries over the studied period. Some drops are common to pure importers and mixed countries (*e.g.*, following 2008 and 2019), while others are group-specific (*e.g.*, following 1997 for pure exporters and 2001 for pure importers).

While 200 countries were involved in the global roundwood trade in 2020, only 31 countries (15.5% of the total) contributed to at least 1% of the export or import value (Figure 4). This suggests a certain degree of market concentration in the trade of roundwood. These 31 countries showed different behaviours, and we identified roughly three groups. First, Asian countries, namely China, India, Japan, the Republic of Korea and Vietnam, form a group of importers. Importers have a higher trade value for imports than for exports and have diversified their import connections more than their export connections. Second, several countries belong to the group of exporters. Their export value is higher than their import value, they have a higher

number of export partners compared to their import partners, but their number of export trading partners varies. While Papua New Guinea only export to a limited number of 13 countries, net exporters such as Australia, New Zealand, Congo, Cameroon, Brazil and the Russian Federation, have moderately diversified their number of export trading partners (between 20 and 45). New Zealand, the USA, and the Russian Federation stand out as the world’s three largest suppliers of roundwood. In particular, the USA shows a unique export pattern with a high diversification of its export trading partners (95 export connections). Finally, we can draw a third group of countries that tend to export as much as they import in trade value, with a balanced number of exporting and importing partners. This group is mainly made up of European countries but also includes countries such as Canada and Malaysia.

The trade situation has changed significantly between 2000 and 2020 (Figure 4). In 20 years, China has overtaken Japan as the main importer of roundwood. Japan’s import value decreased dramatically from more than \$2.33 billion in 2000 to about \$562 million in 2020, a decrease of 76%. On the other hand, China’s import value increased considerably from more than \$1.654 billion in 2000 to more than \$8.376 billion in 2020, an increase of about 406%. Surprisingly, the number of China’s export trading partners increased sharply by about 129% between 2000 and 2020 (31 new export trading partners), while the value of Chinese export trade decreased by more than \$1.2 million on the same period (a decline of about 16%), which seems unlikely. In terms of trade value, New Zealand has emerged as the world’s top exporter of roundwood, while maintaining a relatively stable number of trading partners. Although the USA and the Russian Federation remained major exporters of roundwood, they appeared to be less integrated into global roundwood trade. Between 2000 and 2020, the USA has lost a large share of its trading partners to import (a fall of 42%), while slightly reducing its export diversification (a fall of only 8%). Similarly, the Russian Federation lost 14 export trading partners (25%) and 5 import trading partners (42%) in the same period.

### *3.2. Connectivity of the trade network over time*

Results for mean, variance, skewness, and kurtosis of the connections per country are presented in Figure 5. Three general observations can be made regarding the average number of connections per country over time. Firstly, both exporters and importers of roundwood observed an increase in their mean connectivity during the first half of the study period (from 1996 to 2008). During this period, mean connectivity of exporters increased by 23% for exporters (from 12.4 to 15.3 connections per exporter), while that of importers increased by 30% (from 9.9 to 12.9 connections per importer). The average number of connections per country then slightly decreased by 8% for exporters (from 15.3 to 14.1). Mean connectivity of importers decreased further by 18% (from 12.9 to 10.6 connections per importer) from 2008 to 2016 and has since stabilised. Secondly, exporters were, on average, 23% more connected than importers throughout the study period (14.2 connections per exporter versus 11.6 connections per importer). The gap widened between

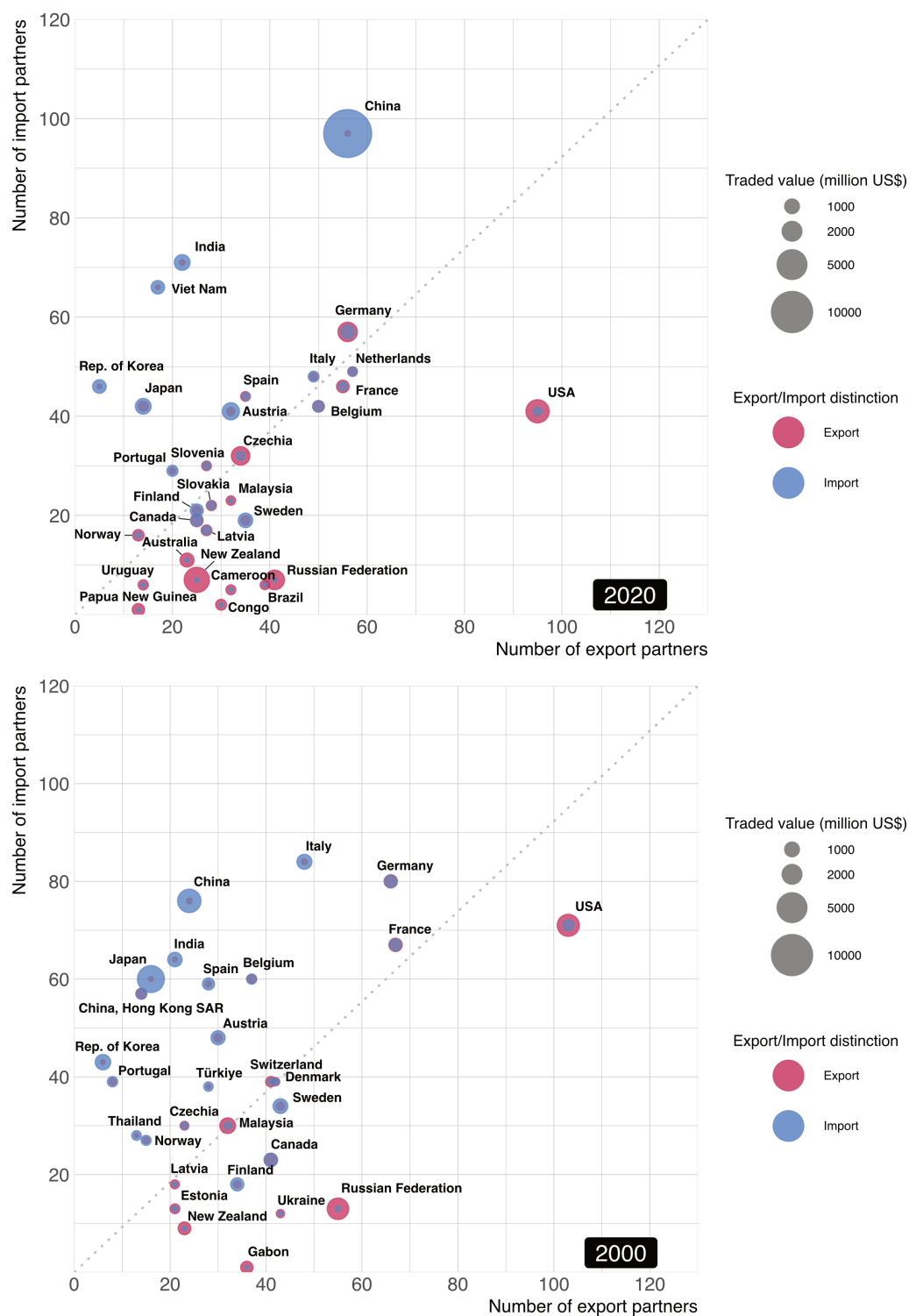


Figure 4: Bubble graph showing the profiles of trading countries in 2020 (top) and in 2000 (bottom). Countries are displayed according to the number of partners with whom the trade exports and imports. The size of the bubbles increases with the value of trade. Blue bubbles refer to imports and red bubbles refer to exports. Only countries accounting for at least 1% of the value of exports or imports in 1996 or 2022 are shown.

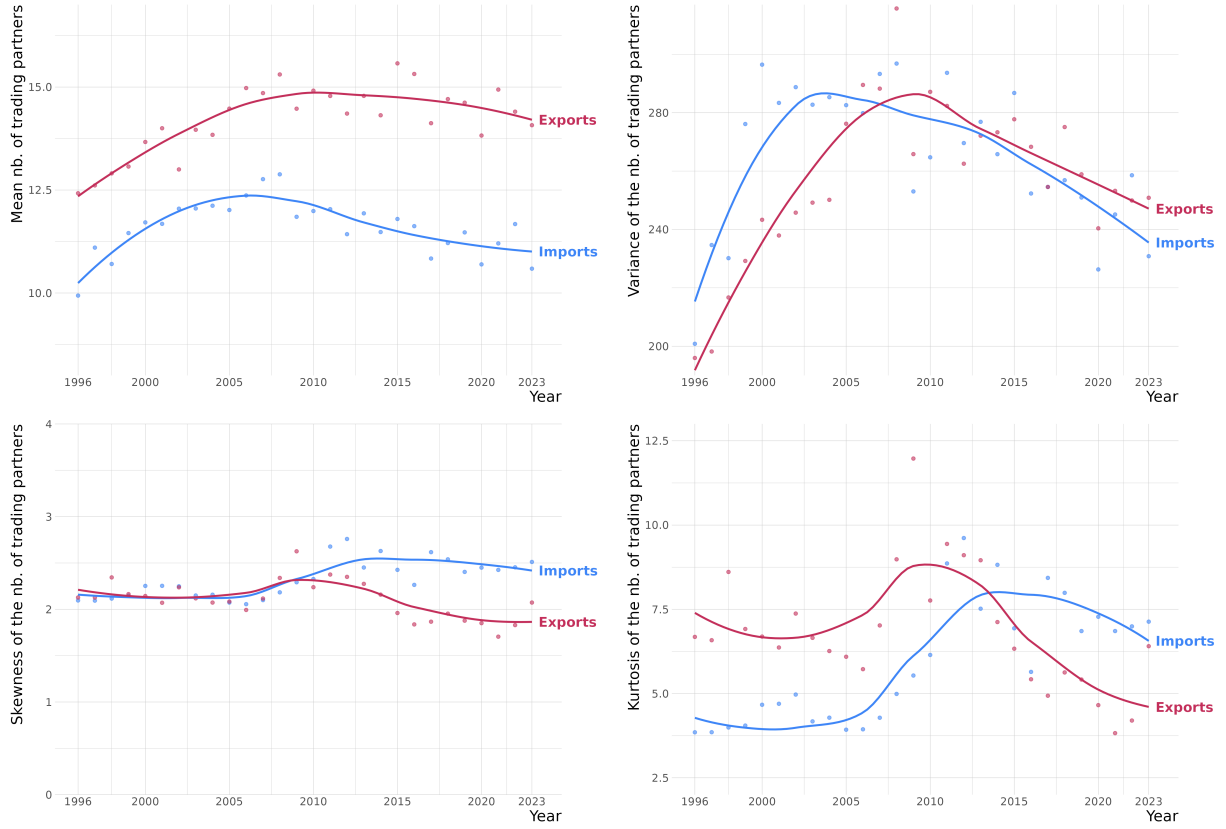


Figure 5: Mean number (top left), variance (top right), skewness (bottom left), and kurtosis (bottom right) of the connections per node. Metrics concerning exports are plotted in red, metrics concerning imports are plotted in blue. Smooth curve is based on a Loess function to highlight trends in the metrics.

the first and second halves of the study period (17% between 1996 and 2008, 27% between 2008 and 2023). Thirdly, aside from general trends, short-term increases and decreases in mean connectivity were observed from year to year, with some shared by both by exporters and importers. For example, mean connectivity of both exporters and importers dropped in the years following 2008, 2016, and 2019.

The variance in the number of connections per node provides additional information on how the connectivity of each country diverges from the overall average. Overall, we observe high variance in connectivity per country for exporters and importers. Exporters and importers comprise countries with a wide range of trading partners, some of which have a significantly lower number of connections than average (poorly connected countries), while others have a significantly higher number of connections than average (highly connected countries). Variance in the connectivity per country increased for importers from 1996 to 2003 and for exporters until 2008, before decreasing until 2023. Between 1996 and 2005, variance in connectivity per country was, on average, higher for importers than for exporters. This suggests that, during this time



period, importers showed greater spread in connectivity compared to the mean. After 2005, exporters and importers displayed similar variances in connectivity. Similar short-term increases and decreases to those observed in mean connectivity per node were seen in the variance from year to year.

Skewness provides information about the distribution of highly and poorly connected nodes within a network. Skewness in connections per country is always positive for both exporters and importers, indicating a greater proportion of countries with low to high connectivity. It remained stable on average for both exporters and importers between 1996 and 2005, followed by an increase until 2010 for exporters and until 2012 for importers. Until 2010, the degree of skewness in connectivity was similar for exporters and importers. Since 2010, the skewness in connectivity has become, on average, higher for importers than for exporters, has slightly increased for importers, and has decreased moderately for exporters. That is, there was a greater proportion of poorly connected countries among importers than among exporters, which supports and complements our findings regarding the mean number of connections.

Kurtosis indicates whether countries diverge from the mean connectivity in a scarce or abundant manner. During the study period, kurtosis of connections per country remained positive for both exporters and importers. This suggests that countries whose connectivity diverges from the mean connectivity are rarer than those whose connectivity is close to the mean. From 1996 to 2014, skewness of connectivity was higher for exporters than for importers, meaning that exporters diverging from the mean connectivity were, on average, rarer than importers. The reverse was true after 2014. Until 2023, kurtosis of connectivity decreased, while remaining positive. This fall is steeper for exporters than for importers. As with our other network metrics, we observed several short-term fluctuations in skewness and kurtosis over time from year to year, though these were less pronounced.

### *3.3. Market concentration in roundwood trade over time*

Between 1996 and 1998, the Herfindahl-Hirschman Index (HHI) initially fell for both exports (a decline of 38%, from 0.18 to 0.11) and imports (a decline of 52%, from 0.21 to 0.1) indicating a rapid shift from moderate to low market concentration in roundwood trade (Figure 6). This decline was followed by an increase in the HHI for exporters until 2006, reaching a HHI of 0.15, before falling again until 2011 and reaching a HHI of 0.08. Market of roundwood exports then remained stable and lowly concentrated until 2023, with an average HHI of 0.08 since 2011. In contrast, market concentration of roundwood imports increased sharply, becoming moderately concentrated after 2009 (HHI of 0.17) and highly concentrated after 2013 (HHI of 0.25). After a steep decline from a HHI of 0.26 to 0.18 between 2015 and 2016, market concentration level recovered the following year to reach a HHI of 0.35. From 2017 to 2021, imports remained highly concentrated, with an average HHI of 0.35, before falling to 0.24 in 2023. On average, over the last decade, imports have remained highly concentrated, whereas exports have remained lowly concentrated for

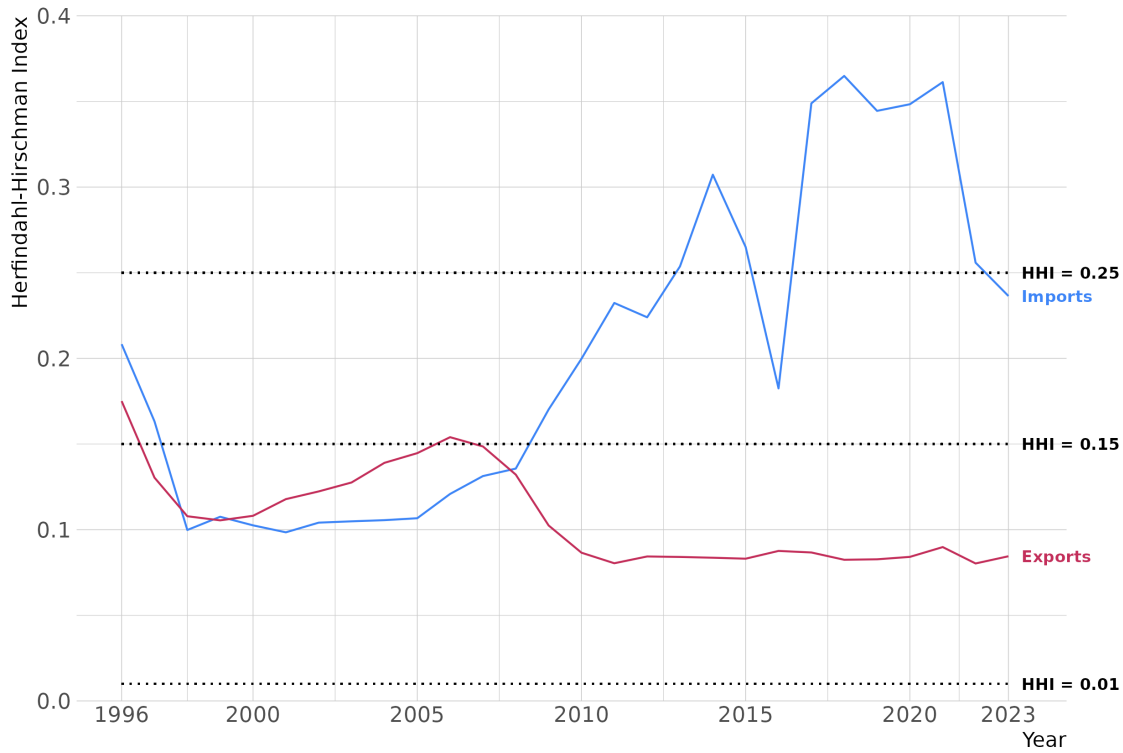


Figure 6: Herfindahl-Hirschman index values over time. Index related to exports are displayed in red, those related to imports in blue.

27 years.

Contributions from individual countries to the total network trade value provide a more detailed picture of market concentration (Figure 7). These contributions correspond to the proportion of the network's total trade value that would be lost if a particular country is omitted from the network, *i.e.*, the proportion of total trade value flowing through that country. Over the study period, only thirteen countries contributed at least 5% to the network's total trade value once. Referring to Figure 4, main contributors to the total trade value can be divided into three groups: importers (China, India and Japan); European countries (Germany, Czechia, Austria, Sweden, France, Poland); and traditional wood exporters (Canada, New Zealand, the Russian Federation, and the USA).

Among importers, Japan's share of total trade value decreased considerably from around 44% in 1996 to less than 6% in 2023. On the other hand, India's contribution increased steadily from around 2% in 1996 to around 16% in 2012, after decreasing to 6% in 2023. Most notably, China's share of the total trade value increased sharply, from around 4% in 1996 to more than 56% in 2021, before decreasing to 44% in 2023.

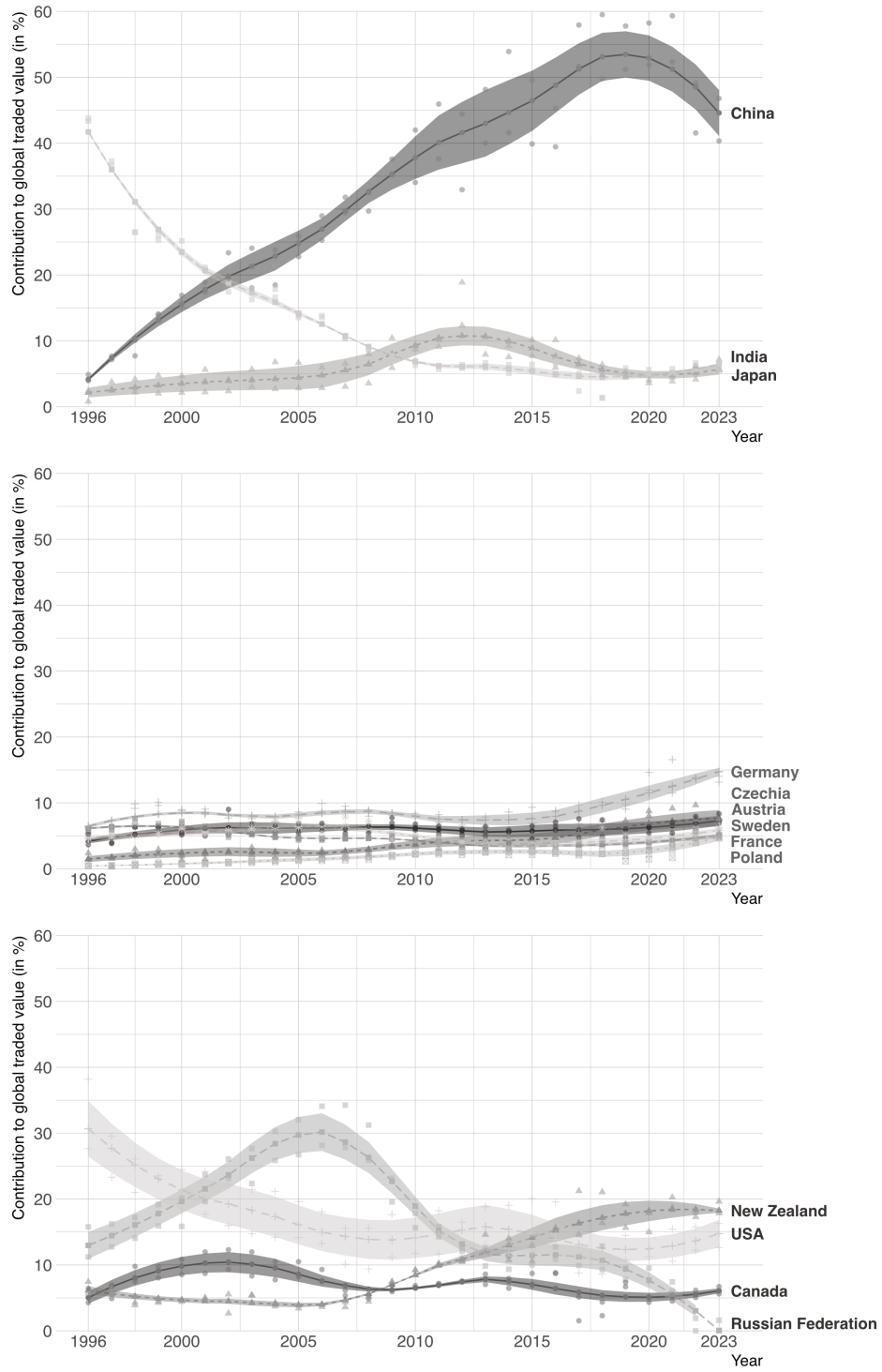


Figure 7: Contribution of different countries to the total traded value of the network. Only countries that have contributed to more than 5% of the total traded value at least once during the study period are shown. The envelope corresponds to the uncertainty in the reported values. Contributions are displayed by group of countries: importers (top); mixed countries (middle); and exporters (bottom).

Together with results from Figures 4 and 6, this indicated that around 56% of the total trade value flowed through China in 2021 due to its imports, which is consistent with the high level of market concentration in roundwood imports in over the past decade. The decline in the concentration of roundwood imports since 2021 is likely due to China’s decreased trade contribution.

Germany stands out among European countries with a 14% contribution to trade in 2023. The Czech Republic, Austria, Sweden, France, and Poland present similar contributions, between 5% and 8% in 2023. While France’s contribution to trade remained stable at around 4.7% over the study period, other European countries increased their contributions. The contribution of Austria and Sweden moderately increased from around 4% in 1996 to 8% and 7% in 2023, respectively. The sharpest increases in contributions to trade among European countries are observed for Germany (rising from 6% in 1996 to 14% in 2023), the Czech Republic (rising from 2% in 1996 to 6% in 2023), and Poland (rising from 0% in 1996 to 5% in 2023). These levels of contribution remain relatively low compared to those of main importers such as China.

Among exporters, the contribution of the USA significantly decreased over the studied period, falling from 33% in 1996 to 13% in 2007. It then stabilized at an average of around 13.7% over the 2007-2023 period. Canada’s contribution to total trade value increased from 5% in 1996 to 11% in 2002, before decreasing to 6% in 2007. It has remained stable since then, averaging around 6.2%. By contrast, New Zealand’s contribution initially slightly fell from 7% in 1996 to 4% in 1998, then stabilised at an average of around 4.4% between 1998 and 2008, before rising significantly to 19% in 2023. On the other hand, Russia exhibits a unique pattern of varying contributions to the total trade value throughout the studied period. Initially, Russian contributions increased from 13% in 1996 to 31% in 2007, before dropping sharply to 12% in 2012. This figure then stabilised at an average of around 11.4% between 2012 and 2018, before dropping again to below 1% in 2023. This correlates with findings presented in Figure 4, which suggests that Russian trade integration has decreased over time. Except for Russia, which appears to be influenced by short- to medium-term shocks, all contributors to the roundwood trade exhibit long-term variations in their contribution.

#### 4. Conclusion and Discussion

Contrary to our expectations, our results suggest that the global roundwood trade network displayed significant resilience to exogenous disruptions. Primarily, we show that the trade network followed its long-term trend toward greater import concentration and polarization around China, rather than experiencing major short-term shifts. Interestingly, despite China’s substantial growth in market power in recent decades, our findings suggest that its influence on the roundwood trade has declined in recent years, suggesting an impending shift.

Certainly, the network structural metrics showed low to moderate sensitivity to shocks and disruptions.

The number of pure exporters, pure importers, and mixed countries, showed slight short-term drops over the studied period (Figure 3). Short-term increases and decreases in connectivity or market concentration metrics were also observed from year to year (Figures 5, 6). These rises and falls in the network structure likely result from three broad categories of events. First are economic disruptions, such as financial or banking crises (*e.g.*, the 2008 global financial crisis or the 2016 Chinese financial crisis) and supply chain disruptions (*e.g.*, the Covid-19 pandemic). Second are political events, such as trade disputes (Van Kooten and Johnston, 2014; Johnston and Van Kooten, 2017; Pan et al., 2021) or bilateral agreements, which affect trade relationships between countries. Third are ecological disasters. Hurricanes, tsunamis, and earthquakes can result in direct and indirect damage, as well as periods of reconstruction that can intensify the need for imports or the ability to export. Forest fires and storms may affect the availability of roundwood, thereby altering exports and imports throughout the supply and production chains. However, these shocks seem to have no lasting impact on the network structure, only affecting it in the short term, with a quick recovery the following year. This suggests that the trade network is resilient to exogenous shocks.

In fact, our results rather show that the roundwood trade network has followed long-term trends over the past decades. In the long term, we found that while the number of countries participating in the roundwood trade network remained relatively stable, it underwent a notable shift in composition, with countries engaging more in both exports and imports (Figure 3), suggesting a better integration of countries in the network and trade intensification. Indeed, the network’s connectivity tightened at the turn of the 21st century (Figure 5), a trend consistent with broader globalization (Prestemon et al., 2003). Our analysis of network composition and connectivity further reveals an uneven structure: a few highly-connected countries (the hubs) dominate and concentrate trade, while most of the network consists of poorly-connected countries that barely contribute to roundwood trade volumes (Figures 4, 5). These hubs play a critical role in network’s functionality (Huang et al., 2024) and can wield considerable market power, with potential anti-competitive effects on poorly-connected countries, which constitute the majority of the trade network.

Throughout the study period, many major hubs in the international market, including the USA, Canada, Western Europe, Scandinavia, and Russia, maintained a high number of trading partners. However, our findings highlight long-term shifts in the trade landscape over recent decades. We observed a decline among traditional core importers and exporters, including Japan, Russia, and the USA, concurrent with the rise of new key players like China and New Zealand (Figures 4, 7). Especially, our findings show that China has become *the* central player in the roundwood trade, substantially increasing its number of import and export partners. By 2021, China’s imports accounted for 56% of the total roundwood trade value, leading to a highly concentrated and polarized import market (Figures 6, 7). This confirms findings from other studies (Ke et al.; Long et al., 2019; Zhou et al., 2021; Shen and Lovrić, 2022; Huang et al., 2024).

This could appear as a paradox: although forest resources are geographically concentrated in a few countries, our results show that the roundwood export market is not similarly concentrated (Figure 6). The relatively low export market concentration levels observed during the last decade are presumably due to Russia’s withdrawal from the export market initiated in 2007. The increase in export market concentration at the beginning of the 20th century coincided with Russia’s growing contribution to trade (Figures 6, 7). In 2007, Russian roundwood exports represented 34% of the global roundwood export volumes. Russia contribution to roundwood trade then fell from 31% in 2007 to less than 1% in 2023 due to successive export tax increases on roundwood, which preceded a complete export ban in 2022 (Figure 7) (Lin and Zhang, 2017; UNECE/FAO, 2022a,b; FAO, 2024b; Guan and Yang, 2024). Russia’s position as the main exporter of roundwood has since been overtaken by New Zealand, which accounted for 20% of total exports in 2023. In 2023, other roundwood exporters significantly contributed to global export volumes: the USA (15% of global roundwood exports), Germany (10%), Czechia (6%), France and Canada (4% each), Poland, Latvia, and Norway (3% each), and Papua New Guinea (2%). Such distribution of export volumes may explain the relatively low concentration levels of the roundwood export market.

In contrast, our findings suggest that the import market has become highly concentrated primarily due to demand from China (Figures 6, 7), which, paradoxically, also possesses the fifth-highest forest endowment and presents the first-highest average annual net gain in forest area (FAO, 2024b). Indeed, due to Chinese government efforts in spending, as well as China’s market and policy reforms driven by forest conservation demand, China has operated a drastic expansion of its forestry and planted forest extensive margins over the last decades (Démurger et al., 2009; Ke et al.; Zhang, 2019; Zhao et al., 2022). However, despite an increase in China’s forest area and volume, low economic tree planting efficiency and poor forest management have resulted in low stand quality and growth rates (Hoffmann et al., 2018; Hou et al., 2019; Ke et al.; Zhang, 2019). As a result, domestic timber consumption — primarily for industrial and construction uses — has outpaced domestic production, making China highly dependent on imported wood products, which now account for approximately half of its total timber supply (Démurger et al., 2009; He and Xu, 2011; Hoffmann et al., 2018; Hou et al., 2019; Ke et al.).

Such demand for imported roundwood fosters co-dependence between China and roundwood exporting countries. In fact, China serves as the main trading partner for most major exporters, making them highly reliant on its demand. For instance, in 2020, China imported 46% of roundwood exports from the USA, 67% from Russia, 77% from Congo, 78% from Papua New Guinea, and 86% from New Zealand. The case of New Zealand perfectly illustrates this co-dependence. Its rise as a major exporter is closely tied to China’s increasing demand and Russia’s concurrent withdrawal from the roundwood export market. The share of New Zealand’s roundwood exports to China surged from just 1.2% in 1996 to 90.3% in 2023. To mitigate risks from potential disruptions caused by hubs like China or to limit co-dependence, countries can diversify

their trade relationships (Huang et al., 2024). The United States appears to have pursued this strategy throughout the study period, as shown in our results (Figure 4).

This overall suggests that roundwood trade flows are predominantly demand-driven rather than supply-pushed. In the case of China, the primary use of wood for industrial and construction uses (Hou et al., 2019) echoes the role of population and urbanization in shaping demand for materials (Steinberger et al., 2010), which has been identified in the literature (UNECE/FAO, 2022b; Mathieu and Roda, 2023; Villamor et al., 2024). Urbanization, through the growth, maintenance, and operation of buildings, infrastructure, and durable goods, is a major determinant of material consumption (Fernández; Hu et al.; Krausmann et al.; Deetman et al.), which may have a considerable impact on roundwood trade. Regions of the world undergoing population increase and urbanization, such as emerging markets in Asia (Deetman et al.; UNECE/FAO, 2022b), are or are becoming centers of gravity that attract roundwood trade flows, with potential shifts in the role of countries within the trade network.

Most interestingly, China’s contribution to the roundwood trade appears to have begun a decline after 2021 (Figure 7), potentially signaling a new phase in the global roundwood market. Three concurrent and reinforcing circumstances may drive this decline: external geopolitical disruptions, domestic self-sufficiency policies, and domestic structural economic changes.

The initial decline likely stems from major external trade shocks. Most notably, Russia’s 2022 roundwood export ban significantly reduced China’s import volumes; in 2021, Russia was China’s third main supplier, accounting for 7.2% of its roundwood imports (a share that fell to 3.2% in 2022). Consequently, China appears to be shifting its import strategy from raw logs to processed wood products, absorbing significant volumes of Russian plywood, for example, that were previously destined for Western markets following Ukraine war-related sanctions (Scott). This shock was likely exacerbated by the still ongoing 2018 US-China trade war (Muhammad and Jones, 2021; Pan et al., 2021). While the U.S. share of China’s imports increased from 8.5% in 2021 to 10.9% in 2023 (possibly to compensate for Russian withdrawal from the export market), China’s import volume from the U.S. has dropped by 29% over the same period. Given the current geopolitical climate, a Russian ban lift is unlikely, and escalating U.S.-China trade barriers are expected to cause further significant trade disruptions and diversions in the medium term (Attinasi et al.; World Bank; World Trade Organization).

A second, more policy-driven factor is China’s strategic ambition to enhance self-sufficiency and reduce reliance on wood imports by relying on domestic demand and more comprehensive domestic supply chains (FAO; UNECE/FAO, 2022b; Attinasi et al.). High reliance on imports, particularly with sourcing concentration risks intensifying, presents geopolitical risks for China. In this regard, China announced its Plan for the Construction of the National Reserve Forest Project in 2018. This project aims to foster a net increase of

200 million m<sup>3</sup> per year by 2035 from 20 million newly planted hectares of national reserve forest—an amount designed to cover China’s current total net imports of forest products. This domestic focus aims to make the country less export-oriented and mitigate sourcing risks.

Thirdly, China’s contribution decline in roundwood trade network may result from domestic economic crisis and structural changes. For the last four years, China has known a real estate crisis which, coupled with slowed productivity growth, ageing population and high debt levels, has significantly slowed its domestic demand for roundwood ([World Bank](#)), which again echoes the role of urbanization in fueling demand for materials such as wood. Furthermore, while China’s position in global value chains has been fueled by labour-intensive industry development ([Su et al.](#)), last-decades increases in labour costs and investments in research and development towards advanced technologies has led China to pivot from consumer goods production and exports to technology-intensive capital production and exports ([FAO](#); [Attinasi et al.](#)). In fact, labour-intensive consumer goods production is currently moving out of China, such as Vietnam ([FAO](#); [Attinasi et al.](#)).

Finally, the decline may be compounded by domestic economic crises and structural shifts. Over the past four years, the real estate crisis in China, coupled with slower productivity growth, an aging population, and high debt levels, has significantly dampened domestic demand for roundwood ([World Bank](#)), which again highlights the role of urbanization in driving demand for materials such as wood. Furthermore, China is undergoing a structural pivot: driven by rising labor costs and investments in research and development towards advanced technologies, China is shifting from labor-intensive consumer goods production and exports ([Su et al.](#)) to technology-intensive capital production and exports ([FAO](#); [Attinasi et al.](#)).<sup>17</sup> This structural change inherently reduces the domestic manufacturing sector’s demand for imported roundwood.

In light of these persistent factors, China’s declining integration into the roundwood trade network is likely to continue. A potential “post-China” era in the global roundwood market raises crucial concerns: the potential contours of a fragmented trade world marked by policy uncertainty ([Attinasi et al.](#); [World Trade Organization](#)) and the necessity of identifying new, sustainable markets for timber supply for major exporters, such as New Zealand ([Villamor et al., 2024](#)).

By considering multiple network metrics, we obtained a clearer picture of the evolution of the network’s structure than using a single metric alone ([Shanafelt et al., 2017](#); [Salau et al., 2022](#)). The mean number of connections gives us a global measure of network connectivity, but tells nothing of the distribution of connections throughout the network. By measuring variance, skewness, and kurtosis we observed changes in

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<sup>17</sup>In fact, labour-intensive consumer goods production is currently moving out of China, to countries such as Vietnam ([FAO](#); [Attinasi et al.](#)).



the variation of connections per node, the proportion of poorly to highly-connected nodes, and the scarcity or abundance of countries that diverge from the mean connectivity over time. This provides a thorough diagnosis of the situation of the trade network. As a complement to traditional market concentration indexes, measuring a country’s contribution to traded value provides a detailed overview of each trader’s relative market power. It is crucial to recognize that network analysis should not be viewed as a replacement for traditional methods but rather as a powerful complement. It offers a macro-level, systemic perspective that can inform and enrich the micro-level insights derived from econometric models or the aggregate flow analyses from gravity models. Such multi-methodological approach would allow to leverage the strengths of each technique, leading to a more holistic and robust understanding of complex trade phenomena.

However, our results show that, despite the powerful explanatory capacity of network analysis, the quality of the underlying trade data is paramount. The validity and interpretability of the results are directly influenced by the accuracy, completeness, and consistency of the data, as pointed out in the literature (Lovrić et al., 2018; Wang et al., 2020; Zhou et al., 2021; Huang et al., 2024). While network analysis partly deals with data discrepancies by simultaneously taking into account exports and imports, it reveals data discrepancies such as inconsistent reporting, missing values, and outliers (Kallio and Solberg, 2018; Chen et al., 2022). Hence, our results show that China exported roundwood to 32 more countries in 2020 compared to 2000, while simultaneously reporting a decrease of \$1.2 million in export value on the same period (a decline of about 16%), which seems unlikely (Figure 4). This further highlights the caution that should be brought by modelers and data scientists when analysing bilateral trade data, while emphasizes the need for methods to process trade data and correct quality issues or for harmonized and consistent databases (Gaulier and Zignago, 2010; Rougieux et al., 2017).

Similarly, our results suggest that the country-level perspective is not always the most relevant in trade analysis. In particular, results highlight the singular trade balance of many European countries, which export as much roundwood as they import. This would suggest to rather consider the European Union as a whole, in order to get a clear vision that is not blurred by individual European countries behaviours and that will better reflect the European continent’s trade weight and openness.

While network analysis captures complexity and describes its organisation, further exploration of the determinants and dynamics is necessary to understand the rules that govern trade organisation, as well as to develop a unified indicator system, as network metrics are diverse. Multi-layer networks, in particular, could provide a more comprehensive analysis of global wood product supply chains by linking each wood product network according to value chain logics.

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## 5. Information

### 5.1. Funding statement

This study was supported by two grants from the French Grand Est Region (N° 19\_GE8\_019 20P05044) and the Lab of Excellence ARBRE (N° WP4/20PN17), by the French National Research Institute for Agriculture, Food and Environment (INRAE), and by AgroParisTech.

### 5.2. CRediT authorship contribution statement

Valentin Mathieu: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration.

David W. Shanafelt: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Supervision.

### 5.3. 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.

### 5.4. Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used (1) Asta in order to review the litterature aside traditional litterature search tools such as Scopus and Google Scholar and (2) Gemini and DeepL tools to improve English writing. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

### 5.5. Data availability

Data and code are available on [GitHub](#).

### 5.6. Acknowledgements

We thank Felix Bastit and Clément Nedoncelle for their helpful and relevant comments and suggestions, as well as the following audience: BETA internal environment, Labex ARBRE, Chaire RENEL, the 9th annual conference of the French Association of Environmental and Resource Economists (FAERE), DEEPSURF 2022 Energy and Ecological transition international conference, and the 16th social science research days (JRSS), Paris-Saclay Conference on Trade and Environment, 26th World Congress of the International Union of Forest Research Organizations (IUFRO) - Forests and Society towards 2050. All remaining errors are our own.