Wood flows through the Danish economy

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Prescott Huntley Brownell II, Bogomil Emilov Iliev, and Niclas Scott Bentsen
Foreword

An agreement on the 2022 Finance Act was reached 6 December 2021. The partners behind the act agreed to prepare a forest plan (skovplan) by the end of 2022. One element of the forest plan is an analysis of wood flows in the Danish economy. As a complete assessment and mapping of wood flows in Denmark, the Forest council (Skovrådet) more than once recommended a wood flow analysis being conducted (Skovrådet 2021).

This report was commissioned by the Danish Environmental Protection Agency in June 2022. A draft report was submitted to the EPA by the end of December 2022 and the final version published in March 2023.

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We further thank Simon Auken Beck, TMI; Peter Kofod Kristensen, Ørsted; and Bo Jellesmark Thorsen, Department of Food and Resource Economics, University of Copenhagen for reviews and valuable comments to the draft report.

The content, assessments, and conclusions presented here are the sole responsibility of the authors.
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## Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CEAP</td>
<td>European Commission circular economy action plan</td>
</tr>
<tr>
<td>CMU</td>
<td>Circular material use</td>
</tr>
<tr>
<td>CN</td>
<td>Combined nomenclature</td>
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<tr>
<td>DMC</td>
<td>Indicator of domestic material consumption</td>
</tr>
<tr>
<td>DST</td>
<td>Statistics Denmark</td>
</tr>
<tr>
<td>EE-MRIO</td>
<td>Environmentally extended multiregional input-output database</td>
</tr>
<tr>
<td>EXIOBASE</td>
<td>Global multi-regional environmentally extended supply-use and input-output database</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation of the United Nations</td>
</tr>
<tr>
<td>HWP</td>
<td>Harvested wood products</td>
</tr>
<tr>
<td>IOT</td>
<td>Input-output table</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>JFSQ</td>
<td>Joint Forest Sector Questionnaire</td>
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<tr>
<td>MFA</td>
<td>Material flow analysis</td>
</tr>
<tr>
<td>MATIO</td>
<td>Multiregional input-output database</td>
</tr>
<tr>
<td>NFI</td>
<td>National Forest Inventory</td>
</tr>
<tr>
<td>PSUT</td>
<td>Physical supply and use table</td>
</tr>
<tr>
<td>RMC</td>
<td>Indicator of raw material consumption</td>
</tr>
<tr>
<td>RoW</td>
<td>Rest of the World</td>
</tr>
<tr>
<td>SDG</td>
<td>UN Sustainable development goals</td>
</tr>
<tr>
<td>SEEA</td>
<td>System of environmental-economic accounting</td>
</tr>
<tr>
<td>SNA</td>
<td>System of national accounting</td>
</tr>
<tr>
<td>SUT</td>
<td>Supply and use table</td>
</tr>
<tr>
<td>SWE</td>
<td>Solid wood equivalents</td>
</tr>
<tr>
<td>VS</td>
<td>“Varestatistik” or Danish Industrial Commodity Statistics</td>
</tr>
</tbody>
</table>
1. Abstract

Nationally and internationally a number of plans and strategies have called for attention to the way forests and forest resources are managed, i.e., the EU Bioeconomy strategy of 2018, the Circular Economy Action Plan of 2020, and the EU Forest Strategy for 2030 in 2021. In Denmark, the Climate Act of 2020 commits to a reduction in greenhouse gas emissions of 70% relative to 1990 by 2030. As forests and wood products are included in the national greenhouse gas accounts, they will have a role to play in meeting the commitments.

To inform legislative and strategic processes supporting the commitments a deeper insight into how forest and wood resources are managed is required, and prior to this report no detailed overview of how wood products flow through the Danish economy was available.

The purpose of this analysis was 1) to quantitatively map the material flow of wood within and to and from Denmark, to better understand how wood is utilized, 2) to estimate Denmark’s consumption-based “woodprint”, or how much global wood extraction is caused by Danish economic activity, and 3) to assess the level of cascading resource use and circularity within the wood product sectors.

Methodologically, the analysis builds on Material Flow Analysis (MFA), which quantifies flows and stocks of materials in a system. A key characteristic of MFA is that flows must balance according to the law of conservation of mass, i.e., the mass of material inputs must equal mass of stocks and material outputs. The main source of information and data is the national accounts and the derived monetary supply-use tables, input-output tables, and the physical supply-use tables. Statistics Denmark has a long tradition of compiling national accounts of high quality and resolution. Official statistical data were complemented and verified using alternative information sources such as data from energy statistics, FAOSTAT, EXIOBASE, and scientific literature.

The overall mapping of wood flows was conducted for 2016 and 2018, and is reported in m³ solid wood equivalents, which is a measure of how much equivalent raw wood is actually contained in wood products.

The total domestic consumption of roundwood and semi-finished products increased from 13.1 million m³ solid wood equivalents in 2016 to 17.5 million in 2018. 76% of that increase was attributed to increased consumption of wood for energy purposes. Increased import of wood covered most of the increased consumption, but domestic harvest also increased by 4%.

The mapping suggests that large volumes of wood used in Denmark are not recorded in harvest or production statistics. While the uncertainty in quantifying un-documented flows is high by nature, the analysis suggests that 44% of the domestic extraction of wood is un-documented. However, underestimations of import, and domestic harvest from forests or overestimation of exports would all result in that figure being an overestimation. Previous wood flow analyses have also noted undocumented flow in other countries. We assume that these flows have their origin
outside the forest area in short rotation willow and poplar plantations, Christmas tree plantations, wind breaks and hedge rows, nature conservation areas, parks and gardens.

Wood for energy constitutes the main use of wood in Denmark. In 2016, 90% of the total domestic wood consumption was allocated to energy generation. The corresponding figure for 2018 was 87%.

The consumption-based woodprint analysis provided a measure of the size and source of the footprint of wood extraction attributable to the Danish consumption of products and services. In 2016 the Danish woodprint was 7.4 million m$^3$ of wood extraction; in 2018, 8.5 million m$^3$. The woodprint mainly originated in Europe: Sweden, Germany, Finland, Poland, Estonia, Latvia, Norway and Russia. Outside Europe, the USA and China were the countries mainly affected by the Danish woodprint.

The circular material use rate of wood was estimated to be 8.4% in 2018. If imported wood for energy use was disregarded, the circularity metric increased to 17.8%. The cascading factor of the total wood use was calculated to 1.44 in 2018. A significant part of the wood resource is used for energy purposes where recycling is impossible. As expected, the cascading factors for the wood and paper industries were higher, with 1.88 and 3.58 respectively in 2018.
2. Udvidet dansk resume


Formålet med denne analyse er at skabe et overblik og kortlægning af træets vej gennem den danske økonomi. Ambitionen er at skabe bedre forståelse for hvordan træressourcer bruges og handles og at bidrage til den løbende debat om produktion, anvendelse, import og eksport af træ og træmaterialer. Formålet søger vi opfyldt ved at forfølge tre separate men stadig forbundne delmål.

3. Analyse af cirkulariteten og kaskadeanvendelsen af træ og træmaterialer i Danmark.


Udvikling af wood flow modellen og analyse af træstrømme tager udgangspunkt i det fysiske materialestrømsregnskab kombineret med data fra andre kilder vedr. energianvendelse, udenrigshandel, konvertering og forarbejdning af træprodukter.

Analysen af cirkularitet og kaskadeanvendelse bygger på metoder udarbejdet af Eurostat, samt tidligere analyser af træstrømme i Tyskland og EU.

2.1. Resultater

Den overordnede kortlægning af træstrømme for 2018 og 2016 er præsenteret i Figur 1, Figur 2, samt Tabel 1 angivet i solid wood equivalents (SWE), som er et mål for hvor meget friskskovet råtræ, der skal til at forsyne det registrerede forbrug af træ og træprodukter.


Det samlede indenlandske forbrug af træ steg fra 13,1 millioner m³ (SWE) i 2016 til 17,5 millioner m³ (SWE) i 2018. 76 % af stigningen i træforbruget kan tilskrives en stigning i forbruget af træ til energi. Det øgede forbrug blev for en stor del vedkommende dækket af øget import, men den indenlandske hugst og ekstraktion steg også med 4%. Importen af træ udgjorde en stor og stigende andel af det samlede forbrug. I 2016 udgjorde import 64 % af det indenlandske forbrug plus eksport. I 2018 var den andel steget til 79 %.

Tabel 1. Hugst og handel med træ i Danmark i 2016 og 2018 opgjort i 1000 m³ SWE.

<table>
<thead>
<tr>
<th>År</th>
<th>Registreret Dansk hugst</th>
<th>Ikke-registreret dansk hugst</th>
<th>Total</th>
<th>Import</th>
<th>Eksport</th>
<th>Dansk forbrug til andet end energi</th>
<th>Danske forbrug til energi</th>
<th>Dansk forbrug i alt</th>
</tr>
</thead>
</table>

Kortlægningen peger på, at der indgår store mængder træ i den danske materialestrøm, som ikke er registreret i hugststatistikken eller som hugst andre steder. Den uregistrerede mængde udgør 44 % af den samlede indenlandske hugst og anvendes primært til energiformål. Det antages, at træet høstes fra arealer, der ikke er registreret som skov, f.eks. energipil, energipoppel eller juletræer fra landbrugsarealet, læhegn, naturarealer, parker og haver. Der er stor usikkerhed i
størrelsen af den uregistrerede mængde. Kvantificeringen baserer sig på den mængde træ, der mangler for at balancere træforbruget med hugsten. Særligt er der usikkerhed omkring den udokumenterede hugst af brænde, som muligvis er overestimeret, såvel som hugsten af træ til energi fra arealer uden for skoven.


Den overordnede kortlægning viser, at træ til energi udgjorde en væsentlig del af det indenlandske forbrug; 87 % i 2018 og 90 % i 2016. Den detaljerede allokering af træ til energiformål er vist i Figur 3 og Figur 4.

Woodprint modellen giver en anden type resultater end wood flow modellen. Med woodprint modellen estimeres den mængde høstet træ, Danmarks forbrug af varer og tjenester er ansvarlig for, altså hvor meget træhugst er indlejret i dansk forbrug eller hvor stort et fodafrugt sætter danskernes forbrug på egne og andre landes skove. Danmarks eksport af varer medfører et woodprint i anden lande og tælles ikke med i den danske del af opgørelsen. I 2016 var det danske woodprint 7,4 millioner m³. Det steg til 8,5 millioner m³ i 2018. Det danske woodprint i udlandet sættes primært i Europa, i Sverige, Tyskland, Finland, Polen, Estland, Letland, Norge og Rusland. Uden for Europa er det primært i USA og Kina, Danmarks woodprint sættes. Det gælder produkter lavet af træ, men også andre typer af produkter. Hvis forarbejdning i Danmark kræver energi, og hvis energi delvist er produceret med træbiomasse, og hvis dele af den biomasse er importeret til Danmark, så vil produktet have et woodprint i både Danmark og udlandet. Den beregnede hugst af træ relateret til den danske eksport var 5,3 millioner m³ i 2016 og 6,1 millioner m³ i 2018.

Kaskadefaktoren er et mål for hvor mange gange en ressource genbruges inden for den danske økonomi. Kaskadefaktoren for den samlede træanvendelse var 1,44 i 2018.

En stor del af træressourcen anvendes til energi, hvor der ikke er mulighed for genanvendelse. Det er derfor som forventet at kaskadefaktoren for træ- og papirindustri sektorerne isoleret var højere, henholdsvis 1,88 og 3,58 i 2018.

### 2.2. Diskussion


Sankeydiagrammerne illustrerer primært træstrømme taget direkte fra statistiske datakilder, men principippet om bevarelse af masse medfører at udokumenterede træstrømme er blevet identificeret og forsøgt kvantificeret gennem balancering af forsyning og forbrug. Træstrømme er kvantificeret gennem balancering: hugst af brænde til privat forbrug, anden træbiomasse til energi, samt output fra træindustrien, der bruges til færdige træprodukter.

I 2018 er den udokumenterede hugst af brænde anslået til 1,8 millioner m³. Til sammenligning var den rapporterede hugst af brænde i skovene 284.400 m³. Metoderne til opgørelse af brændeforbrug er blevet ændret over tid og det opgjorte brændeforbrug var lavere i 2021 end i 2018 (1,7 mod 2,4 millioner m³). Det vides ikke om faldet dækker over et reelt fald i forbruget eller over ændrede opgørelsesmetoder, men den udokumenterede hugst af brænde ville være mindre i 2021.

Anden træbiomasse til energi dækker over træflis og er kvantificeret ved at trække rapporteret hugst af energitær og import fra forbruget af træflis og eksport. Denne træstrøm kan indeholde flis fra pil og poppel i kort omdrift fra landbrugsarealet, læhegn, parker, juletræer m.m. Denne udokumenterede træstrøm er opgjort til 1 million m³ i 2018. Der er stor usikkerhed om tallet, og underrapportering af import og indenlandsk, og overrapportering af eksport vil medføre et for højt estimat.
Træindustrien producerer en række halvfabrikata, der nemt kan konverteres til m³ SWE, men der produceres også en række færdige træprodukter, hvor konvertering til m³ SWE er mere usikker. Massen af disse produkter er opgjort i den nationale materialestrømsregnskab, men mange af disse indeholder andre materialer end træ, f.eks. glas i døre og vinduer, eller plast, tekstil og metal i møbler.

3. Introduction

Wood is perhaps the most versatile of our natural resources. The properties of wood make it suitable for a wide range of uses, which have continued to increase with technological development. The use of wood for construction and to provide energy are some of the oldest uses – and they remain highly relevant, while the increasing ability of wood-derived materials to replace petroleum-derived materials along with steel and concrete mean it is likely that demand for wood will increase in the coming years. Wood is a renewable natural resource, but it is also limited, and the trees that produce it mainly come from forests which provide us with many other tangible and intangible values. The amount of wood we use (and how we use it) therefore has important implications for the management of our forest resources on a national, European, and global scale.

3.1. EU and Danish policy framework

The European Union (EU) 2021 Forest Strategy for 2030 (European Commission 2021) aims to support the socio-economic functions of forests for rural areas and to boost a forest-based bio-economy within the boundaries of sustainability. Given the increasing and sometimes competing demands on forests, a key element in the strategy is to ensure that the amount of wood used remains within the sustainability limits and is optimally utilised in line with the cascading principle\(^1\) and the circular economy approach.

The European Commission adopted the new circular economy action plan (CEAP) in March 2020 (European Commission 2020). It is one of the main building blocks of the European Green Deal, Europe’s new agenda for sustainable growth. The EU’s transition to a circular economy is planned to reduce pressure on natural resources and create sustainable growth and jobs. It is also a prerequisite to achieve the EU’s 2050 climate neutrality target and to halt biodiversity loss.

The 2018 update of the EU Bioeconomy Strategy (European Commission 2018) intends to accelerate the deployment of a sustainable European bioeconomy so as to maximise its contribution towards the 2030 Agenda and its Sustainable Development Goals (SDGs), as well as the Paris Agreement.

Although lacking a dedicated bioeconomy strategy, Denmark has formed a national bioeconomy panel with the aim to prepare recommendations to the government on the development of a bioeconomy strategy. In their latest recommendations of 28 September 2022 (Det Nationale

\(^{1}\) Under the cascading principle, wood is used in the following order of priorities: 1) wood-based products, 2) extending their service life, 3) re-use, 4) recycling, 5) bioenergy and 6) disposal.
Bioøkonomipanel 2022), the panel points towards cascading use of bioresources, not limited to forest resources, and on considerate use of forest biomass in long-lived products.

Finally, the Danish Climate Act of 26 June 2020 (Folketinget 2020) stipulates a reduction in territorial greenhouse gas emissions of 70% relative to 1990 by 2030 and climate neutrality no later than 2050 in line with the goals of the Paris Agreement (§1). At the same time, it is emphasized that initiatives taken to reduce territorial emissions must ensure that emissions are not moved to other countries (§1, stk. 3.4).

Meeting the above policies and strategies on national and supra-national level requires an extended level of insight and understanding of resource flows through the economy.

### 3.2. Wood flow analyses

Over the last 20 years, various European countries have undertaken economy-wide material flow analyses (MFA) to better understand their supply and use of wood. There have also been EU wide analyses; see for example Mantau (2012), while more recently, online tools have been developed to describe wood flows within the EU using Sankey diagrams (Cazzaniga 2022). A global analysis has also been undertaken according to the principles of MFA (Bais, Lauk et al. 2015).

Just as national forest resources vary, so do countries’ use of wood. The purpose of conducting wood flow analyses can also vary; recent efforts have been undertaken to understand circular or cascading use of wood in Portugal (Gonçalves, Freire et al. 2021) and in Finland with comparison to other EU countries (Sokka, Koponen et al. 2015) while an analysis has been conducted in France to inform about potential effects on the wood resource chain with changes in log export policy (Lenglet, Courtonne et al. 2017).

Finally, analyses may have a more general objective to improve the understanding of wood flows in a country: to answer questions such as where does it come from and how is it used, and what are the implications for the economy and natural resource management (Weimar 2011, Parobek, Paluš et al. 2014).

### 3.3. Aim and approach of this study

The overall aim of this project is to provide a quantitative mapping and overview of the material flow of wood within and to and from Denmark, to better understand how wood is utilized and to inform discussions with different perspectives on the optimal use of wood.

We also estimate Denmark’s consumption-based “woodprint”, or how much global wood extraction is caused by Danish economic activity.

Lastly, the project aims to assess the level of cascading resource use and circularity within the wood products sectors.
The analysis builds on the system of national accounting and data from the physical supply and use tables (PSUT) of Statistics Denmark complemented with forest inventory and harvest data, national energy and waste statistics and data from FAOSTAT - the latter being a primary source for tracking wood consumption back to its origin.

4. Materials and methods

4.1. Material flows in general and scope of our analysis

Methodologically, the analysis builds on material flow analysis as described by Brunner and Rechberger (2016). MFA is an analytical method to quantify flows and stocks of materials and substances in a system. A key characteristic of MFA is that flows must balance according to the law of conservation of mass, i.e., since it can be neither created or destroyed, the mass of material inputs must equal mass of stocks and material outputs. In practical terms, this balancing principle between supply and use may help identify unmeasured flows of materials that have not been captured by available data.

At a national economic level, material flow analysis includes all material flows from nature (i.e. resource extraction), imports, domestically processed output, and exports (Eurostat 2018). By quantifying these various flows and examining their relationships, MFA can be an informative tool for policy decisions relating to the various material flows.

The boundary of our MFA system is limited to the Danish economy. All material flows consisting entirely or partially of wood were examined. As some streams are covered by multiple data sources, all relevant sources were reviewed, with a focus on using original source data where possible to minimise the number of conversions applied. For derived data, investigations of conversion factors and assumptions used were also undertaken.

It was decided to limit the scope of the study to wood and wood-derived fibres. We therefore excluded the relatively small flows of non-timber forest products such as bamboo, rattan, and cork. Textiles and fabrics derived from cellulose were also excluded, as it could not be ascertained if these products were actually produced from wood or from another type of biomass.

4.2. National accounts, supply-use and input-output tables

The System of National Accounting (SNA) and the System of Environmental-Economic Accounting (SEEA) frameworks are internationally agreed statistical standards on how to compile economic activities and how to integrate economic and environmental data to analyse interrelationships between the environment and the economy (United Nations 2008, SEEA 2022). These standards facilitate the Danish goal to build a framework based on national and international data of high validity.
Statistics Denmark (DST) has a long tradition of compiling national accounts of high quality and resolution that have been a main source for the description of the wood-related economic activities used in this project. We build on the structure of the Danish economy as described in the national monetary supply-use tables (SUT), the input-output tables (IOT), and the physical supply-use tables compiled by DST.

The supply and use tables describe the supply of goods and services by producing industries and import as well as the use of products for intermediate and final consumption, including export (European Commission 2008). After a comprehensive balancing process, supply and use tables provide information on the production processes, their interdependencies and use of products to satisfy both industries’ and consumers’ needs, thus linking industries, products and sectors (European Commission 2008).

The input-output tables are a special transformation of the supply and use-tables, which show the connections between imports, production and uses in the economy (European Commission 2008, Statistics Denmark 2022). Based on assumptions about the relations between industries’ inputs and outputs, the tables enable modelling of inter-industry connections in the economy – and between the economy and the environment for the environmental areas where the green national accounts have been developed (United Nations 2008, Statistics Denmark 2022).

**4.3. Physical supply and use-tables**

For this project, the physical supply-use tables are a key resource as they provide data enabling categorisation and measurement of the wood-related production, trade and consumption at product and industry level.

The PSUT are an extension to the monetary supply and use-tables used in national accounting. A part of the Environmental-Economic Accounts or “Green National Accounts” and published for the 2016 year, they have recently been updated to include 2018 data. The PSUT “describe the magnitude (measured in tonnes) and nature of materials and commodities flowing in the economy and between the economy and nature” (Gravgård and Nursen 2014). The tables cover the entire economy and are constructed from various data sources at DST with inputs and outputs balanced manually.

Following the structure of the National Accounts, in addition to imports, there are 117 industry groups that are engaged in domestic production (acting as producers and intermediate consumers) and around 1800 physical products, as well as 135 categories of final consumption (including consumption by the public sector, households, and exports). The inputs to industries from natural resource extraction have been additionally included, as have flows of residuals (emissions, solid waste, etc.) to the environment.

The physical products are coded to correspond with the European goods classification system, the Combined Nomenclature (CN), and so can be grouped accordingly. In terms of wood flows, this
means that there is direct correspondence to, for example, Chapter 44 of the CN “Wood and Articles of Wood; Wood Charcoal” as well as products that can be found in Chapter 94 “Miscellaneous Manufactured Articles” including furniture and prefabricated buildings. The structure of the PSUT includes a wood product sub-grouping, with products from the above chapters as well as several others.

4.4. Reference unit

By convention, economy-wide MFA use metric tonnes as the standard unit of analysis. However, wood and wood products are often better understood in other units, depending on where the reference point lies along the processing chain. A forester managing the harvest of wood deals in volume units, such as m$^3$; a biomass energy plant pays by energy content (measured by weight and moisture content for wood chips) and a furniture maker sells wooden furniture by the piece. All these stages could be measured in mass, but this presents various analytical problems when it comes to wood.

For one, as a hygroscopic material, wood includes varying amounts of water depending on the stage of processing or use. The mass of water can be adjusted for, and water is often excluded in economy-wide MFA. However, as wood is further processed into finished products it is often mixed with other materials such as plastics or adhesives. While economy wide-MFA may be agnostic about the ratio of the mass of wood to adhesives in plywood, for wood flow analysis it is crucial to understand the actual amount of wood in the product. Finally, wood as a natural resource is by convention measured in m$^3$. It is therefore not necessarily straightforward to understand the volume of wood resource contained in 5 tonnes of wood product.

In order to provide a meaningful analysis of the natural resource flow from extraction to finished product, it has been suggested that a more appropriate reference unit when dealing with wood and wood products is “m$^3$ solid wood equivalent” also known as “m$^3$ wood fibre equivalent” (Weimar 2011). This reference unit has since been used for wood flow analyses in, among others, Finland (Sokka, Koponen et al. 2015), France (Lenglet, Courtonne et al. 2017), and Portugal (Gonçalves, Freire et al. 2021). The m$^3$ of wood in this unit is the same as the volume of one m$^3$ of wood at the time of harvest. In this instance the wood fibres are at the fibre saturation point, i.e., the point before which the wood has begun to shrink from loss of moisture. Conversion factors have been published (FAO 2022) that enable the conversion of semi-finished and some finished products back to the m$^3$ of solid wood equivalent (SWE) in the product.

The use of SWE also eliminates the double counting of recycled processing residues that could occur if using other wood volume conversions for products, such as the raw wood equivalent. The raw wood equivalent describes the total volume of wood resource required to produce a product which includes wood that is removed during processing and could be used in turn to produce other products. Tallying the raw wood equivalent required for each product would be double counting the resource.
4.5. Wood Flow Model

For this analysis, a wood flow model based on the PSUT was constructed that incorporates data from various sources. The model is linked to a Sankey diagram that represents the different flows and can output values for years with published PSUTs, i.e., 2016 and 2018.

As it was decided to use the m$^3$ SWE as the reference unit, and as the PSUT uses tonnes which have in some cases been converted from primary sources using m$^3$, it was often necessary to return to the primary sources of the PSUT to convert directly to m$^3$ SWE rather than converting from a derived mass of tonnes to reduce compounding error from multiple conversions. It was also important to examine the assumptions involved in any conversions in the primary sources.

In the PSUT, as wood moves from forest to finished product, it flows between industries, being produced initially by the forestry industry with the harvest of timber, and then being utilized by other industries for the production of goods that are again used in further processing or consumed by households. Wood products are used not only in the manufacture of products but also to produce electricity or heat on an industrial and household scale. The key advantage of using the PSUT as the framework of the model is that different data sources are reconciled through a balancing process and flows of physical goods within the economy are allocated according to monetary flows where no other information is available. The PSUT also provides a mass balance for every industry classification within the PSUT showing the transfer of intermediate products between industries.

It is not useful to simply sum all the flows of wood products in the PSUT to obtain a total supply or use of wood products. This is because the same wood may pass through several different industries during processing. To avoid double counting and to obtain a more complete picture of the reliance on imports at different points in the value chain it is necessary to group flows in a processing hierarchy.

As the product codes in the PSUT align with the CN system, they are therefore also analogous to other international classifications including the Harmonised System (HS). Among these is the Food and Agriculture Organisation (FAO) Classification of Forest Products, which describes the correspondence between the HS system and the FAO forest product definitions and is related to the degree of wood processing involved, from logs through to semi-finished products such as plywood and secondary products such as furniture (FAO 2022). The Intergovernmental Panel on Climate Change (IPCC) also refers to FAO wood product categories in guidelines for reporting on carbon storage in Harvested Wood Products (HWP) (IPCC 2006).

The PSUT product codes for wood products were arranged into groups representing roundwood (including fuelwood), lightly processed wood (including wood pellets), and the semi-finished categories of sawn wood and wood panels. Products with further processing were classified as secondary products. The PSUT also includes flows of wood residues for energy and collected wood waste for recycling or energy use, which are not disaggregated in the HS/CN system but are
included in our model grouping. Excluding the relatively small flow of cork products, a total of 42 relevant codes are listed in the 2016 PSUT wood group (47 in 2018). It was apparent that products representing flows of wood for energy were absent; these had been classified in a separate energy group. After these flows were included 47 codes comprised the wood product group. Many of these codes are aggregated and include groupings of CN codes; the amount of aggregation can vary but is according to the CN structure.

Flows of paper were also included on a simplified basis for 2018. The PSUT includes a group of paper products, however there is not currently any production of pulp from wood in Denmark. The flows are therefore not directly connected to domestic wood harvest.

After the PSUT product codes were grouped according to the processing chain, each was investigated within the PSUT database source files to ascertain the origin of the data. With the exception of the codes representing natural resource extraction, each product code includes data on the supply side (domestic production, use of domestic stock, import) and on the use side (used in intermediate production, domestic final consumption, and export).

4.6. Multiregional input-output databases and footprints

In order to track the use of imported wood back to its national origin and to develop a model to estimate the wood footprint attributable to Danish production, import, export and consumption, we relied on the so-called multiregional input-output databases (MRIO). MRIO-based models attempt to capture the various economic relationships amongst several regions or the global economy as a whole (Miller and Blair 2009). The fundamental structure of the MRIO models is similar to the single country IO models, although the amount of data necessary to build the MRIO databases is substantially larger (Miller and Blair 2009).

Triggered by discussions on international trade of products and measuring environmental (primarily focused on emissions) responsibility resulting from interactions between trade and the environment, several global environmentally extended multiregional input-output (EE-MRIO) databases have been constructed within the last few decades (Tukker and Dietzenbacher 2013). Today there are a few established EE-MRIO databases, such as EXIOBASE, EORA, ICIO, FIGARO, developed and maintained at different research institutions or international organisations. The models are built-up under the same principles and with similar data sources, but the level of detail of economic and environmental data could be substantially different. A description and comparison of these databases is outside of the scope of this project, see e.g., (Tukker and Dietzenbacher 2013, Moran and Wood 2014, Tukker, Wood et al. 2020) for more details.

Calculations of the various types of economy-wide footprints, such as climate, water, land, etc. that have been published in recent years are almost entirely based on input-output modelling and an EE-MRIO database (Vanham, Leip et al. 2019). Internationally linked input-output models have proven to be a robust way to keep track of the environmental stressors that occur due to direct and indirect activities along the global value chains.
The MRIO models are based on the countries' national accounts and foreign trade statistics, enabling the calculation of an economic input-output system including global trade of goods and services. Within the calculations, all sub-deliveries of products between industries in the individual countries and across different countries are taken into account. For each country, the production by economic sectors is divided into product types or industries. By linking this production with environmental data from the green national accounts and other sources, average industry- or product-specific environmental factors can be calculated at country level. Then, tracing the countries' production, trade and consumption activities distributes the resulting environmental metrics throughout the global economic system.

4.7. Production-based and consumption-based accounting

Although the concepts of the production and consumption-based accounting have been primarily described in the realm of emission accounts, see e.g., (Franzen and Mader 2018, Pedersen 2021), the principle holds for any kind of environmental impact that could be linked to measured economic activity. The distinction between production-based and consumption-based environmental accounts is made depending on how the traded goods and services (and the associated environmental impact) are registered in these accounts. The production-based account includes domestically produced products, no matter where in the world they are consumed, while excluding the imported goods and services to the reporting country. In contrast, the consumption-based account includes both the domestically produced and imported products, while excluding the goods and services exported to foreign consumers. This topic relates to the discussion in the literature on the producer versus consumer responsibility for environmental loss (Lenzen et al., 2007; Tukker & Dietzenbacher, 2013). Lenzen, Murray et al. (2007) point out that, if the consumer is to blame, all the environmental impacts, e.g., emissions or extraction of wood, must be attributed to the final consumption of a country resulting in this country’s footprint. Within the producer responsibility, on the other hand, the country’s wood extraction and the related environmental effects would be linked to the total production within this country (Lenzen, Murray et al. 2007).

Vanham, Leip et al. (2019) define environmental footprints as “indicators of pressure of human activities on the environment.” (Hoekstra and Wiedmann 2014) specify that footprints are “indicators of human pressure on the environment and form the basis for understanding environmental changes that result from this pressure (such as land-use changes, land degradation, reduced river flows, water pollution, climate change) and resultant impacts (such as biodiversity loss or effects on human health or economy).”

Measuring footprints aims to give a complete picture of environmental pressures and is based on “life cycle thinking” throughout the whole value chain, from production to consumption and even waste management (Vanham, Leip et al. 2019). Footprints address different environmental concerns and can measure both resource use and waste generation (Hoekstra and Wiedmann
The basic footprint unit is the footprint of a single process or activity. This “unit footprint” forms the basis of a footprint of a product, consumer, producer, or for the footprint within a certain geographical area (Hoekstra and Wiedmann 2014). When using an EE-MRIO database, the unit footprint depends on the type of the database and the aggregation level of its products and industries. Within the industry-based monetary version of EXIOBASE, for instance (see section 4.6), one industry and its measured environmental impacts form a unit footprint. In the case of wood extraction, the unit footprint would be cubic meter extracted wood per industry output measured in monetary units. Regarding footprints addressing wood resources, there have been efforts to measure the wood resource use at global, e.g., (Zhang, Li et al. 2020), regional, e.g., (O'Brien and Bringezu 2018) and country level, e.g., (Egenolf, Vita et al. 2021). However, we are not aware of any publications presenting a wood footprint for Denmark.

We define the Danish wood footprint (woodprint for short) as the extracted wood resources anywhere in the world that can directly and indirectly be attributed to the Danish final consumption. The domestic extraction is based on FAOSTAT’s definition and data, which are described further in section 4.11.

4.8. Woodprint model

A consumption-based accounting for wood resources focuses on domestic wood extraction caused by consumption anywhere in the world. Such accounting seeks to locate the origin of the wood extraction by tracing the value chains related to production, trade, and consumption globally. Therefore, it includes not only the country of consumption, but also all the other countries and their economic activities that took part in the value chain directly or indirectly. In the case of Denmark, all the resources used abroad to satisfy its consumption are included in the account, while resource extraction related to production of goods and service for Danish export are excluded.

As stated above in section 4.6, an EE-MRIO database can be set up as an input-output model, with which it is possible to calculate an environmental footprint for Denmark. In all existing EE-MRIO databases, Denmark’s economic and environmental data is an explicit part of the model, which makes it possible to link the Danish data to the economic activities of all the other countries in a database and thus trace the environmental impacts linked to the Danish domestic consumption.

2 The Danish final consumption is defined as the sum of the final consumption of resident households, non-profit institutions serving households (NPISH), government consumption expenditure, gross capital formation and changes in inventories. It includes all goods and services that are part of the national accounts and it is not restricted to wood products alone. Source: UN, 2008
In 2021 Statistics Denmark developed a Danish climate footprint model in cooperation with the Danish Energy Agency\(^3\) (Iliev, Jensen et al. 2021). The method used in DST’s model is inspired by the Swedish PRINCE model for calculating the environmental impacts linked to Swedish consumption (Statistics Sweden 2022), which uses the global EE-MRIO database EXIOBASE in combination with national economic and environmental account produced at Statistics Sweden.

The Danish climate footprint model couples Statistics Denmark’s economic-environmental accounts with EXIOBASE. Using Danish input-output tables and emission data alone, the model can calculate the amount of greenhouse gas emissions that Danish consumption gives rise to in Denmark. This part of the model corresponds to the already existing DST IO model (Statistics Denmark 2022). Next, the import of products for both intermediate use and final consumption are added to the climate footprint model. Using multipliers from EXIOBASE, the model can calculate the emissions caused by the production of this import abroad. These multipliers tell us the amount of emissions caused by the Danish import from all around the world, broken down by industry and country. In this way, EXIOBASE and the Danish input-output model are linked together using data for Denmark’s import divided by both industries and countries. These industry-specific and country-specific multipliers are currently available for the years 2010 to 2020. Iliev, Jensen et al. (2021) present a detailed description of the method and the mathematical background behind the Danish climate model.

The woodprint model is essentially an extension of the climate footprint model, where the climate information in the model is replaced with wood extraction. Instead of calculating greenhouse gases as a stream of pollution to nature, which is in a sense a by-product of a production process or the use of products, the wood footprint model calculates resource use, where the unit footprint is an extracted amount of roundwood per unit of production.

**4.9. Primary data sources for the wood flow model**

As noted, the PSUT uses various data sources from within DST, some of which in turn draw on other sources. For products used for energy and waste flows, data is directly taken from the Energy Account and Waste Account (both parts of the Green National Accounts) which are derived from data sources at the Danish Energy Agency (referred to in this report as the Energy Statistics) and the Danish Environmental Protection Agency, respectively.

The DST sources include the PSUT (2016 and 2018), Energy Account, Waste Account, Industrial Commodity Statistics, International Trade in Goods (with corrections made during the development of the National Accounts), and Felling of Wood in the Danish Forests.

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\(^3\) The development of the climate footprint model is an ongoing project lead by DST and the Danish Energy Agency.
The source used for each wood product grouping and its treatment is described below; note that multiple sources were often available for each stream and a judgement had to be made on which to use.

4.9.1. Roundwood

Supply from Domestic harvest/production/usage of stock. In the PSUT, the domestic extraction of wood is derived from two sources. The felling statistics (SKOV55) were the source for the harvest of industrial timber, while the Energy Accounts (ENE1HO) provided data for the domestic harvest of wood used for energy (firewood for household consumption and wood chips – “energy wood”). The felling statistics use m$^3$ for all assortments while the Energy accounts present firewood in m$^3$ and wood chips in tonnes. The felling statistics (SKOV55) reports the harvest’s disaggregation to assortments, which informs this analysis. In total felling volumes, there is good correspondence between the felling statistics and the National Forest Inventory (NFI) (Nord-Larsen, Johannsen et al. 2020), however the NFI does not report fellings disaggregated to assortments.

As the Energy accounts are usage-based while the felling statistics describe actual extraction from forest areas, in our model it was decided to use the felling statistics as the primary source for all domestically harvested wood - as output from the forestry industry. This was necessary to highlight the difference between the overall utilization of domestic woody biomass for energy and the documented harvesting of wood for energy from Danish forests. The difference between these two flows should roughly represent the significant (and difficult to quantify) flow of woody biomass for energy from sources other than forests, including landscape care wood, garden waste, etc. In the PSUT this difference was partially handled as a usage of domestic stock, while we have chosen to represent it as a balancing flow from other natural sources.

Supply from imports. The import of roundwood for fuel (firewood and wood chips) in our model is sourced from the Energy Account. As above, firewood is reported in m$^3$. This figure is derived from the Energy Agency statistics (published in TJ) and converted to m$^3$ before publication in the Energy Account. The PSUT source database also includes data from the foreign trade of commodities (UHV) database of import statistics, however this is in tonnes. The Energy Agency apparently estimates the import fraction for 2016 and 2018 at 12%, based on surveys of use by households and interviews with businesses (Ea Energy Analyses 2017). There is a significant difference between the two figures (with the Energy Account indicating an import more than twice as large as the trade statistics) but it was decided to use the Energy Accounts for consistency, as this is where the overall use is also derived as described below.

For wood chips, two sources in the database were compared. In this case the Energy Accounts are identical to the UHV import statistics and are in tonnes. Tonnes were converted to m$^3$ SWE. Imports of industrial roundwood are in the PSUT reported by the trade statistics, and are presented in both kg and m$^3$. After investigation it was decided to use the m$^3$ figure provided, with some manual corrections for obvious errors. The manual corrections were guided by the available values in all three units: monetary in DKK, physical in kg and physical in m$^3$. This allowed the
construction of average unit prices (DKK per kg and DKK per m³) and conversion factors of volume to mass (m³ per kg) at CN-level. All the CN-codes used as data sources for the construction of the PSUT were evaluated with regard to the average unit prices and conversion factors. In the cases in which the physical values reported diverted considerably from the average unit prices and/or conversion factors, an expert judgement had to be made. Based on values for similar product codes or different flows within same code (e.g., extreme value for the unit price of import compared to the Danish production and export), corrections were made to “smooth” the outliers. According to discussions at DST, no previous investigation has been conducted into whether the mass or volume reported for trade in roundwood can be considered more reliable. After calculating the ratios of volume to mass for each entry (the conversion ratio) it was found that these conversion ratios were in aggregate similar to published conversion factors for coniferous and broadleaf timber.

Use of roundwood. The use of wood chips is distributed to both industries and households while firewood is exclusively used by households according to the Energy Accounts (ENE1HA). Industrial roundwood use was allocated to industries according to the PSUT distribution. Very small balancing flows to domestic stocks as balancing flows in the PSUT were disregarded in this case. For export flows, the Energy Accounts were used (ENE1HO) for fuelwood and the trade statistics figures in m³ were used for other roundwood, following a mass to volume ratio analysis.

4.9.2. Wood simply worked or processed (including wood pellets)

Supply from domestic production/usage of stock. In this category, which includes wood pellets, charcoal, hoopwood, stakes, treated timber, and wood wool, the PSUT source data indicates two sources for domestic production – the Industrial Commodity Statistics (production statistics) for all products, and the Energy Account for wood pellets.

Apart from a significant domestic production of pellets, there is limited domestic production of treated timber and little or no domestic production of the other products in this category. As the PSUT does, we have used the Energy Account for pellet production (in tonnes) attributed to the wood industry (ENE1HO) and the production statistics for the other products (tonnes and m³ in the case of treated timber). There is a significant supply of pellets from domestic stock in the PSUT and Energy Account (ENE1HO) in 2016, while there is a flow to stock in 2018.

Supply from imports. Pellet import is described by the Energy Account (ENE1HO) in the PSUT and we have taken this number which is nearly identical to the trade statistics. Import of treated timber is presented in m³ in the trade statistics so this figure was used instead of the tonne figure used in the PSUT; the remainder of the products were converted from tonnes to m³ SWE.

Use of simply worked wood products. The use of pellets by industries in the PSUT is distributed according to the Energy accounts (ENE1HA) and this has also been adopted in our model, since the Energy Agency statistics provide distribution data by type of power plant (CHP, private electricity or heat producers (autoproducers), etc.,) for both heat and electricity but does not link energy
producers to their specific industries. The use of the other products in this category is allocated according to the PSUT distributions to industry and households. Export data is provided by the PSUT in tonnes and it has been converted to m³ SWE, with the exception of treated timber where the m³ figure from the detailed UHV database was used.

4.9.3. Sawnwood

Supply from domestic production/usage of stock. Domestic production of sawnwood is taken from the production statistics in m³; a conversion factor is applied to account for shrinkage.

Supply from imports. Sawnwood is a single aggregated code in the PSUT and includes more than 40 CN product codes from the import statistics. The secondary unit in the import statistics also varies from m³ to m². An analysis of the variation of ratios between value and reported weight and volume revealed a much higher degree of variation than that found in raw timber or simply processed products; nevertheless, manual corrections were made as earlier described, and m² units were converted to m³ where necessary, and conversion was made to m³ SWE.

Use of sawnwood. The use of sawnwood is distributed according to the PSUT distributions in 2016 and 2018. In general, as one moves through additional stages of processing, the distribution of usage becomes more widespread across the economy. For example, while it is primarily the wood industry that uses the timber produced by the forestry industry, nearly every industry utilizes some sawnwood for intermediate consumption, and it is also consumed by private households. PSUT figures for tonnes are used for export with the appropriate conversion factors.

4.9.4. Wood Panels

Supply from domestic production. This category includes products such as veneer sheets, chipboard, plywood, and fibreboard; domestic production figures in the production statistics vary, and are reported in Danish kroner, m³, and tonnes. Where available, the direct m³ number was used with conversion to m³ SWE, in other cases the figure in tonnes was used and converted appropriately.

Supply from imports. It was decided to use the figures in tonnes (PSUT and trade statistics were identical) for the imports of wood panels. While some products are reported in Danish Kroner (DKK), kg, and m³, panels may also be reported in m². Analysis of the raw data seems to indicate that through human error m² values may be reported as m³ in some cases. It was therefore decided to use the figures in tonnes.

Use of wood panels. Just as with sawnwood, use is distributed according to the PSUT, and export figures use PSUT data in tonnes to reduce possible errors in reporting between m² and m³.

4.9.5. Wood Waste and Residues

The PSUT uses multiple sources for products considered “wood waste,” drawing on entries from both the Energy and Waste accounts. The term waste is often used interchangeably with residues,
but here clarification is needed. The Energy Account tracks industrial residues and by-products used for energy production and refers to it as wood waste, while the Waste Account describes wood in various forms discarded as waste and collected by the waste collection system as wood waste. Residues may be traded directly with energy producers, never entering into the waste system so will not appear in the waste accounts. From now on in this report, we consider what is labelled as wood waste in the Energy Accounts to be residues and refer to it accordingly, while “wood waste” will refer to the materials passing through the waste handling system and registered in the Waste Account.

The PSUT handles wood waste in a two-stage process: unprocessed wood waste is collected from industries and households by the waste collection industry with a portion going to further processing and a portion going directly to incineration or export. The portion going for further processing becomes processed wood waste, of which a portion is provided to the wood industry for recycling with the remaining portions going to incineration or export.

Supply or domestic production of wood waste. The collection of wood waste in tonnes is allocated as coming from various industries and households in the Waste Accounts and the PSUT uses this distribution to describe the source of the supply of unprocessed wood waste. The PSUT distributes this collected waste to either further treatment and recycling or directly to incineration.

Supply from import of wood waste. Numbers in tonnes are provided in the Waste Account and used by the PSUT for import of wood waste.

Use of wood waste. As noted above, in the PSUT the waste collection industry is the user of unprocessed waste, with a portion of unprocessed waste going to incineration. The processed wood waste is distributed to the wood industry for re-use, to the waste industry for incineration, and a further portion to export. The PSUT draws on the Waste Account for this information. It should be noted that the Energy Agency statistics would count wood collected for incineration not as labelled “wood waste” (which is residues), but in other streams of waste for incineration.

Supply from domestic production of wood residues for energy. The Energy Agency provides statistics on the use of wood residues for energy production. However, no origin information is provided. The Energy Account estimates the sources of these residues in tonnes and is used by the PSUT. We have therefore used these numbers to describe the origin of residues for energy. We have assumed that wood pellets are made within the wood industry from unreported residues.

Supply from import of residues. There is no information provided by any source about the import of raw wood residues for energy. However, it should be noted that wood pellets imported into Denmark for energy use may be produced from these wood industry residues in other countries.

Use of residues. As described for other wood fuels, the Energy Agency and the Energy Account distribute usage of residues differently, with the Energy Agency focusing on type of power plant while the Energy Account groups energy producers as industries according to electricity or heat production.
4.9.6. Finished products and paper

Import/Export of finished products and paper. These flows were taken directly from the tonne figures in the trade statistics and conversion factors applied. This was only possible for the 2018 year as available conversion factors correspond to that version of the HS trade classification.

4.10. Secondary data sources for the wood flow model

A number of data sources secondary to the National Accounts and the primary data sources were consulted for the development of the wood flow model, either to provide data directly or to compare with the PSUT and the previously mentioned source data. In some cases, the source data noted above was derived from these secondary sources. A short list and description follows.

Danish National Forest Inventory. The National Forest Inventory (NFI) is produced annually by the Department of Geosciences and Natural Resource Management at the University of Copenhagen. It uses a nationwide sampling plot methodology to estimate forest stocks, increment and removals from year to year.

The Forest Account (a part of the DST National Accounts). The forest account is published every year and provides information on forest stocks, increment and harvest and is based on the NFI and other DST sources.

Danish Energy Agency Statistics. Published every year by the Danish Energy Agency, these statistics provide data on production and consumption of energy. Included is information on three different wood fuel types, including chips, pellets, and the aforementioned “wood waste” or residues. Data is provided on domestic extraction or production as well as imports of these resources, though export of wood fuels is not covered.

Danish Nature Agency Sales and Harvest Data. Provided directly by the Nature Agency, this data presents the sale of timber for years prior to 2020, while from 2020 it presents actual harvest data for forests managed by the Danish Nature Agency. It includes assortment information (i.e., distinction between broadleaf and conifer, energy wood and industrial timber). The Nature Agency represents 18% of the total forest area with management principles and aims not representative to the forest area in general.

4.11. Data sources for the Woodprint model and EXIOBASE

The woodprint model uses both Danish and international data sources. For the Danish part, the input-output tables produced at DST are a main source of the economic data. In addition, the felling statistics (SKOV55) provide the numbers for the harvest of timber in Denmark. The amount of wood harvest is then assigned to the forestry industry, which is the only extracting sector in the woodprint model. The resulting extraction coefficient of the industry is about 0.0008 m³ per 1 DKK in 2018, which is equivalent to 1,250 DKK per m³, or 800 m³ per 1 million DKK of economic activity within the industry. The interpretation of the coefficient is that the production of 1 million DKK by
the forestry industry in Denmark in 2018 generated about 800 m$^3$ domestic wood harvest. This coefficient is in line with the coefficients calculated for the forestry industries in other countries in the database used for the woodprint calculations in this project (described in the next paragraph). Selected estimates for 2018 are: 800 m$^3$ per 1 million DKK in Austria, 1200 per 1 million DKK in Norway, 1700 m$^3$ per 1 million DKK in Germany and Sweden, 1600 m$^3$ per 1 million DKK in Finland. The difference in the coefficients among countries does not necessarily measure their relative resource productivity since the forestry sector also uses services to run its business. In Denmark for instance, about half of the Forestry’s monetary input is services, according to DST’s IO tables, which might explain the lower harvest coefficient compared to other Scandinavian countries.

A footprint calculation is a data-heavy calculation that requires not only domestic data, but also data on all countries involved in the production of goods and services consumed in Denmark. In other words, for a complete wood footprint analysis an EE-MRIO database is needed. The database chosen in the case of the climate footprint and the wood footprint models is the monetary industry version of EXIOBASE, which contains 163 industries (Stadler, Wood et al. 2021). This version follows a similar structure to the Danish input-output tables, with the same principles and data source types to the Danish input-output tables. It links production and consumption information across 44 countries and 5 overall regions (Rest of World (RoW) Asia and Pacific, RoW America, RoW Europe, RoW Africa, and RoW Middle East).

The model describes the trade flows in the form of imports and exports at two levels – industries and countries. The complete database contains matrices with dimensions (49 countries/regions x 163 industries) x (49 countries/regions x 163 industries) that link both industries and countries/regions to each other.

The current version of EXIOBASE 3.8.2. (released in October 2021) provides time series of EE-MRIO tables within the period 1995 – 2022 (the years 2020, 2021 and 2022 are projected with the last information available at the time of compiling) for 44 countries (27 EU member plus 17 major economies) and five rest of the world regions.

An important part of EXIOBASE is its environmental data, called “environmental extensions” can be coupled to the economic data, thus assigning environmental effects to economic activity. There

\[ ^4 \text{Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Greece,} \]
\[ \quad \text{Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania,} \]
\[ \quad \text{Sweden, Slovenia, Slovakia, United Kingdom, United States, Japan, China, Canada, South Korea, Brazil, India, Mexico,} \]
\[ \quad \text{Russia, Australia, Switzerland, Turkey, Taiwan, Norway, Indonesia.} \]
are over 400 emission categories and 600 material and resources categories found in the database.

There are four types of resource extraction of wood in EXIOBASE used for our calculation. These are presented in Table 1.

| Table 1. Types of wood extraction used in our calculations. Source: (Stadler, Wood et al. 2021). |
| Domestic Extraction Used - Forestry - Coniferous wood - Industrial roundwood |
| Domestic Extraction Used - Forestry - Coniferous wood - Wood fuel |
| Domestic Extraction Used - Forestry - Non-coniferous wood - Industrial roundwood |
| Domestic Extraction Used - Forestry - Non-coniferous wood - Wood fuel |

The domestic extraction numbers in EXIOBASE are reported in tonnes and it is unclear when they were last updated. Therefore, it was decided to replace all the domestic wood extraction within EXIOBASE’s database with data from FAOSTAT. Thus, the amounts reported for each country in the woodprint model correspond to FAOSTAT’s Forestry Production and Trade statistics on the production quantity of roundwood by country (FAOSTAT 2022). These statistics include officially reported domestic wood harvest (under bark) in m³. Since the collection of the data is based on the Joint Forest Sector Questionnaire (JFSQ) and not all countries report to FAOSTAT regularly, some of the countries’ time series include semi-official, estimated, or calculated data (FAOSTAT 2022). The quality of FAOSTAT’s production quantities was not evaluated within this project.

The essential difference between EXIOBASE and FAOSTAT is the distribution of the roundwood extraction by extracting industry, which is only reported by EXIOBASE. As expected, most of the domestically extracted wood is placed in the forestry sector, but in some cases, there are other industries, such as furniture manufacturing, which supply domestically extracted roundwood according to EXIOBASE. This information could not be verified, but since the non-forestry sources of roundwood supply are very small, it is not considered a big source of uncertainty in the model. For this report, the four domestic extracted wood types were summed up in one category – total domestic wood extraction used.

4.12. Quantification of circularity and cascading

4.12.1. Circular material use

At the EU level, Eurostat has developed the circular material use (CMU) rate, which measures the circularity rate, or the share of material recycled and fed back into the economy (Eurostat 2018). The CMU rate is defined as the ratio of the circular use of materials (U) to an indicator of the overall material use (M):

\[
\text{CMU} = \frac{U}{M} \quad (1)
\]
According to this calculation method, a high CMU would mean that there is a substitution of primary with secondary materials in the economy, thus reducing the environmental impacts of resource extraction (Eurostat 2018).

The overall material use $M$ in equation (1) represents the overall amount of primary raw materials used by an economy (Eurostat 2018). Eurostat points out that the indicator “raw material consumption” (RMC) would be the ideal choice in the calculation. RMC represents the total global amount of primary raw materials directly and indirectly used by an economy. RMC represents the portion of annual global raw material extraction attributable to the final use of an economy (Eurostat 2018).

Conceptually, the RMC corresponds to the footprint measure, since it attempts to estimate the amount of raw materials extracted throughout the value chain world-wide for the production and ultimately consumption of goods and services by an economy. Unfortunately, using the Danish wood footprint as an estimate of the overall material use $M$ was not deemed feasible at this stage of the project due to limitations of the woodprint model explained in section 6.2.

A good proxy for the RMC and our best estimate of the total material use in the economy is the indicator domestic material consumption (DMC), which measures the total amount of resources and materials used directly within an economy. DMC is defined as the annual quantity of raw materials extracted from the domestic territory, plus the physical imports and minus the physical exports of materials (Eurostat 2022). A known drawback of the DMC is that it does not include upstream flows of raw materials used in the production of the traded goods, nor does it include resources related to the services part of the economy. Furthermore, many of the traded products include heterogeneous materials (e.g., a car contains metal, glass, plastic, and other materials), which makes it difficult to classify the import and export flows into homogenous product groups. Nonetheless, DMC is considered a good approximation in the absence of RMC.

In our calculation of DMC, we included the domestic wood harvest, added the import of roundwood, semi-finished and finished products and subtracted the export of these flows. We used our wood flow model estimates for deriving these flows.

Having chosen the appropriate indicator in the denominator of the CRU formula, the overall material use $M$ is measured by adding the amount of circular use of materials $U$ to this measure, i.e.

$$M = DMC + U \quad (2)$$

The circular use of materials $U$ in (2) attempts to measure the direct or indirect substitution of primary raw materials (Eurostat 2018). According to Eurostat, $U$ can be approximated by the amount of recycled waste domestically, which is corrected for imports and exports of waste sent for treatment abroad. This is done to consider the countries’ efforts to collect waste for recovery, including waste collected domestically and later exported for treatment abroad (Eurostat 2018).
Eurostat measures the waste recycling from its waste statistics. In principle, the recycling amount could be disaggregated into legally collected and declared waste, which is recovered, treated, and fed back to the economy (i.e., part of the waste management system); and residual material or by-product of production processes, which does not enter the waste management system, but it circles back into the economy in a more direct way.

An important step in the calculation of $U$ is that (Eurostat 2018) includes recycling, but excludes energy recovery and backfilling\(^5\).

The circular material use is then presented mathematically as

$$U = R - IMP^w + EXP^w, \quad (3)$$

where $R$ = Recycled materials, $IMP^w$ = amount of imported waste sent for recovery, and $EXP^w$ = amount of exported waste sent for recovery.

Combining equations 1-3, the total CMU becomes:

$$CMU = \frac{R - IMP^w + EXP^w}{DMC + R - IMP^w + EXP^w} \quad (4)$$

**4.12.2. Cascading use**

Within Eurostat’s CMU indicator all imported products for domestic use are included in the DMC indicator, but we don’t actually know whether they were made from primary, reused or recycled materials. This information is, however, valuable, if true circularity is to be tracked within the economy. The way materials are used within the domestic economy at industry and even product level gives a clearer picture of the potential for improving circularity. Mantau (2015) developed a method for utilisation of the cascading use of materials and calculating cascading factors; he defines the cascade use as multiple uses of wood resources by utilisation of residues, recycling of materials during the production process, or recovery of resources post consumption. The cascade factor measures the use of residuals or recycled and recovered materials in the economic system.

If no such flows exist, only primary wood resources will be used to produce wood products and the cascade factor would be 1. Contrary to Eurostat’s CMU indicator, secondary materials used for energy are included in the cascade use of materials.

There are two general cascade factors distinguished (Mantau 2015):

\(^5\) The term backfilling refers to “means a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials”. Source: https://ec.europa.eu/eurostat/documents/342366/4953052/Guidance-on-Backfilling.pdf/c18d330c-97f2-4f8c-badd-ba446491b47e
• Product-based cascades, where “…a cascading use of biomass takes place when biomass is processed into a bio-based final product and this final product is used at least once more either for materials or energy.”

• Industry-based cascades, in which “cascading use of biomass in an industrial sector takes place when residues and recycling materials are processed.”

Here, industry-based cascading factors were calculated based on the information available and the general focus on economy-wide wood flows in Denmark. The calculation follows the approach described by Mantau (2015), wherein every cascade use of materials is added to the primary resource extraction and then related to the initial primary resource to arrive at a cascade factor. The general formula is:

\[
\frac{\text{Primary + Cascade (residue,recycled or recovered) material use}}{\text{Primary material use}}
\]  

(5)

5. Results

The overall results of the wood flow model are presented using Sankey diagrams in the following pages, with flows at scale to each other. On the left side of the diagram is found domestic harvest of wood, with import flows on the upper side. The general flow of the diagram is from left to right, through domestic intermediate use and final consumption, while exports flow out of the economy toward the bottom. The diagrams are followed by a detailed description of the flows, industries, and processes.

The PSUT have been published covering both 2016 and 2018, making it possible to illustrate a short time series of the Danish wood flows – with the caveat that the development of the national PSUTs is ongoing. Inter-industry flows are considered to be improved in the 2018 version. The overall totals of domestic extraction, import and export, and total domestic use should be considered comparable. Conversion factors have recently been published that are compatible with the 2018 version of the Harmonised System/Combined Nomenclature, so it was possible to include import and export flows of paper and finished products for the 2018 year.

Primary data sources used by the PSUT also exist for other years, enabling further comparisons of specific flows across a longer time horizon.
Figure 1. Sankey diagram of wood flows through the Danish economy in 2016 reported in 1000 m³ solid wood equivalents (SWE). Wood flows from forest harvest to final consumption are illustrated from left to right. Imported wood enters from the top and exported wood flows from the bottom of the diagram. The individual flows are further explained and characterised below.
Figure 2. Sankey diagram of wood flows through the Danish economy in 2018 reported in 1000 m³ solid wood equivalents (SWE). Wood flows from forest harvest to final consumption are illustrated from left to right. Imported wood enters from the top and exported wood flows from the bottom of the diagram. The individual flows are further explained and characterised below. The inset in bottom left shows import and export of wood in finished products and wood-fibre derived paper.
### Diagram Flows (Wood assortments or categories)

<table>
<thead>
<tr>
<th>Assortment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood</td>
<td>Harvested wood that may be burned in domestic stoves, fireplaces, etc.</td>
</tr>
<tr>
<td><em>brænde</em></td>
<td></td>
</tr>
<tr>
<td>Energy wood (chips)</td>
<td>Wood that is harvested and chipped for energy production. It may consist of branches and other harvest residues or other assortments that are to be chipped for energy use. End use is primarily by industries.</td>
</tr>
<tr>
<td><em>energitræ (flis)</em></td>
<td></td>
</tr>
<tr>
<td>Broadleaf timber</td>
<td>Non-coniferous timber for use other than as a fuel (such as to produce veneer or sawnwood or other semi-finished products).</td>
</tr>
<tr>
<td><em>løvtræ tømmer</em></td>
<td></td>
</tr>
<tr>
<td>Coniferous timber</td>
<td>Coniferous timber for use other than as a fuel (such as to produce veneer or sawnwood or other semi-finished products).</td>
</tr>
<tr>
<td><em>nåletræ tømmer</em></td>
<td></td>
</tr>
<tr>
<td>Pellets</td>
<td>Wood pellets are produced domestically from sawmill residues or imported. Used across the economy including industries and households.</td>
</tr>
<tr>
<td><em>træpiller</em></td>
<td></td>
</tr>
<tr>
<td>Other simply worked</td>
<td>Includes a variety of lightly worked products such as poles, sticks, wood wool and flour, treated roundwood, and charcoal.</td>
</tr>
<tr>
<td><em>andre letforarbejdede produkter</em></td>
<td></td>
</tr>
<tr>
<td>Sawnwood</td>
<td>Wood that has been processed from raw timber to produce boards, beams, planks, sleepers, etc. This sawnwood may be used directly or to produce other finished products such as furniture.</td>
</tr>
<tr>
<td><em>savskåret træ</em></td>
<td></td>
</tr>
<tr>
<td>Wood panels</td>
<td>Includes veneer sheets and panels made from wood or particles of wood, such as plywood, chipboard, fibreboard, etc. These may be used directly or to produce other finished products such as furniture.</td>
</tr>
<tr>
<td><em>træpaneler og plader</em></td>
<td></td>
</tr>
<tr>
<td>Wood waste</td>
<td>This stream includes waste wood collected by the waste collection industry – i.e., wood or wood products that have been discarded.</td>
</tr>
<tr>
<td><em>træaffold</em></td>
<td></td>
</tr>
<tr>
<td>Residues</td>
<td>In this representation, these are industrial byproducts of processing wood that are used for energy. Some industrial residues may be retained within the wood industry for use in non-fuel products but there is no source for this information.</td>
</tr>
<tr>
<td><em>rester</em></td>
<td></td>
</tr>
<tr>
<td>Wood in other products</td>
<td>This is the balance of the non-fuel wood flows into the wood industry minus the production of sawnwood, wood panels, pellets, and residues. It is assumed that the remaining wood is in finished products produced by the wood industry.</td>
</tr>
<tr>
<td><em>træ i andre produkter</em></td>
<td></td>
</tr>
</tbody>
</table>
Processes and Labels

Forest harvest (hugst)
This is the documented felling of wood from Danish forests and can be found in the Danish Statbank (SKOV55). It is assumed to be harvested by the Forestry industry.

Forestry industry (skovbrug)
According to the Danish Industrial Classification (Dansk Branchekode DB07), this industry group includes producers of roundwood (including timber and wood chips from the forest).

Other woody biomass sources of fuelwood (andet træ til energi)
This is a balancing flow representing the difference between the reported use of wood chips for energy use and the reported harvest of wood for energy use in forests. It may include woody fractions of garden waste, or wood chips made from trees outside of forests.

Roundwood supply (forsyning af rundtræ)
The roundwood supply includes 3 streams: fuelwood (mainly wood chips for energy), firewood for household use, and industrial timber. This domestic supply is the total domestic production + import available for use.

Wood industry (træindustri)
DB07 notes that this group includes producers of semi-finished wood products such as sawnwood (lumber from sawmills) and wood panels (such as plywood) as well as finished products such as wood packaging and products for use in construction such flooring, mouldings, doors, windows. Furniture is not included.

Firewood of unknown source (brænde fra ukendte kilder)
This stream is a balancing flow representing the difference in the reported use of firewood in the Energy account and the Energy statistics and the reported harvest of firewood in the felling statistics.

Construction industry (byggeri)
Includes construction of new buildings, civil engineering works, renovation, remodelling and repair businesses related to buildings.

Furniture industry (møbelindustri)
The furniture industry makes furniture of wood and other materials, and processes wood in various ways as a part of this process.

Other industries (øvrige industrier)
This includes the remaining industries not shown elsewhere on this diagram.

Electricity and co-generation plants (elektricitets- og varmeværker)
This represents the electricity production industry and includes companies that operate power plants that produce electricity and combined electricity and power -meaning that this industry also produces heat.

Heating plants (varmeværker)
This industry classification includes the heating companies that produce steam and hot water for district heating.
Domestic consumption (households, etc.)

This represents final consumption by households and the public sector, as well as additions to stocks and capital formation.

(privat og offentligt endeligt forbrug)

Some overall wood flow summary figures are found in Table 2 below; notably, all flows are seen to increase from 2016 to 2018. The total domestic use of wood as a raw material (extraction and trade in roundwood and semi-finished wood products) increases by 33% between 2016 and 2018, with 76% of that increase accounted for by the increase in the use of wood for energy.

Table 2. Extraction and trade in including roundwood and semi-finished wood products and semi-finished wood products (1000 m³ SWE). Total domestic use is equal to domestic extraction + imports – exports.

<table>
<thead>
<tr>
<th>Year</th>
<th>Recorded domestic extraction</th>
<th>Unrecorded domestic extraction</th>
<th>Total</th>
<th>Total Import, roundwood and semi-finished</th>
<th>Total Export</th>
<th>Domestic Non-energy Use</th>
<th>Domestic Use for Energy</th>
<th>Total Domestic Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>3,704</td>
<td>2,889</td>
<td>6,593</td>
<td>13,736</td>
<td>2,897</td>
<td>2,341</td>
<td>15,117</td>
<td>17,459</td>
</tr>
<tr>
<td>2016</td>
<td>3,557</td>
<td>2,767</td>
<td>6,324</td>
<td>8,446</td>
<td>1,669</td>
<td>1,252</td>
<td>11,848</td>
<td>13,101</td>
</tr>
</tbody>
</table>

When import and export flows of wood in finished products and paper and waste are added (Table 3), there are significant increases in import and exports. Total domestic use also increases, though to a lesser extent, given that imports increased only fractionally more than exports.

Table 3. Extraction and trade including roundwood, semi-finished wood products, wood waste, wood in finished products, pulp and paper, and paper waste. (1000 m³ SWE). Total domestic use is equal to domestic extraction + imports – exports.

<table>
<thead>
<tr>
<th>Year</th>
<th>Recorded domestic extraction</th>
<th>Unrecorded domestic extraction</th>
<th>Total</th>
<th>Total Import</th>
<th>Total Export</th>
<th>Domestic Non-energy Use</th>
<th>Domestic Use for Energy</th>
<th>Total Domestic Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>3,704</td>
<td>2,889</td>
<td>6,593</td>
<td>16,658</td>
<td>5,504</td>
<td>2,620</td>
<td>15,127</td>
<td>17,747</td>
</tr>
</tbody>
</table>

A consistent portion of the recorded domestic extraction comes from public forest managed by the Danish Nature Agency (Naturstyrelsen), as seen in Figure 3 below.
In 2018, the state forests produced approximately 16% of the wood supply from domestic forests (604,064 m³ out of a total of 3,704,400 m³). Figure 4 presents a detailed breakdown by assortments between Nature Agency and other forest owners.
5.1. Wood for energy use

While the main Sankey diagram illustrates the overall use of wood for energy, the following diagrams present a more detailed disaggregation by type of fuel and energy generation facility. The overall total amount of wood flowing to energy use is derived from the Energy Accounts using conversion factors, while the distribution of use by type of facility and to the consumption sector is according to the Energy Agency Statistics. Wood pellets clearly represent the largest flow of wood for energy, with the majority of the supply coming from imported sources. The domestic production is equivalent to approximately 5% of the overall domestic use (not considering export). There is a distinct pattern in the use of different forms of wood for energy. Wood chips are mainly used in district heating and combined heat and power production. Firewood is exclusively used for domestic heating in single family homes and wood pellets for either combined heat and power on the centralised large-scale units or for domestic heating. The difference between 2016 and 2018 is most notable as increased use of wood pellets in combined heat and power production (+36%) provided for by increased import (+25%).

Figure 4. Bar chart illustrating proportions of selected harvest assortments coming from the Nature agency's forest estate, as well as assortment contributions to total harvest from private, non-state publicly owned, and other state-owned forests.
5.2. Use of residues and waste wood

Wood residues, by definition, originate mostly from industry, with the wood industry being the largest producer (and also the largest consumer). The residues not consumed by the wood industry are sent to the electricity and heating industries or sold for firewood.

Wood waste comes from both industry and domestic residuals from consumption (households, etc.,) in similar proportions, though slightly more wood waste is produced by industry, with the construction industry as the single largest producer. More than half of the wood waste collected (around 56%) is sent to the wood industry for reprocessing into other products, while the remainder is incinerated domestically (18%) or exported for recycling (9%) or incineration (13%).
Figure 5. Sankey diagram representing wood flows for energy in 2016. Total of residues on the left side includes wood destined for domestic pellet production. The distribution of wood waste between types of power generation facility are unknown. Totals shown do not include flows of wood in mixed waste streams.
Figure 6. Sankey diagram representing wood flows for energy in 2018. Total of residues on the left side includes wood destined for domestic pellet production. The distribution of wood waste between types of power generation facility are unknown. Totals shown do not include flows of wood in mixed waste streams.
5.3. The Danish woodprint

This section presents the main results from the calculations of the Danish woodprint and its origin. The data behind the model contains time series for the period 2010 to 2020.

Table 4 presents the main results of the woodprint model calculations for the domestic and foreign (both imported and exported) wood extraction related to Danish economic activity between 2010 and 2020. The Danish wood harvest is used in the Danish economy to produce goods and services for domestic consumption or for export, shown in rows 2 and 3 in the table. Similarly, the wood extraction abroad that is assigned to the Danish import could be used to deliver products on the domestic market or export them abroad. These two general use categories are shown in rows 5 and 6 in the table. Rows 1, 4, 7 and 8 are aggregation rows with the last one summing up the domestically generated woodprint in row 2 and the woodprint accumulated abroad in row 5. This amounts to the Danish woodprint, illustrated further in Figure 7.

---

The year 2020 is considered a preliminary year with substantial uncertainty attached to it due to the effects of the COVID-19 outbreak, and the fact that the current economic and environmental projections in EXIOBASE have not been updated after the pandemic.
Table 4. Wood extraction in Denmark and abroad related to Danish production and consumption.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Documented Danish wood extraction</td>
<td>1. = 2. + 3.</td>
<td>2,655</td>
<td>3,915</td>
<td>3,557</td>
<td>3,902</td>
<td>3,704</td>
<td>3,826</td>
</tr>
<tr>
<td>2. Danish wood extraction related to Danish consumption</td>
<td></td>
<td>1,852</td>
<td>2,646</td>
<td>2,429</td>
<td>2,488</td>
<td>2,386</td>
<td>2,424</td>
</tr>
<tr>
<td>3. Danish wood extraction related to Danish export</td>
<td></td>
<td>803</td>
<td>1,270</td>
<td>1,129</td>
<td>1,414</td>
<td>1,318</td>
<td>1,402</td>
</tr>
<tr>
<td>4. Wood extraction abroad related to Danish import</td>
<td>4. = 5. + 6.</td>
<td>9,071</td>
<td>9,261</td>
<td>9,091</td>
<td>9,607</td>
<td>10,950</td>
<td>10,447</td>
</tr>
<tr>
<td>5. Wood extraction abroad related to Danish consumption</td>
<td></td>
<td>5,362</td>
<td>5,159</td>
<td>4,961</td>
<td>5,349</td>
<td>6,137</td>
<td>5,524</td>
</tr>
<tr>
<td>6. Wood extraction abroad related to Danish export (re-export)</td>
<td></td>
<td>3,710</td>
<td>4,102</td>
<td>4,131</td>
<td>4,258</td>
<td>4,813</td>
<td>4,922</td>
</tr>
<tr>
<td>7. Total wood extraction related to Danish export</td>
<td>7. = 3. + 6.</td>
<td>4,513</td>
<td>5,372</td>
<td>5,259</td>
<td>5,672</td>
<td>6,131</td>
<td>6,324</td>
</tr>
<tr>
<td>8. Danish woodprint</td>
<td>8. = 2. + 5.</td>
<td>7,214</td>
<td>7,805</td>
<td>7,389</td>
<td>7,837</td>
<td>8,523</td>
<td>7,948</td>
</tr>
</tbody>
</table>

There are several trends that could be observed in Table 4 and Figure 7. The woodprint has been fluctuating in the observed period, with the lowest value of 7.2 million m$^3$ in 2010 and the highest – 8.5 million m$^3$ in 2018. The average woodprint in the period was about 7.8 million m$^3$ and there is a general increasing trend in the period 2010 – 2020. Figure 7. also shows that the woodprint related to the Danish import of goods and services has been consistently higher than the domestic wood extraction. On average, the import-related woodprint was 2.3 times higher than the domestic one. Regarding the wood extraction related to the Danish export, it is worth noting that the domestic extraction is significantly lower than the import. On average, the Danish reexport required four times more wood extraction than the export related to domestic production in Denmark, which can be seen in Figure 7. as the difference between the dark and light green coloured part of the bars not part of the woodprint. These estimates correspond well with the general result of the wood flow model showing a physical import of wood substantially higher than the domestic supply.
The origin of the woodprint caused by the import in 2018 is presented in Figure 8. The total of 6.1 million m³ woodprint is divided into five regions as classified in EXIOBASE. Of these regions, Europe is responsible for about 4.6 million m³ (76%) of the woodprint, followed by America (750,000 m³ or 12% of total) and Asia and Pacific (480,000 m³, 8% of total).
Figure 8. Danish imported woodprint by world regions of origin in 2018. The five regions shown are America, Africa, Europe, Middle East, and Asia and Pacific. The countries in the respective regions are classified after geographical location according to the UN classification as implemented in EXIOBASE. The concordance table used can be found on https://ntnu.app.box.com/v/EXIOBASEconcordances under CountryMappingDESIRE.xlsx. Source: Statistics Denmark and EXIOBASE.

Figure 9 presents the distribution of the Danish woodprint at the individual country level globally, excluding Denmark. As seen on the figure, most of the wood extraction associated with Danish consumption originates in the European countries neighbouring Denmark. The largest non-European contributors were the USA and China, respectively extracting about 400,000 and 200,000 m$^3$ of roundwood, to produce goods and services consumed in Denmark.
To further examine the origin of the woodprint from the most significant region, Figure 10 focuses on Europe and shows the individual countries’ contribution. The biggest domestic extraction of wood related to the Danish consumption occurred in the countries surrounding Denmark, implying that that the majority of products requiring wood use for Danish consumption do not travel long distances. Indeed, Sweden’s forests provide most of the Danish consumers’ wood extraction needs. In 2018, about 1.3 million m$^3$ of the Swedish domestic extraction ended up in the Danish domestic consumption according to our model. This corresponds to 21% of the woodprint in Europe and 15% of the total global woodprint. Other European countries bearing the woodprint include Germany, Poland, Finland, Estonia, and Latvia, which extracted about 300 to 600 thousand m$^3$ each in 2018.

Appendix II presents the Danish woodprint’s distribution in all individual countries and regions found in EXIOBASE in 2016 and 2018.
Figure 10. Danish imported wood footprint by country of origin within Europe in 2018. The European countries shown in grey are not represented individually in EXIOBASE, but clustered together under the region RoW Europe. The concordance table is found on https://ntnu.app.box.com/v/EXIOBASEconcordances under the name CountryMappingDESIRE.xlsx. Source: Statistics Denmark and EXIOBASE.

5.4. Circular material use

Table 5 presents the CMU rate for the Danish wood flows in the year 2018. Following Eurostat’s calculation method results in a CMU rate of 8.4%. According to the method, all import flows in the DMC should be counted, including wood for energy purposes. The calculations were also made excluding wood imported directly as a fuel product for energy production as there is no obvious opportunity for other domestic use of this stream. From the whole-economy perspective, the use of imported wood for energy is a large part of the total use. However, it was also desired to highlight the overall circularity factor without this flow to better understand the circularity in the rest of the economy. Table 5 shows a significantly higher material use rate of 17.8% when excluding the import of wood for energy. This shows the importance of the wood for energy flows within the Danish economy, as well as the potential baseline for circularity, if these flows were to be directed to other uses.
Table 5. Circular material use rate for the Danish wood flows, 2018.

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular material use (CMU) rate including imported wood for energy (1./(1.+2.))</td>
<td>8.4%</td>
</tr>
<tr>
<td>Circular material use (CMU) rate excluding imported wood for energy (1./(1.+3.))</td>
<td>17.8%</td>
</tr>
<tr>
<td>1. Circular use of materials U (1000 m³)</td>
<td>1631</td>
</tr>
<tr>
<td>Recycled wood waste</td>
<td>746</td>
</tr>
<tr>
<td>(-) Amount of imported waste sent for recovery</td>
<td>65</td>
</tr>
<tr>
<td>(+) Amount of exported waste sent for recovery</td>
<td>951</td>
</tr>
<tr>
<td>2. Domestic material consumption including imported wood for energy (DMC) (1000 m³)</td>
<td>17,753</td>
</tr>
<tr>
<td>Domestic resource extraction</td>
<td>6,593</td>
</tr>
<tr>
<td>(+) Import of wood and paper products</td>
<td>16,658</td>
</tr>
<tr>
<td>(-) Export of wood and paper products</td>
<td>5,498</td>
</tr>
<tr>
<td>3. Domestic material consumption excluding imported energy wood (DMC_E) (1000 m³)</td>
<td>7,509</td>
</tr>
<tr>
<td>Domestic resource extraction</td>
<td>6,593</td>
</tr>
<tr>
<td>(+) Import of wood and paper products</td>
<td>6,413</td>
</tr>
<tr>
<td>(-) Export of wood and paper products</td>
<td>5,498</td>
</tr>
</tbody>
</table>

5.5. Cascading use

The results of the cascading use in the Danish economy as a whole and the selected wood and paper industries individually are presented in Table 6 and Table 7.

Table 6. Cascade utilisation in the total Danish wood flows in 2018.

<table>
<thead>
<tr>
<th>Cascade factors for the Danish economy</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascade classes</td>
<td>18</td>
</tr>
<tr>
<td>Cascade factor</td>
<td></td>
</tr>
<tr>
<td>calculation</td>
<td></td>
</tr>
<tr>
<td>(1.000 m³)</td>
<td></td>
</tr>
<tr>
<td>Cascading factor</td>
<td></td>
</tr>
<tr>
<td>factor</td>
<td></td>
</tr>
<tr>
<td>1. Wood resources from trees</td>
<td>7,726</td>
</tr>
<tr>
<td>2. Residues in wood products</td>
<td>(1. + 2.)/1.</td>
</tr>
<tr>
<td>3. Residues in energy</td>
<td>(1. + 3.)/1.</td>
</tr>
<tr>
<td>4. Recycling in products</td>
<td>(1. + 4.)/1.</td>
</tr>
<tr>
<td>5. Recovery in energy</td>
<td>(1. + 5.)/1.</td>
</tr>
<tr>
<td>6. Residue utilisation</td>
<td>(1. + 2. + 3.)/1.</td>
</tr>
<tr>
<td>7. Recycling + recovery cascades</td>
<td>(1. + 4. + 5.)/1.</td>
</tr>
<tr>
<td>8. Cascades in products</td>
<td>(1. + 2. + 4.)/1.</td>
</tr>
<tr>
<td>9. Residuals + recycling in energy</td>
<td>(1. + 3. + 5.)/1.</td>
</tr>
<tr>
<td>10. Total cascades</td>
<td>(1. + 8. + 9.)/1.</td>
</tr>
<tr>
<td>*The amount of residues is unknown.</td>
<td></td>
</tr>
</tbody>
</table>

52
With this method of calculation, the initial cascading factor is always 1, indicating the use of raw wood resources in the economy, which Mantau (2012) refers to as wood resources from trees. This category includes both domestic harvests and imported wood, as well as other woody biomass utilised in the Danish economy. When residues and recycled materials are utilised in production processes, the cascade factor grows. The recycling and recovery of products has a higher cascade factor than residue utilisation, 1.25 against 1.19 in 2018. However, since the amount of residues recovered in products is unknown, an underestimation of the cascade factor of residue utilisation might occur. It is not expected that this amount is significant in the case of Denmark. Summing the two aggregate cascade uses of wood and paper products gives a total cascading factor of wood in the Danish economy estimated at 1.44 in 2018. The result shows that the wood resources are used almost one and a half times in the Danish economy before oxidization or long-term final consumption.

For comparison, the cascading factors of the wood and paper industries were separately calculated (Table 7). It shows a higher cascade use of wood resources in both industries, with paper mills having a considerably higher cascade factor than the wood industry; 3.58 compared to 1.88 in 2018. While the paper industry recycled all the material into making new products and sent almost nothing for incineration, the wood industry split the use of secondary material between recycling and incineration almost evenly. The results for Denmark are contrasted with international data in section 6.4.

<table>
<thead>
<tr>
<th>Cascade classes</th>
<th>Wood industry Cascading factor calculation</th>
<th>(1,000 m³)</th>
<th>Wood industry Cascading factor</th>
<th>(1,000 m³)</th>
<th>Paper industry Cascading factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wood resources from trees</td>
<td>1,121</td>
<td>1</td>
<td>102</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2. Residues in energy</td>
<td>(1. + 2.)/1.</td>
<td>507</td>
<td>1.45</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3. Recycling in products</td>
<td>(1. + 3.)/1.</td>
<td>482</td>
<td>1.43</td>
<td>263</td>
<td>3.58</td>
</tr>
<tr>
<td>10. Total cascades in the industry</td>
<td>(1. + 2. + 3.)/1.</td>
<td>989</td>
<td>1.88</td>
<td>263</td>
<td>3.58</td>
</tr>
</tbody>
</table>

6. Discussion and conclusion

By illustrating Danish wood flows in solid wood equivalent, we are able to visualize imported flows of wood relative to our own domestic resource and extraction. In addition to the significant use of wood for energy, it is clear that Denmark is a wood importing country, with domestic extraction alone insufficient to support domestic consumption of wood products (even without energy use). Perhaps unsurprisingly, after energy uses, the wood industry is the largest user of wood, followed by the construction and furniture industries. Below we address certain aspects of our analysis in further detail and compare the results of the wood flow and woodprint.
6.1. Estimated flows and uncertainties, and conversion factors

The Sankey diagrams mostly represent wood flows taken directly from statistical sources, but the principle of conservation of mass means that some undocumented flows have been revealed and appear as an estimation. For example, this can occur when statistics on the use of a resource do not match with statistics on extraction. This does not necessarily represent an error in the data (though that is of course one potential explanation) but may mean that there is extraction or use undocumented by statistics. Some sources estimate extraction based on reported use, such as the firewood statistics from the Energy Agency and Energy Account. It is then necessary to determine if the extraction is documented by direct sources. In the case of firewood, there do exist statistics that document part of this flow, i.e., the harvest of firewood from forest areas. However, this flow is lower than the reported use in the Energy Statistics. If it is assumed that the official statistics are accurate, it is then possible to estimate the difference between the reported supply and use, and this flow represents the undocumented harvest of wood for firewood (see Figure 11 for a visualisation of the method).

Three flows shown in the diagrams have been estimated through balancing between reported use and reported supply. The flows are not directly documented in the PSUT, or they may be represented but are aggregated with other flows. As noted, the first is the flow of firewood harvested for household use, shown on the diagram as “firewood of unknown source.” In 2018, this flow is estimated to be more than 1.8 million m\(^3\), in comparison with the domestic harvest of firewood from forests, which is estimated to be 284,400 m\(^3\). It should be mentioned that the statistical method for estimating domestic firewood use has changed over time, and a significantly lower use of firewood has so far been estimated in the years since 2018, as seen in Table 8 below. It is unknown whether this represents an actual change in use or reflects changes in survey methodology, but it results in a decrease in undocumented harvest from nature.

| Table 8. Supply and use of firewood and estimated undocumented inflow of firewood in Denmark from 2015 to 2021 (1000 m\(^3\)). Data sources: Statistics Denmark, Energy Accounts (Energiregnskab) ENE1HO and Harvest statistics (Hugsten i skove og plantager i Danmark), SKOV55. |
|---------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|
| Import                         | ENE1HO   | 255    | 366    | 362    | 334    | 194    | 155    | 192    |
| Export                         | ENE1HO   | 0      | 115    | 111    | 86     | 46     | 9      | 67     |
| Use in households              | ENE1HO   | 2,449  | 2,414  | 2,414  | 2,384  | 1,567  | 1,462  | 1,669  |
| Harvest in forests             | SKOV55   | 380    | 298    | 357    | 284    | 215    | 233    | 269    |
| Undocumented flow              |          | 1,814  | 1,865  | 1,806  | 1,851  | 1,205  | 1,083  | 1,275  |

Second is the flow of “other woody biomass sources of fuelwood.” This flow of fuelwood refers to wood chips for energy, and is derived by subtracting the harvest of fuelwood reported by forest owners and reported imports from the use of wood chips for energy in the Energy Account and
reported exports. This estimated flow probably comes from outside the forest area and may include wood chips coming from short rotation willow and poplar plantations, wind breaks and hedgerows, landscape maintenance work, such as removal of hazard trees, and woody portions of the garden waste stream. In some municipalities in Denmark, this stream is collected and separated into woody and non-woody portions, with the woody portion going to energy use. In 2018, the undocumented extraction of woody biomass for energy amounted to more than 1 million m$^3$. This figure is uncertain. Underestimations of import, and domestic harvest from forests or overestimation of exports would all result in our figure being an overestimation. Domestic harvests are validated against the NFI, but there is a minimum threshold for reporting to the trade statistics. Companies with a total import or export trade values below 11 million DKK are not required to report to Statistics Denmark. Some of the previously referenced wood flow analyses have also noted this undocumented flow in other countries, and it is logical that wood chips are also produced outside of forests.

The combined undocumented harvest of wood in Denmark in 2018 is estimated at nearly 2 million m$^3$, against the documented harvest of 3.7 million m$^3$. Even if the undocumented harvest is overestimated, these numbers remind us that there may be significant sources of woody biomass outside of forests, which are utilised as a resource.
Figure 11. Example illustration of the estimation of unreported wood flows from nature for energy. The top half represents the overall flows, while the bottom half shows the total sum of supply and use. The unreported wood flow from nature is assumed to equal the difference between reported supply (harvest and import) and the reported use (final use for energy and export).

The third estimated flow is the output of wood from the wood industry into finished products. This is derived by subtracting the documented outputs of the wood industry (including the semi-finished products of sawnwood and wood panels, as well as net production of wood pellets and residues) from the documented inputs (excluding inputs of pellets, wood chips, and residues for energy which are assumed to be oxidized.) The wood industry outputs a wide range of semi-finished products which are simply converted into m³, but also a wide range of finished products for which conversion factors into m³ SWE are more uncertain. While the mass of these finished products in tonnes is estimated in the PSUT, many of these products contain varying amounts of other materials, such as, i.e., glass in the case of doors and windows. However, with the principle
of conservation of matter we may estimate the SWE output of the wood industry across all of the finished product categories. In 2018, this was approximately 405,000 m³. This figure is also uncertain; if the estimation of inputs to the wood industry are inaccurate, our estimation of outputs could be affected. There are other possible uncertainties; if there were undocumented use of wood residues for energy within the wood industry, our output would also represent an overestimation. If the wood industry is using products categorised as finished wood products to produce other finished wood products, then these would also not be captured in this figure, as they have not been considered under inputs.

Finally, it is again worth noting that we have used published conversion factors from several sources in constructing our model. These factors are in turn based on various assumptions and aggregations, which also introduce uncertainty to our result, particularly for very large flows such as wood pellets. One example is the import of wood pellets; there are multiple sources offering figures for import either in tonnes or TJ. Across the range of sources and conversion factors considered for use in our model, the result varies from 4 million m³ to 5.4 million m³. Selecting the Energy Account as the data source and applying the median European value for m³sw/mt of pellets as published in the recent FAO guide to forest product conversion factors (FAO, ITTO et al. 2020) provides our result of 4.8 million m³ SWE. Similarly, for the import of wood chips, we could estimate a range of 220,000 m³ vs 391,000 m³ depending on the data source and the conversions. In this case we have used the lower estimate, relying on the Energy Account and an aggregated broadleaf/conifer conversion factor for Europe. This degree of variation suggests that further investigation and data collection around these large flows might improve estimates.

### 6.2. Comparing the wood flow model and the woodprint

The wood flow model and the woodprint are two methodologically different ways of analysing wood flows in the economy. While the former relies on the mapping of the physical Danish economy based on material flow accounting principles, the latter is a consumption-based account that relies on monetary IO and MRIO data at a global level. In the wood flow model, wood resources and products are reported in physical units. On the other hand, the woodprint flows are not necessarily actual physical flows, but rather environmental effects/responsibilities attached to the economic transactions within the economy. That is why it is inaccurate to speak of “import of woodprint” or “imported woodprint”, but rather “the woodprint related to the import”.

Although a direct comparison between the two models is not possible, it is useful to look at the results from the two models, shown side by side in Figure 10. The figure illustrates the main flows within the two accounts, which illuminates some additional differences between the two approaches. Here we examine each of the flows.

The recorded domestic extraction is identical within both models since the data source is the same. However, unrecorded domestic extraction, which refers to the wood flow streams Other woody biomass sources of fuelwood and Firewood of unknown source, is only found in the wood
flow model. In the woodprint model, these unknown sources are not part of the domestic extraction of wood for two reasons. First, FAOSTAT’s wood production statistics only include official wood harvest and while we may estimate unrecorded production in Denmark we have not done that for other countries. Second, it is difficult to assign an extraction industry to a wood resource of unknown origin, since this flow could originate from a variety of sources, including households, industries and the public sector. However, the IO tables require that an extraction industry exists in order to integrate the use of wood biomass in the production process. Even if these flows are included in the Danish IO tables under some industry (this could be the energy production industry in the case of Other woody biomass sources of fuelwood), they will be missing in the accounts of all the other countries trading with Denmark.

In terms of import, Figure 10 shows a larger import in the wood flow model of about 14 million m³ in 2018 compared to a wood extraction of 11 million m³ related to the import in the woodprint model. In principle and under the conditions of identical data sources and calculation method, the woodprint of the total import must be higher than the physical import since it includes this physical import plus all the other wood flows generated throughout the global value chain to satisfy the Danish final demand. However, due to reasons explained above, the two import aggregates should not be compared directly.

Regarding the export, presented in the figure as the darkest green colour, the woodprint model estimated that in 2018 twice as much roundwood as part of the value chain related to the Danish export compared to the physically exported wood products from Denmark expressed in SWE, i.e., the estimate given by the wood flow model. This is consistent with the general fact that Denmark is an open economy that trades extensively with the outside world and produces many goods and services for export. As described earlier (Table 4, Figure 7), much of the Danish import is re-exported further. When looking at the physical wood flow itself, much of the wood ends up as input for electricity and heat production and thus, the export of wood products is limited. Within the woodprint model, if the electricity and heat generation is used to produce products that are then exported, the wood used as input in the power stations is assigned to the export – even if there is no wood in the exported product.
Figure 12. Comparison of the wood flow model and the woodprint model, 2018, 1000 m$^3$. *Total import and export refer only to the wood flow model. Within the woodprint model, total import and export is interpreted as the woodprint associated with the total import and export of goods and services to and from Denmark.

Another important distinction between the wood flow and the woodprint models is the principle guiding the trade in goods when they are being sold to and bought from the rest of the world. The data sources behind the wood flow model (the PSUT and the Foreign Trade Statistics) follow the border passage principle, which considers the value of the physical flow of goods crossing the Danish border (Statistics Denmark 2022). The woodprint model is based on the national accounts’ monetary data, meaning that it follows the change of ownership principle, according to which trade occurs at the time of change of ownership. Thus, the border passage principle does not take the change of ownership into consideration and the change of ownership principle does not consider whether the goods cross the Danish border or not (Statistics Denmark 2022).

The implication for the import and export estimates generated by the two models is unknown. Although it is estimated that the part of the Danish economy that never crosses the country’s border has been increasing (Bo, Burman et al. 2017, Wanscher 2019), it is unclear how much this development is affecting the Danish woodprint.

Finally, as the woodprint depends on FAOSTAT statistics which are reported by participating countries, there may be under or over-reporting of wood extraction in other countries. The accuracy of the data is not known, though recent research indicated that the global harvest was underestimated in 57 countries by 368 million m$^3$ and overreported by 44 countries by 16 million m$^3$ (Buongiorno 2018). Since the FAO statistics correspond to official harvest statistics from forest
areas, just as in Denmark, woody biomass removals may be underestimated, though it is unknown what effect this would have on the Danish woodprint.

6.3. The carbon stock in wood products

The inflow of wood to the Danish economy either from import or from domestic harvests contributes to a stock of carbon in buildings, furniture, and other products, the Harvested Wood Products (HWP) carbon stock. While this project does not quantify the HWP carbon stock, part of the stock is quantified in relation to Denmark’s national inventory report to the UNFCCC (Schou, Suadicani et al. 2015). The inventory report quantifies the amount of carbon stored in the three semi-finished products: sawnwood, wood panels, and paper and cardboard originating from wood harvested in Danish forests. In 2020, the HWP carbon stock originating from Denmark was estimated to 5.0 million tonnes (Nielsen, Plejdrup et al. 2022). Assessment of the 2013 HWP carbon stock (Schou, Suadicani et al. 2015) found that app. 18% of the total HWP carbon stock originates from harvests in Danish forests.

6.4. Circular material use and cascading

The resulting estimate of the CMU of wood resources for Denmark is consistent with the circularity rates available for other resource types. Pedersen (2021) calculated a Danish CMU rate of 8% for all material types and 10.7% for plastic in 2018, with a range of 6 - 8% for all material types and 10 - 12% for plastic in the period 2011 – 2019. According to Eurostat (2023), The EU27’s CMU rate for the total resource mix was 11.7% in 2018 (ranging from 11 - 12% in the period 2010 – 2021), while the CMU rate for the category “biomass”, which includes wood and wood products, was 9.4 in the same year and varying from 8.5 - 10% in the period 2010 – 2021.

The Danish total cascading factor of 1.44 seems to be a bit lower than cascading factors calculated for the EU or for individual countries. (Mantau 2012) estimated a total cascading factor of 1.57 for the EU in 2010, which is very similar to the factor calculated by Sokka, Koponen et al. (2015) for Finland for 2013. Gonçalves, Freire et al. (2021) estimated a total cascading factor of 1.59 (±10%) for Portugal for the year 2015. At individual industry level, Mantau (2012) estimated a factor of 1.55 for the wood industry and 2.38 for paper products in 2010, which were lower than what we arrived at in the Danish case. However, he did not consider residues for energy for the wood industry, which in our calculations corresponds to half of the cascading use of wood. In general, one must be cautious when interpreting the different factor estimates across countries, since they cannot be compared directly due to different methodological approaches or other factors such as different reference years. Unfortunately, no time series of the cascade factors exist for those countries, which makes it difficult to do a direct comparison of the factors across countries.

The cascading factor is calculated within a territorial system boundary; however, some of the imported wood products may carry on cascading use in the country of origin, which is not captured by the calculation. The main imported wood product is wood for energy and particularly
wood pellets are partly made out of wood industry residues (Nielsen, Bentsen et al. 2022). For 2016, some utility companies reported to the voluntary industry agreement on sustainable biomass use that part of their imported wood supply originated in industrial residues (Larsen, Bentsen et al. 2019), i.e., cascading wood use. A compiled overview is not published for 2018, but (Nielsen, Bentsen et al. 2022) report that of wood pellets used in Denmark in 2020, 53% were composed of industry residues and 2% of harvest residues. For wood chips, the fractions were 9% and 39% respectively. The remainder, 44% for wood pellets and 52% for wood chips, were reported to originate from stem wood, which also to some extent must be considered as harvest residues (Nielsen, Bentsen et al. 2022).

The calculations of the Danish cascading factors presented above do not include individual products, such as pulp, paper, and panels, which would typically have higher cascading factors than the average assigned to an industry or to the economy as a whole. Mantau (2012) made the point that cascades do not usually take place in a single sector but accumulate between several sectors.

It must be noted that the calculation of the cascading factors by Mantau (2015) and Sokka, Koponen et al. (2015) do not include a hierarchical prioritisation of the cascade uses of wood biomass, as defined in the European forest strategies. According to the New EU Forest Strategy for 2030 (European Commission 2021), the use of wood-based products should be prioritised, starting by extending the products’ service life, then re-using them, then recycling and at the bottom of the priority list lie the use of wood for the production of energy and ultimately, the disposal of wood. Implementing this cascading principle is, however, not part of our calculations.

6.5. Future monitoring of wood flows

As we have used the PSUT as the basis for our analysis, we have been limited to the years 2016 and 2018. While it would be possible to project more recent flows using the structure of the 2018 PSUT, it would mean adopting the assumption that the structure of the wood flow in the economy has not significantly changed. While perhaps not entirely accurate, it could be preliminary until an updated PSUT is published.

Regular updates of the wood flow model would enable longer-term monitoring of any significant changes and could help understand how overall wood use responds to policy changes or changing economic or environmental conditions. Future work could also be undertaken to improve the estimations of the model by collecting additional data on industries and streams of interest, and further developing data sharing and collaboration between different stakeholders and data owners, perhaps in a working group. Transforming the spreadsheet-based model into code would make it more easily shared with users and would facilitate automating updates to the wood flow with new data, though some manual oversight of the data would still be required.
The large volumes of undocumented wood flow emphasize the limitations in data coverage and/or accuracy. Further work on monitoring and data collection methods could improve the underlying data for future monitoring of wood flows.

6.6. Final remarks

Our results show that Denmark is clearly a wood consuming country, with domestic consumption more than doubling domestic extraction. Denmark is also a trading nation - wood imports and exports represent significant volumes relative to domestic extraction, and we can see that we import and export a significant woodprint from and to other countries.

While complete data is not yet available for more recent years, we can also see that domestic extraction and import have continued to increase, with the demand for wood increasing faster than domestic extraction, particularly for wood for fuel (Figure 13). The late pandemic and ongoing war in Ukraine will likely be reflected in changing patterns of wood use – the significant former import from Russia is no longer available, and while overall demand for energy dropped partially during the pandemic, high energy prices and energy shortages in Europe during 2022 will certainly be reflected in the Danish use of wood.

Figure 13. Import and consumption of wood pellets and wood chips from 2010 to 2021. Data from the Danish Energy agency, Grunddata 2021.

The effort to produce this report represents the first comprehensive effort to map the overall wood flow in the Danish economy. It should be seen as a first result based on existing data sources
and published conversion factors and can be improved with further investigations into appropriate country-or-product specific conversion factors and efforts to document missing data, or improved data collection for specific streams. While we have estimated wood in other products produced by the wood industry, and overall imports and exports of wood product categories in 2018, there may be wood or wood fibres in other products such as textiles that could be included with additional analysis. However, it is unlikely that these flows are of a magnitude that would change the overall picture.

There are certainly undocumented flows of wood within other streams in the economy, such as in waste streams for incineration not classified as wood or paper but rather as renewable waste for incineration. Our estimate of other woody biomass from nature going to energy may include streams that we are aware of but are not clearly documented elsewhere; for example, we have not specifically counted the production of Christmas trees in this report, and if the domestic consumption of Christmas trees are chipped for incineration and counted under wood chips for energy then they are a part of this already counted stream.

The analysis would not have been possible without the PSUT from Statistics Denmark, and we have been able to follow the flow of wood between industries as a result. It would also be worthwhile to better understand the internal dynamics of key relevant industries, such as the wood industry. By only seeing inputs and outputs of an aggregated industry, we may be missing information about internal wood flow between sub-industries, and therefore further cascading. It may also be beneficial to conduct deeper analysis on available data on trade in wood products and investigate the relative reliability of kg vs m$^3$ or m$^2$ supplementary data in import and export statistics.

Finally, the flow of wood represents many things in the economy, from economic benefit to employment, and can play a key role in the green transition. It is also deeply linked to our forest resources here and abroad, which provide us with many other benefits. We hope that this report will facilitate future discussions on the use of wood in Denmark and stimulate future research.
7. References


Eurostat (2023). Circular material use rate by material type, European Commission.


Folketinget (2020). Lov om klima. E.-o. F. Klima-. **965.**


Mantau, U. (2012). "Wood flows in Europe (EU 27)." *Project Report, Commissioned by CEPI (Confederation of European Paper Industries) and CEI-Bois (European Confederation of Woodworking Industries).*


### Appendix I

The below conversion factors were used in to convert mass to volume, and volume to SWE.

<table>
<thead>
<tr>
<th>Product</th>
<th>Unit in, unit out</th>
<th>Factors</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roundwood</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuelwood (chips)</td>
<td>t/ m³ SWE</td>
<td>mt/odmt, m³SWE/odmt ½ * 2.41 = <strong>1.205</strong></td>
<td>Derived from (FAO, ITTO et al. 2020). Tonnes divided by European median delivered tonne to oven dry tonne for wood chips (2), multiplied by European median Green swe to oven dry tonne (2,41)</td>
</tr>
<tr>
<td>Pellets and Simply Worked</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood pellets</td>
<td>m³ sw/mt pellets</td>
<td><strong>2.24</strong></td>
<td>(FAO, ITTO et al. 2020) Tonnes multiplied by European median m³ solid wood to tonne of pellets at 5-10% moisture content (2,24)</td>
</tr>
<tr>
<td>Treated timber and hoopwood, stakes, and poles, domestic production</td>
<td>t/1000 m³ SWE</td>
<td><strong>870</strong></td>
<td>(FAO, ITTO et al. 2020) Tonnes divided by Denmark conifer sawlog green weight with bark/green m³ bark only. According to VS, domestic production is exclusively coniferous origin</td>
</tr>
<tr>
<td>Hoopwood, stakes and poles, import/export</td>
<td>t/1000 m³ SWE</td>
<td>Imp: <strong>882</strong></td>
<td>(FAO, ITTO et al. 2020) tonnes divided by European average conifer (887)/non conifer (1023) sawlog figures, weighted by import or export volumes</td>
</tr>
<tr>
<td>Wood wool and flour import</td>
<td>t/ m³ SWE</td>
<td><strong>1.205</strong></td>
<td>(FAO, ITTO et al. 2020) Tonnes divided by European median delivered tonne to oven dry tonne (2), multiplied by European median Green SWE to oven dry tonne (2,41) for wood chips, sawdust, and shavings</td>
</tr>
<tr>
<td><strong>Sawnwood</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleepers, import, domestic use, export</td>
<td>t/1000 m³ SWE</td>
<td><strong>550</strong></td>
<td>JFSQ 2020 sawnwood (incl sleepers) coniferous</td>
</tr>
<tr>
<td>Sawnwood, import</td>
<td>t/1000 m³ SWE</td>
<td><strong>574</strong></td>
<td>JFSQ 2020 sawnwood coniferous (550), non-coniferous (700) weighted by import ratios in tonnes</td>
</tr>
<tr>
<td>Sawnwood, domestic use and export</td>
<td>t/1000 m³ SWE</td>
<td><strong>572.41</strong></td>
<td>Weighted ratio between domestic production and imports</td>
</tr>
<tr>
<td>Wood panels (factors are for domestic production, imports, and exports)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Veneer sheets</td>
<td>t/1000 m³ SWE</td>
<td><strong>550</strong></td>
<td>Tonnes divided by JFSQ 2020 Sawnwood</td>
</tr>
<tr>
<td>Chipboard/Particle board</td>
<td>t/1000 m³ SWE</td>
<td>t/1000 m³ p, m³ SWE/ m³ p 650, 1.2</td>
<td>Tonnes divided by JFSQ 2020 Particle board to 1000 m³ of product, multiplied by 1,2 (Weimar 2011) to reach 1000 m³ SWE. Where m³ source figure is used, only the Weimar factor is applied.</td>
</tr>
<tr>
<td>Material</td>
<td>t/1000 m³ SWE</td>
<td>t/1000 m³ p, m³ SWE/ m³ p</td>
<td>Calculation</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------</td>
<td>---------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fibreboard</td>
<td>t/1000 m³ SWE</td>
<td>420, 1.47</td>
<td>Tonnes divided by JFSQ 2020 Fibreboard to 1000 m³ of product, multiplied by 1.47 (Weimar 2011) to reach 1000 m³ SWE</td>
</tr>
<tr>
<td>Plywood</td>
<td>t/1000 m³ SWE</td>
<td>650, 0.96</td>
<td>Tonnes divided by JFSQ 2020 Plywood to 1000 m³ of product, multiplied by 0.96 (Weimar 2011) to reach 1000 m³ SWE</td>
</tr>
<tr>
<td>Densified wood</td>
<td>t/1000 m³ SWE</td>
<td>560</td>
<td>(FAO, ITTO et al. 2020) Tonnes divided by Denmark basic density broadleaves</td>
</tr>
<tr>
<td>Wood waste and Residues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All streams</td>
<td>t/1000 m³ SWE</td>
<td>1.82</td>
<td>(Weimar 2011) Tonnes of air dry matter to m³ SWE.</td>
</tr>
</tbody>
</table>
Appendix II

Woodprint related to the Danish import in all the countries and regions represented in EXIOBASE, 2016 and 2018, 1000 m$^3$. 