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Greenhouse Gas and Carbon Profile of the Global Forest Products Industry, 2007-2022

Nº 1098

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EXECUTIVE SUMMARY

Over the 15-year period from 2007 to 2022, greenhouse gas (GHG) emissions from the forest products industry value chain (not considering biogenic CO_2, which is discussed separately) increased from 1,006 to 1,175 million metric tons CO_2 equivalents (CO_2e). The GHG emissions intensity of the value chain increased slightly, from 1.31 to 1.38 metric tons CO_2e per metric ton of production.

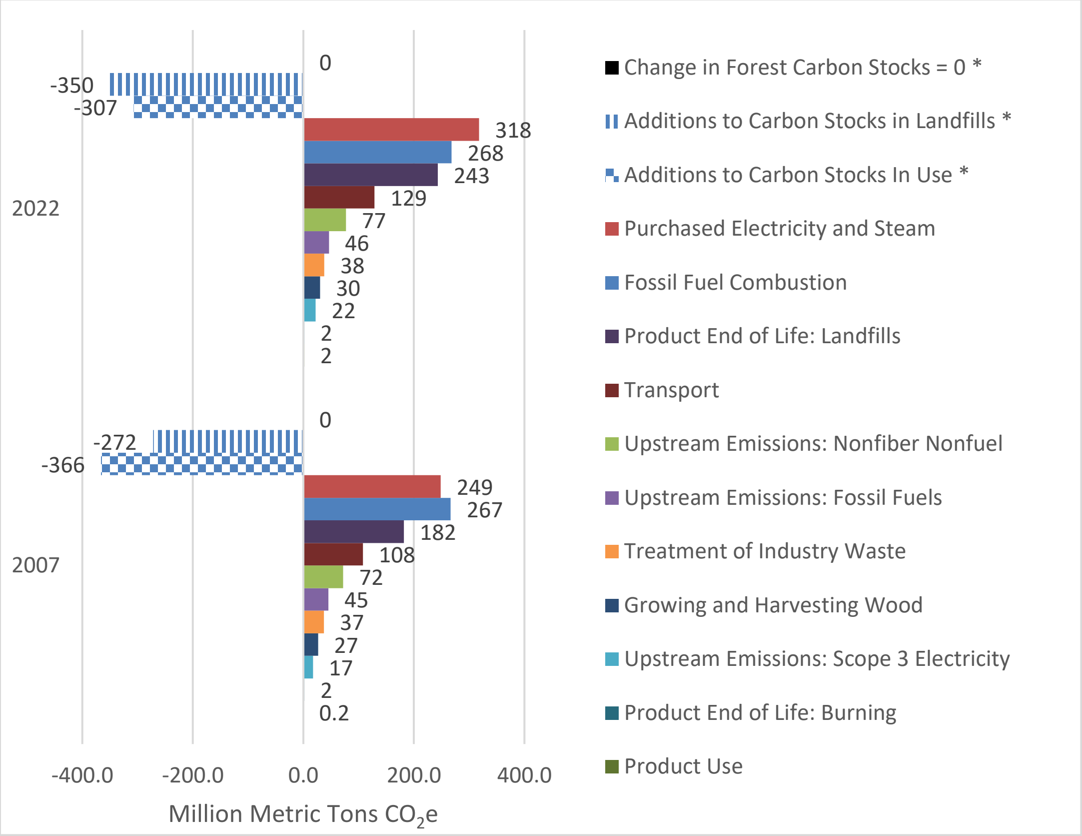
Fuel combustion and purchases of electricity are the two most important sources of emissions in the value chain, each representing 23%-27% of 2022 value chain emissions. Emissions from fuel combustion (i.e., Scope 1 as defined in the GHG Protocol [2004]) remained essentially constant between 2007 and 2022, in spite of a 7% increase in paper and paperboard production and a 14% increase in wood products production. Emissions associated with purchased power (i.e., Scope 2) increased by 28% over this period, faster than the growth in production. The increase is likely due to (1) faster production growth in regions with more GHG-intensive power grids and (2) a trend toward more electricity-intensive technologies. The emissions from product end of life, almost all of which are from landfilling, are a significant part of the industry's profile, representing between 18% and 21% of the industry's global value chain GHG emissions. These emissions, which are the result of landfilling over many past years, are increasing as the amounts of degradable carbon in landfills accumulate. Emissions from fuel combustion, purchased electricity, and end-of-life account for approximately two-thirds of value chain emissions.

The only other element contributing 10% or more of the industry's total value chain emissions is transport. Although there is considerable uncertainty in the estimates, it is likely that transport-related emissions increased between 2007 and 2022 primarily due to increased production but also, for some products, increased long-distance international shipments. Upstream emissions (Scope 3) associated with nonfiber inputs (e.g., additives), purchased electricity, fossil fuels, treatment of industry wastes, and growing and harvesting of wood each represent between 2% and 7% of the overall emissions profile in both 2007 and 2022. Emissions associated with product use (i.e., use of wood pellets for fuel) and emissions from burning products at end of life are negligible.

Calculating net biogenic CO_2 emissions from the industry's value chain requires completing a mass balance including changes in stocks of carbon in (1) the forest, specifically attributable to the forest products industry, and (2) forest products. The total amount of carbon in products in use and in landfills is increasing at the equivalent of about 600 million metric tons CO_2e per year. Wood products (lumber and panels) contribute about 80% of the total net additions. This increase in product carbon stocks should not be netted against

other emissions unless the biogenic carbon mass balance can be completed by including the industry's annual impact on changes in forest carbon stocks. Unfortunately, data are lacking to perform this calculation. However, if one completes the biogenic carbon balance by assuming that, globally, carbon stocks on land providing wood to the industry are stable or increasing, the growth in product carbon stocks can be considered. Using this assumption, the growth in stocks of carbon in products represents a net removal of carbon from the atmosphere adequate to offset all Scope 1 and Scope 2 emissions in the value chain. Even without information on forest carbon stocks, it is clear, therefore, that the carbon stored in forest products is an important element of the industry's overall GHG and carbon profile.

The following figure provides an overview of the GHG emissions and carbon profiles in 2007 and 2022.



GHG Emissions and Carbon Stock Changes in the Global Forest Products Industry Value Chain: 2007 (Bottom) and 2022 (Top)

[Note: The value of zero for change in forest carbon stocks is based on an assumption that carbon stocks are stable on land producing wood for the forest products industry. Asterisks identify the categories used to complete the mass balance of biogenic carbon]

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SOMMAIRE

Au cours de la période de 15 ans se situant entre 2007 et 2022, les émissions de gaz à effet de serre (GES) générées par la chaîne de valeur de l'industrie des produits forestiers (excluant le CO_2 biogénique traité séparément) ont augmenté, passant de 1 006 à 1 175 millions de tonnes métriques de CO_2 équivalents (CO_2e). L'intensité des émissions de GES de la chaîne de valeur a légèrement augmenté, passing de 1,31 à 1,38 tonne métrique de CO_2e par tonne métrique de production.

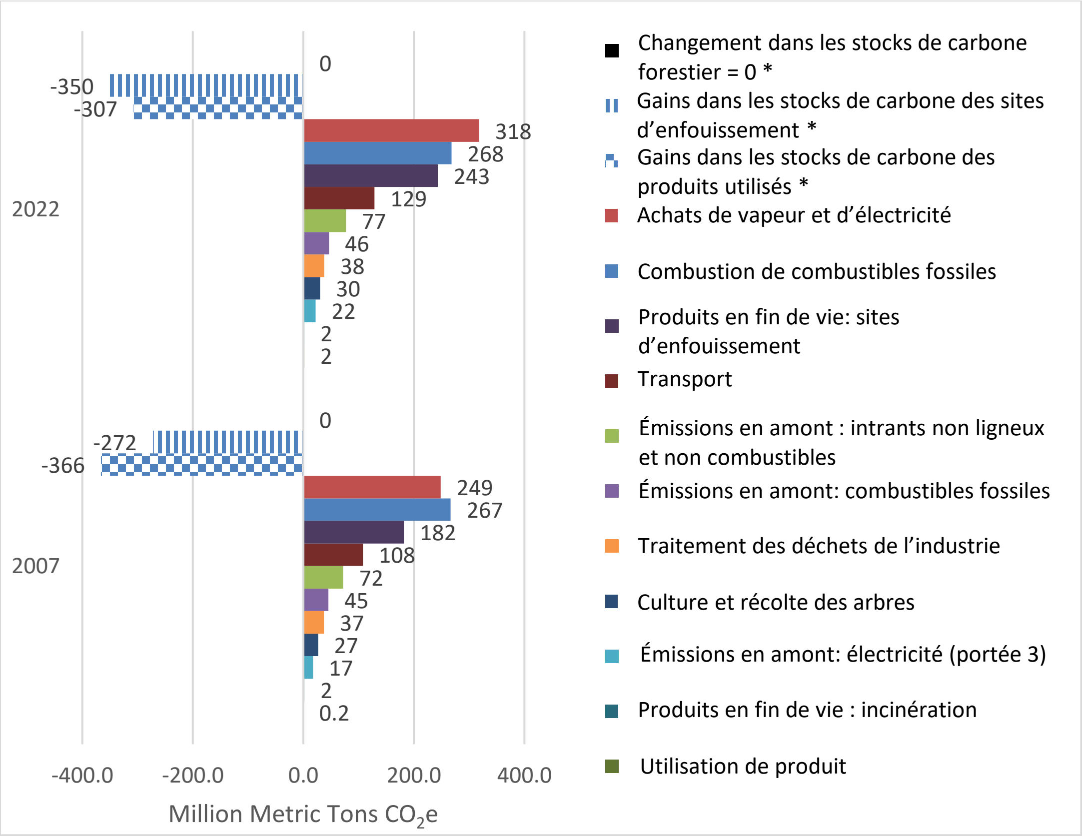
La combustion de combustibles et les achats d'électricité sont les deux principales sources d'émissions dans la chaîne de valeur, chacun représentant 23%–27% des émissions de la chaîne en 2022. Les émissions générées par la combustion des combustibles (c.-à-d. les émissions de portée 1, tel que défini dans le Protocole sur les GES [2004]) sont demeurées généralement constantes entre 2007 et 2022, en dépit d'une augmentation de 7% dans la production de papier et de carton et une augmentation de 14% dans la production de produits du bois. Les émissions associées à l'achat d'électricité (c.-à-d. les émissions de portée 2) ont augmenté de 28% au cours de cette période, soit plus rapidement que la croissance de la production. Cette augmentation est probablement attribuable à (1) une croissance de production plus rapide dans les régions où le réseau électrique a une intensité de GES plus élevée et (2) une tendance vers le déploiement de technologies à forte consommation d'électricité. Les émissions des produits en fin de vie, provenant pour la plupart des sites d'enfouissement, représentent un pourcentage important du profil de l'industrie, soit de 18% à 21% des émissions de GES de la chaîne de valeur mondiale. Ces émissions, qui découlent de l'enfouissement de déchets pendant de nombreuses années, sont en augmentation au fur et à mesure que les quantités de carbone dégradable s'accumulent dans les sites d'enfouissement. Les émissions générées par la combustion des combustibles, l'électricité achetée, et les produits en fin de vie comptent pour environ les deux tiers des émissions de la chaîne de valeur.

Le transport est le seul autre élément dont les émissions représentent 10% ou plus des émissions de la chaîne de valeur totale. Même s'il existe une incertitude considérable rattachée aux estimations, il est probable que les émissions reliées au transport ont augmenté entre 2007 et 2022 en raison principalement d'une augmentation de production mais aussi, pour certains produits, d'une augmentation des expéditions internationales de longue distance. Les émissions générées en amont (émissions de portée 3) associées aux intrants non fibreux (p. ex. les additifs), à l'électricité achetée, aux combustibles fossiles, au traitement des déchets de l'industrie, et à la culture et à la récolte des arbres représentent chacun entre 2% et 7% du profil global des émissions à la fois en 2007 et 2022. Les émissions associées à l'utilisation des produits (p. ex. l'utilisation de granules de bois

comme combustible) et les émissions associées à l’incinération des produits en fin de vie sont des contributeurs négligeables.

Calculer les émissions nettes de CO_2 biogénique de la chaîne de valeur de l’industrie requiert la réalisation d’un bilan de masse qui comprend les changements dans les stocks de carbone reliés (1) à la forêt, spécifiquement attribuables à l’industrie des produits forestiers, et (2) aux produits du bois. La quantité totale de carbone stockée dans les produits utilisés et dans les sites d’enfouissement augmente d’une quantité équivalente à environ 600 millions de tonnes métriques de CO_2e par année. Les produits du bois (bois d’œuvre et panneaux) représentent environ 80% de ces ajouts nets totaux. Ces gains dans les stocks de carbone ne devraient pas être soustraits des émissions de GES à moins de compléter le bilan de masse du carbone biogénique en incluant l’impact annuel de l’industrie sur les changements dans les stocks de carbone forestier. Malheureusement, les données manquent pour effectuer ce calcul. Cependant, si on complète le bilan du carbone biogénique en faisant l’hypothèse que, d’une manière générale, les stocks de carbone sur les terres qui fournissent du bois à l’industrie sont stables ou en augmentation, on peut déterminer la croissance des stocks de carbone. En utilisant cette hypothèse, le résultat est une élimination nette du carbone de l’atmosphère suffisante pour compenser toutes les émissions de portée 1 et de portée 2 de la chaîne de valeur. Même en l’absence de renseignements sur les stocks de carbone forestier, il ne fait donc aucun doute que le carbone stocké dans les produits issus de la forêt est un élément important du profil global d’émissions de GES et de carbone de l’industrie.

La figure ci-dessous donne un aperçu du profil d’émissions de GES et de carbone en 2007 et en 2022.



Changements dans les émissions de GES et dans les stocks de carbone de la chaîne de valeur de l'industrie mondiale des produits forestiers: 2007 (bas) et 2022 (haut)

[Note : La valeur de zéro attribuée au changement dans les stocks de carbone forestier repose sur l'hypothèse que les stocks de carbone sont stables sur les terres produisant du bois pour l'industrie des produits forestiers. Les astérisques identifient les catégories utilisées pour compléter le bilan de masse du carbone biogénique.]

GREENHOUSE GAS AND CARBON PROFILE OF THE GLOBAL FOREST PRODUCTS INDUSTRY, 2007–2022

TECHNICAL BULLETIN NO. 1098
JANUARY 2026

ABSTRACT

In this NCASI Technical Bulletin, an industry greenhouse gas (GHG) and carbon profile for 2022 is developed and compared to an updated 2007 profile. The results reveal that, over this period, GHG emissions from the forest products industry value chain increased from 1,006 to 1,175 million metric tons CO_2 equivalents (CO_2e). This does not include biogenic CO_2, which is discussed below. The GHG emissions intensity of the value chain increased slightly, from 1.31 to 1.38 metric tons CO_2e per metric ton of production.

Fuel combustion and purchases of electricity are the two most important sources of emissions in the value chain, each representing 23%-27% of 2022 value chain emissions. Direct emissions of GHGs from fuel combustion remained essentially constant between 2007 and 2022, despite a 7% increase in paper and paperboard production and a 14% increase in wood products production. Emissions associated with purchased power increased by 28% over this period, faster than the growth in production. The increase is likely due to (1) faster production growth in regions with more GHG-intensive power grids and (2) a trend toward more electricity-intensive technologies. GHG emissions from landfilled products at end of life are also a significant part of the industry's profile, representing between 18% and 21% of the industry's global value chain GHG emissions. These three emissions categories account for approximately two-thirds of value chain emissions. Transport is the only other aspect of the industry's value chain contributing more than 10% of the value chain emissions.

Calculating net biogenic CO_2 emissions from the industry's value chain requires a mass balance of biogenic carbon stocks in (1) the forest, specifically attributable to the forest products industry, and (2) forest products. This study finds that in both 2007 and 2022, the quantities of biogenic carbon stored in products were increasing at the equivalent of about 600 million metric tons CO_2e per year. These gains in stocks, however, cannot be netted against other GHG emissions without completing the biogenic carbon mass balance, which requires an understanding of the change in forest carbon stocks attributable to the global forest products industry, and at present, this understanding is lacking. If one assumes that annual forest growth is adequate to offset annual losses of forest carbon (i.e., stable forest carbon stocks) on land providing wood to the industry, the net removals of carbon from the atmosphere associated with the growth in carbon stocks is adequate to offset all Scope 1 and Scope 2 emissions (GHG Protocol 2004) in the value chain.

KEYWORDS
carbon footprint, value chain, Scope 1, Scope 2, Scope 3, greenhouse gas emissions, GHG

RELATED NCASI PUBLICATIONS

Greenhouse gas and carbon profile of the US forest products industry: 1990 to 2020. November 2024. Technical Bulletin No. 1091.

A review of biomass carbon accounting methods and implications. July 2013. Technical Bulletin No. 1015.

LE PROFIL DES GAZ À EFFET DE SERRE ET DU CARBONE DE L'INDUSTRIE MONDIALE DES PRODUITS FORESTIERS, 2007–2022

BULLETIN TECHNIQUE N^{O} 1098
JANVIER 2026

RÉSUMÉ

Dans le présent Bulletin technique, NCASI établit le profil des gaz à effet de serre et du carbone de l'industrie pour 2022 et le compare à un profil révisé pour 2007. Les résultats obtenus révèlent que, au cours de cette période, les émissions de GES de la chaîne de valeur de l'industrie des produits forestiers ont augmenté, passant de 1 006 à 1 175 millions de tonnes métriques de CO_2 équivalents (CO_2e) (excluant le CO_2 biogénique qui est traité ci-dessous). L'intensité des émissions de GES de la chaîne de valeur a légèrement augmenté, passing de 1,31 à 1,38 tonne métrique de CO_2e par tonne métrique de production.

La combustion de combustibles et les achats d'électricité sont les deux plus importantes sources d'émissions dans la chaîne de valeur, chacun représentant 23%–27% des émissions de la chaîne en 2022. Les émissions directes générées par la combustion des combustibles sont demeurées généralement constantes entre 2007 et 2022, en dépit d'une augmentation de 7% dans la production de papier et de carton et une augmentation de 14% dans la production de produits du bois. Les émissions associées à l'achat d'électricité ont augmenté de 28% au cours de cette période, soit plus rapidement que la croissance de la production. Cette augmentation est probablement attribuable à (1) une croissance de production plus rapide dans les régions où le réseau électrique a une intensité de GES plus élevée et (2) une tendance vers le déploiement de technologies à forte consommation d'électricité. Les émissions de GES des produits en fin de vie enfouis représentent un pourcentage important du profil de l'industrie, soit de 18% à 21% des émissions de GES de la chaîne de valeur mondiale. Ces trois catégories d'émissions comptent pour environ les deux tiers des émissions de la chaîne de valeur. Le transport est la seule autre catégorie dont les émissions représentent plus de 10% des émissions de la chaîne de valeur.

Calculer les émissions nettes de CO_2 biogénique de la chaîne de valeur de l'industrie requiert la réalisation d'un bilan de masse des stocks de carbone biogénique reliés (1) à la forêt, spécifiquement attribuables à l'industrie des produits forestiers, et (2) aux produits du bois. La présente étude montre que, à la fois en 2007 et en 2022, la quantité de carbone biogénique stocké dans les produits ont augmenté d'une quantité équivalente à environ 600 millions de tonnes métriques de CO_2e par année. Cependant, les gains dans ces stocks ne peuvent pas être soustraits des émissions de GES sans avoir réalisé le bilan de masse du carbone biogénique, ce qui nécessite une connaissance du changement dans les stocks de carbone forestier attribuable à l'industrie mondiale des produits forestiers. Présentement, les données manquent pour calculer ce bilan. Si on fait l'hypothèse que la croissance annuelle des forêts est adéquate pour compenser les pertes annuelles de carbone forestier (c.-à-d. des stocks de carbone forestier stables) sur les terres qui fournissent du bois à l'industrie, les quantités nettes de carbone retirées de l'atmosphère grâce à la croissance des stocks de carbone sont suffisantes pour compenser toutes les émissions de portée 1 et de portée 2 (GHG Protocol 2004) dans la chaîne de valeur.

MOTS-CLÉS

chaîne de valeur, émissions de gaz à effet de serre, empreinte carbone, GES, portée 1, portée 2, portée 3

AUTRES PUBLICATIONS DU NCASI

Le profil du carbone et des gaz à effet de serre de l'industrie des produits forestiers des États-Unis : 1990 à 2020. Novembre 2024. Bulletin technique n° 1091.

Une revue des méthodes de comptabilisation du carbone de la biomasse et leurs répercussions. Juillet 2013. Bulletin technique n° 1015.

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GREENHOUSE GAS AND CARBON PROFILE OF THE GLOBAL FOREST PRODUCTS INDUSTRY, 2007–2022

1.0 Introduction

In 2008, the Food and Agriculture Organization of the United Nations (FAO) and the International Council of Forest and Paper Associations (ICFPA) commissioned National Council for Air and Stream Improvement, Inc. (NCASI) to assess, and prepare a report on, the global forest industry's impact on greenhouse gas (GHG) emissions. The report was issued in 2010 as FAO Forestry Paper 159, titled "Impact of the Global Forest Industry on Atmospheric Greenhouse Gases" (FAO 2010). The FAO report is based on conditions in 2007, although data were used from years shortly before or after 2007 when necessitated by data availability. In this report, new estimates are developed for 2022, revealing changes that have occurred over a 15-year period. This report is structured similarly to the 2010 FAO report. In many places, the calculation methods used are the same as in the 2010 FAO report, but in some cases, methods have been changed to improve the estimates. Where this has been done, it is noted in the report. In addition, this report attempts to include sources of emissions not included in the 2010 FAO report. In cases where emissions were not included in the 2010 FAO report or where methods have been changed, new estimates for both 2007 and 2022 are developed in this update.

The 2010 FAO report largely employed a life cycle framework to calculate the GHG and carbon profile of the global industry. The life cycle framework follows a single year's harvest through product manufacturing, product use, and product disposal, calculating the emissions when they occur over time. This is different from the annual inventory framework used, for instance, in national GHG emissions reporting under Intergovernmental Panel on Climate Change (IPCC) guidelines issued for United Nations Framework Convention on Climate Change. Annual inventory guidelines generally require reporting all emissions occurring in a single year, regardless of when the products associated with the emissions were produced (e.g., see IPCC [2006; 2019]). Unlike the 2010 FAO report, this update is based only on the annual inventory approach.

In many cases, the industry's value chain emissions are reported by *Scope*[1]. For the purposes of this report, Scope 1 emissions are those from manufacturing and converting operations in the forest products value chain. Scope 2 emissions are those released by producers of electricity and steam purchased by the forest products industry. Scope 3 emissions are all other emissions in the forest products industry value chain. For a complete description of the emissions scope concept, the reader is directed to the GHG Protocol Corporate Standard (GHG Protocol 2004).

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[1] As of this writing, the Scope concept has not been extended to emissions of biogenic CO_2.

2.0 Overview of the Global Forest Products Industry

2.1 Global Forest Products Industry Output

In 2006, the global forest products industry[2] contributed approximately US$468 billion to the global economy, representing about 1% of the total (FAO 2010). By 2015, this had increased to US$661 billion (FAO 2022a). Including both direct and indirect impacts, the industry accounted for US$1.52 trillion in economic activity in 2015 (FAO 2022a). Using the World Bank's estimate of global gross domestic product (GDP) in 2015 of US$75 trillion (World Bank 2024), the forest products direct contributions represented about 1% of global output, the same as in 2006.

The global forest products sector accounts for about 1% of global employment (FAO 2022a). The distribution of employment among parts of the sector is shown in Figure 2.1.

In 2022, the global industry produced 2 billion cubic meters of industrial roundwood, 463 million cubic meters of sawnwood, 373 million cubic meters of wood-based panels, and 419 million metric tons of paper and paperboard (FAO 2024a). These production values were 15%, 2%, 34%, and 7%, respectively, higher than their values in 2007 (based on data in FAO [2024a]). The growth in wood-based panel production has been especially robust, as shown in Table 2.1 and Figure 2.2.

The forest products industry uses both virgin fiber and recovered fiber. The recycling rate for paper in 2021 was 59.9% (ICFPA 2023)[3]. The corresponding value for 2007 was between 52% and 53% (ICFPA 2023). While some wood products, some wood-based panels in particular, are made using manufacturing residuals, they seldom incorporate discarded postconsumer products.

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[2] In this report, the global forest products industry is intended to include forest management, roundwood production, and the manufacturing and processing of wood and paper products.

[3] ICFPA indicates that "recycling rate is defined as recovered paper used by paper and paperboard mills [divided by] paper and paperboard production."

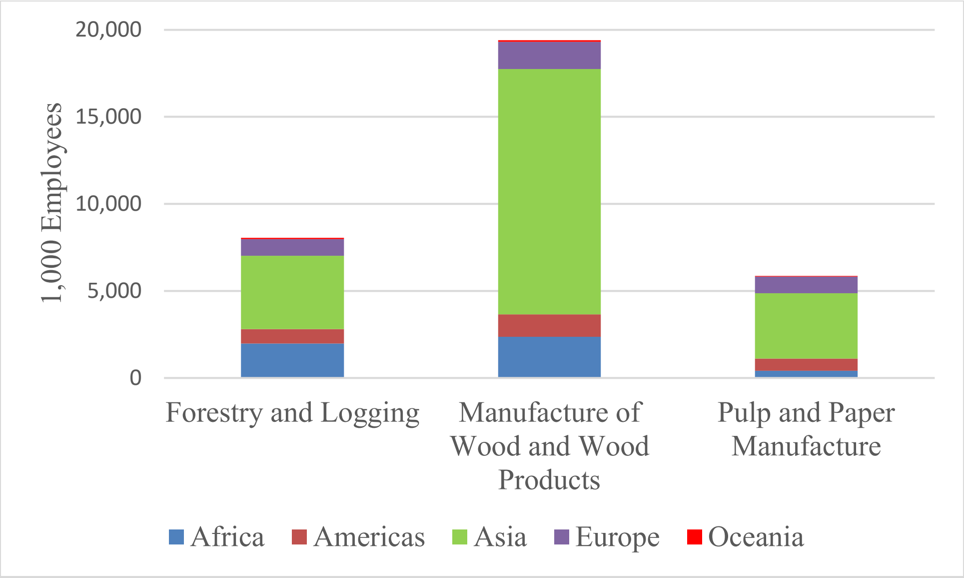

Figure 2.1. Employment in the global forest products industry. [*Source:* FAO (2022a)]

Table 2.1. Global production of forest products in 2007 and 2022 (FAO 2024a).

Product Category	Million Metric Tons 2007	2022
Sawnwood[a]	217	222
Panels′	140	187
Paper and paperboard	392	415

[a] Cubic meters converted to metric tons using the factors developed in FAO (2010). These factors were 0.479 metric tons per cubic meter of sawnwood and 0.497 metric tons per cubic meter of panels.

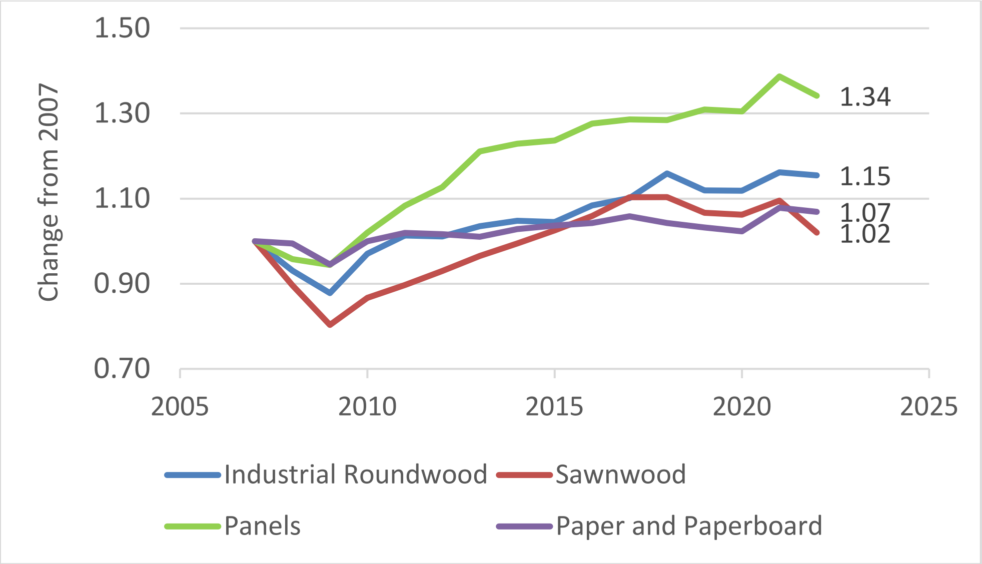

Figure 2.2. Change in forest products output, 2007–2022.

Wood harvesting is distributed around the world, as illustrated in Figure 2.3, and has been increasing in all regions. Between 2007 and 2022, global wood harvesting grew by about 11%, from 3.6 billion cubic meters in 2007 to 4 billion cubic meters. This is less than the growth in global population, which increased by about 18% over that same period (World Bank 2024). One-half of harvested wood is used as nonindustrial fuelwood, mainly for heating and cooking. The fraction used as nonindustrial fuelwood is especially high in Africa and Asia, as shown in Figure 2.4.

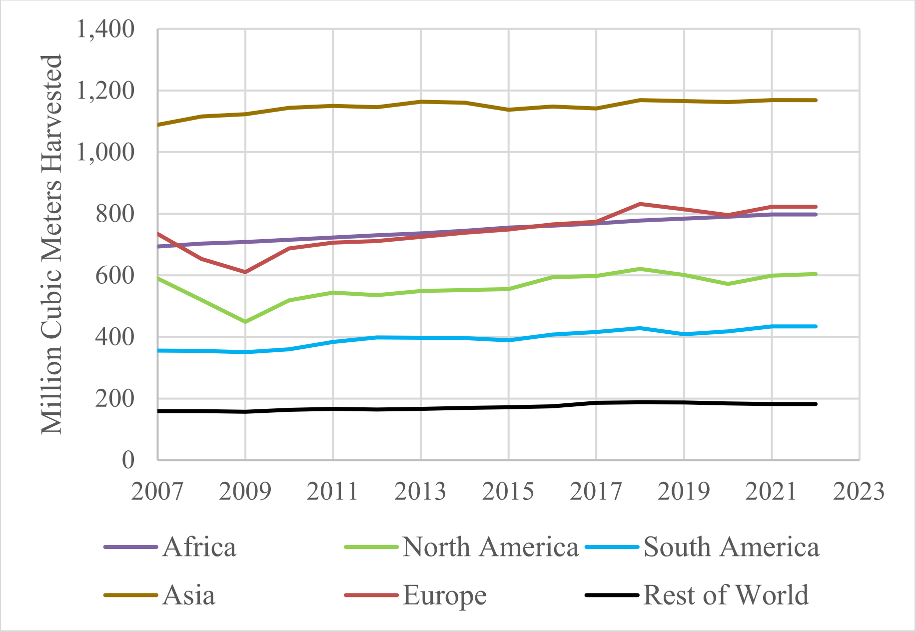

Figure 2.3. Regional distribution of wood harvesting. [*Source:* FAO (2024a)]

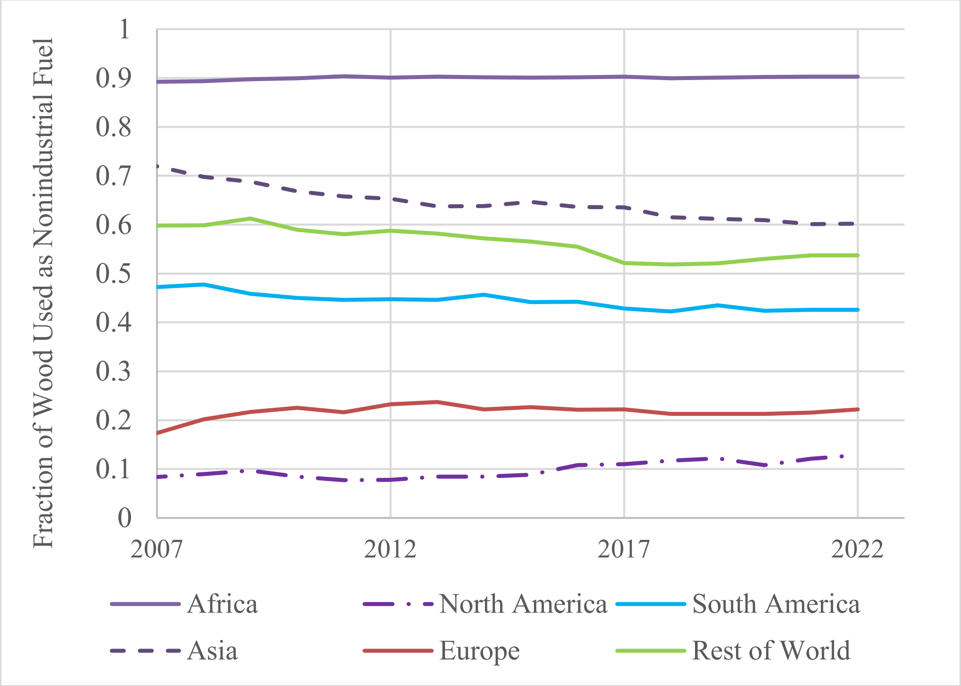

Figure 2.4. Fraction of harvested wood used as nonindustrial fuel. [*Source:* FAO (2024a)]

2.2 Sustainable Forest Management Certification Programs

Sustainable forest management certification programs are widely used in forests producing industrial roundwood for the forest products industry. The forest area operated under third-party certification programs has increased dramatically over the last several decades. In 2000, approximately 50 million hectares were certified under either Forest Stewardship Council (FSC) or Programme for the Endorsement of Forest Certification (PEFC) programs (FAO 2020a). By 2019, this had increased to 426 million hectares (FAO 2020a) or 10.5% of total global forest area.

As of mid-2023, 384.7 million hectares of forest globally were certified under PEFC, FSC, or both programs. This is less than the certified area in 2019, primarily due to the suspension of certificates in Russia and Belarus (FAO 2023). North America and Europe (excluding Russia and Belarus) contain most of the world's third-party certified forests, as is evident in Figure 2.5. In 2022, these areas accounted for almost one-half (46%) of industrial roundwood produced globally (FAO 2024a).

Third-party certification under PEFC and FSC is widely applied to forests supplying wood to the forest products industry. The ICFPA regularly surveys its members on sustainable forest management practices.[4] In 2021, 50% of the forests supplying wood to ICFPA members

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[4] "The ICFPA serves as a forum of global dialogue, coordination and co-operation. Currently, the ICFPA represents 16 pulp, paper, wood and fibre-based associations that encompass 27 countries, including many of the top pulp, paper and wood producers around the world" (from https://ICFPA.org).

were certified under FSC, PEFC, or both programs (ICFPA 2023). ICFPA notes that significant increases in FSC and PEFC certification are not expected in its member countries because most of the remaining wood-producing land in these countries is owned by small forest owners (ICFPA 2023).

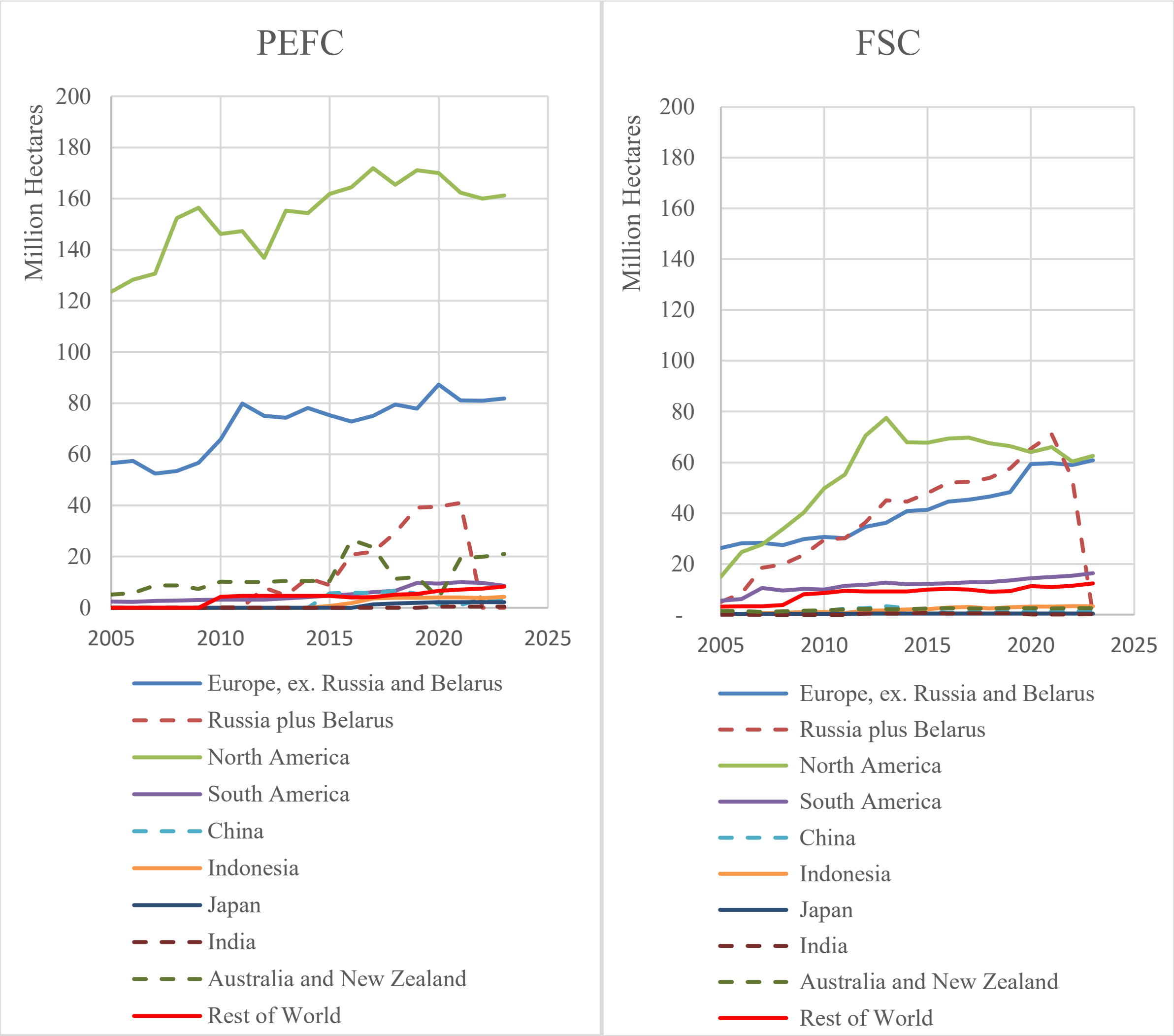

Figure 2.5. Area certified under PEFC and FSC sustainable forest management certification programs. [*Source:* Annual PEFC reviews from PEFC (2024), and data from FSC (2024)]

3.0 Global Forests

3.1 Forest Area and Forest Ecosystem Carbon Stocks

FAO reports that in 2020 the world had a forest area of 4.06 billion hectares, comprising 31% of total land area. The tropics contain 45% of global forest area, while more than one-half (54%) of forest area is in only five countries (Russia, Brazil, Canada, US, and China). The distribution of global forests by climatic domain is shown in Figure 3.1 (FAO 2020a). Global forest area is declining, but the rate of loss is slowing (discussed in more detail later) as are the declines in global forest ecosystem carbon stocks, as shown in Table 3.1 (FAO 2020a).

Global forest ecosystems contained 662 billion metric tons of carbon in 2020[5]. This was distributed between living biomass (44.5%), dead wood and litter (10.3%), and soil (45.2%) (FAO 2020a). The regional distribution of forest carbon and the regional changes in forest carbon from 1990 to 2020 are shown in Table 3.1 and Figure 3.2. These FAO data indicate that forest ecosystem carbon stocks declined modestly (i.e., about 1%) between 1990 and 2020. The changes in forest carbon, however, varied considerably in different regions. Forest carbon stocks were essentially stable or increasing everywhere except Africa and South America.

Table 3.1. Regional distribution of forest ecosystem carbon.

	Million Metric Tons Forest Ecosystem Carbon				Decadal Change (%)		
Region	1990	2000	2010	2020	1990–2000	2000–2010	2010–2020
Africa	94,274	90,137	85,913	80,886	−4.39	−4.69	−5.85
Asia	77,093	78,564	81,938	84,733	1.91	4.29	3.41
Europe without Russia	31,625	34,260	36,833	39,192	8.33	7.51	6.40
Russia	127,119	128,197	131,236	133,250	0.85	2.37	1.53
North and Central America	143,184	144,131	145,572	146,118	0.66	1.00	0.38
South America	161,765	154,917	147,917	144,846	−4.23	−4.52	−2.08
Oceania	33,338	33,111	33,077	33,063	−0.68	−0.10	−0.04
World	668,398	663,317	662,486	662,088	−0.76	−0.13	−0.06

[*Source:* Data from FAO (2020a)]

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[5] The amounts of forest carbon stored in products are addressed later in this report.

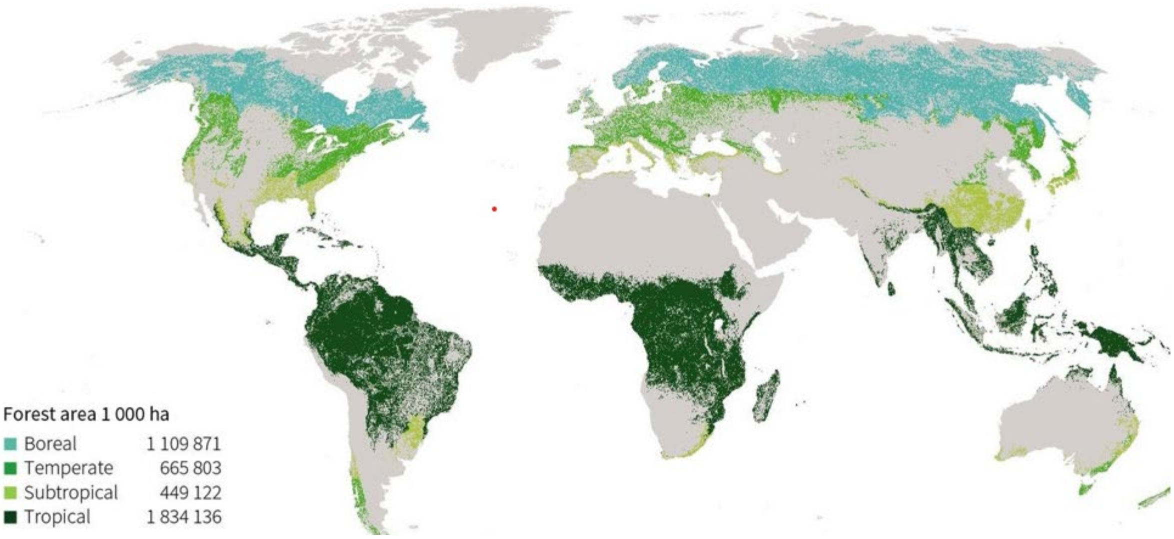

Figure 3.1. Global distribution of forests by climatic domain. [*Source:* FAO (2022a)]

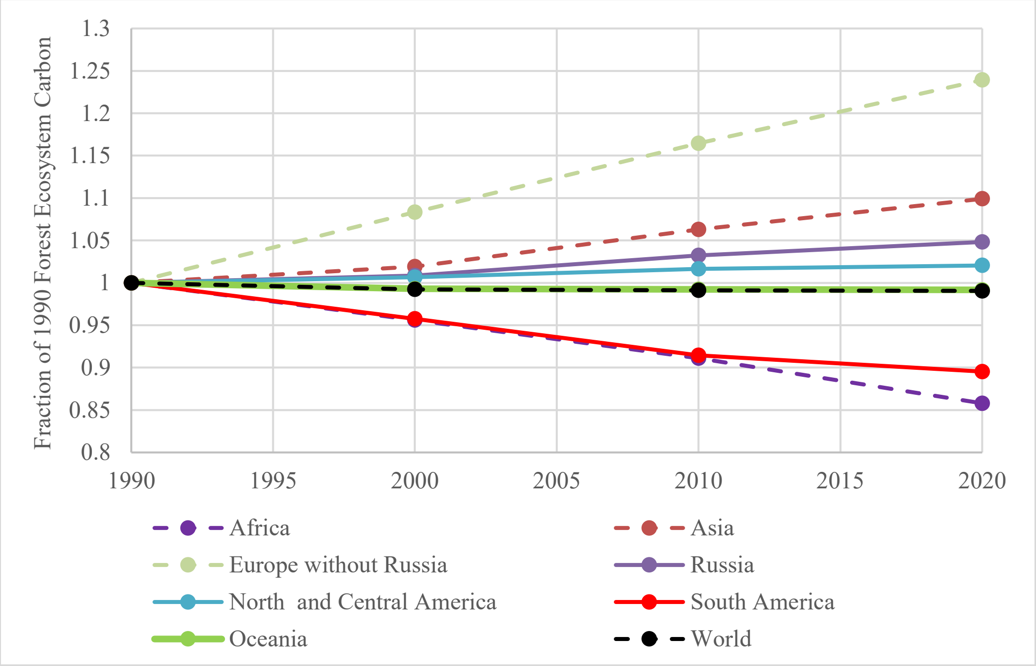

Figure 3.2. FAO data on changes in forest ecosystem carbon from 1990 to 2020. [*Source:* FAO (2020a)]

These findings are consistent with other large-scale assessments. Pan et al., for instance, found that global forest ecosystem carbon stocks declined by 5% between 1990 and 2020 (Pan et al. 2024). The data from Pan et al., shown in Figure 3.3, also illustrate differences between forest types. Net losses of forest carbon have been concentrated in the tropics, while forest carbon stocks in boreal and temperate forests have increased over this period.

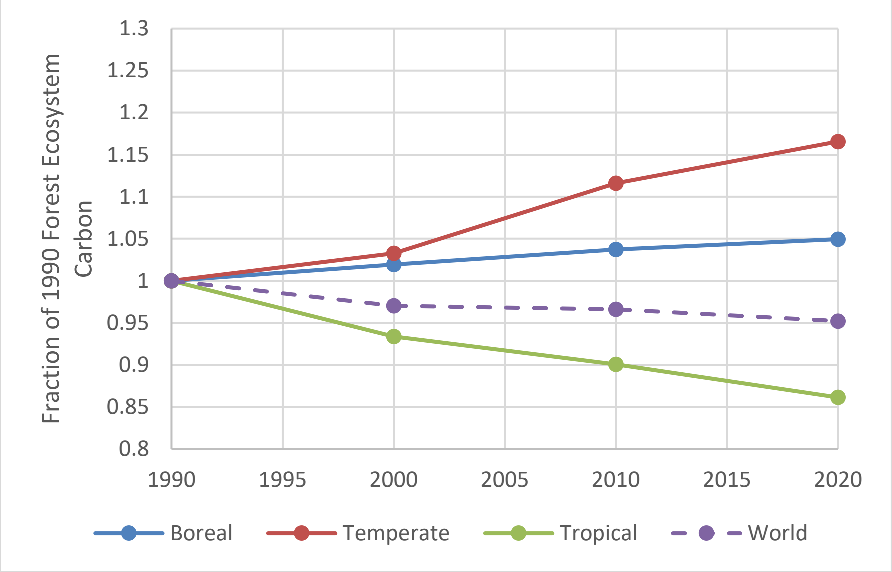

Figure 3.3. Pan et al. data on changes in forest ecosystem carbon from 1990 to 2020. [*Source:* Pan et al. (2024)]

3.2 Deforestation, Afforestation, and Forest Degradation

Forest area is increasing in some regions while decreasing in others. Since 1990, global forest area has been declining, but due to decreasing deforestation, in recent years the losses have been declining. From 1900 to 2000, global forest area decreased by 7.8 million hectares per year, while between 2000 and 2010 the loss was 5.2 million hectares per year. Between 2010 and 2020, the loss was further reduced to 4.7 million hectares per year (FAO 2020a). Figures 3.4 and 3.5 illustrate that since 1990, most of the net loss in forest area occurred in South America and Africa.

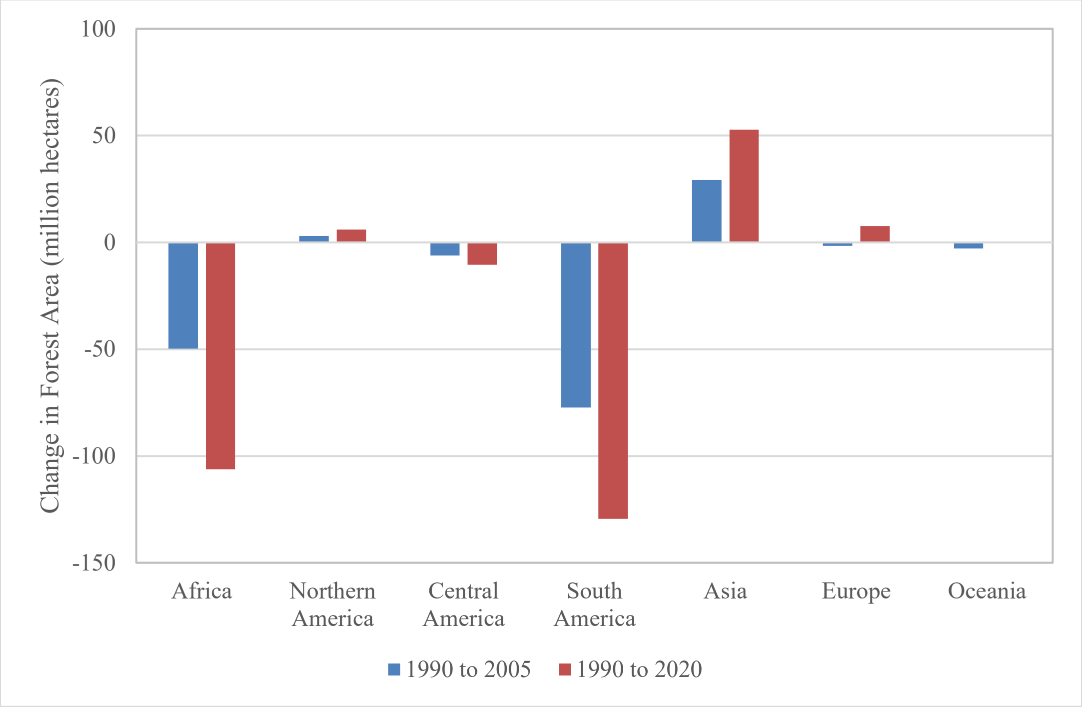

Figure 3.4. Regional changes in forest area since 1990. [*Source:* Data from FAO (2024b)]

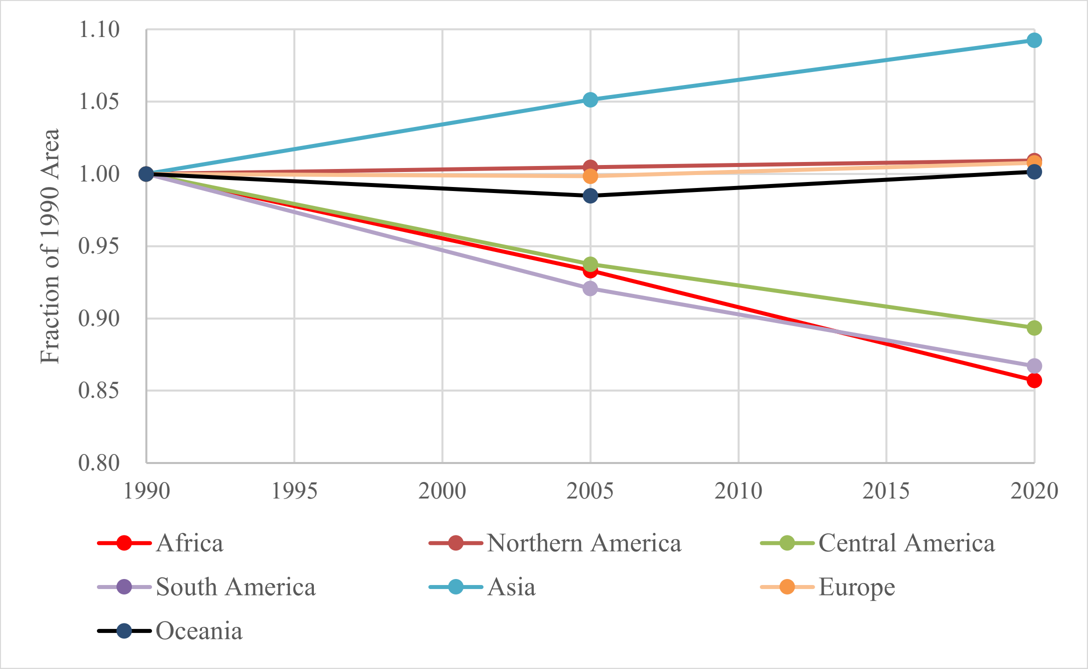

Figure 3.5. Relative changes in regional forest area since 1990.
[*Source:* Data from FAO (2024b)]

Looking specifically at deforestation[6], FAO reports that "420 million ha of forest was lost through deforestation between 1990 and 2020, although the rate slowed over the period. Deforestation occurred at a rate of 15.8 million ha per year in 1990–2000, 15.1 million ha per year in 2000–2010, 11.8 million ha in 2010–2015 and 10.2 million ha per year in 2015–2020 . . . More than 90 percent of deforestation in 1990–2020 was in the tropical domain" (FAO 2020a).

Forested areas have increased most rapidly in Asia. This is primarily due to afforestation in China where, from 2010 to 2020, the net annual increase in total forest area was 1.94 million hectares per year, of which planted forest represented 1.14 million hectares per year or 59% (FAO 2020a).

The extent of and trends in forest degradation are more difficult to assess than those for deforestation. This is in part due to inconsistent criteria used to identify forest degradation. FAO has defined forest degradation as "the long-term reduction of the overall supply of benefits from forests, which includes wood, biodiversity and other products and services" (FAO 2024c). However, FAO has found that "countries use various definitions of degraded forest and it is infeasible, therefore, to aggregate and compare data on forest area at the regional and global levels" (FAO 2020a). Furthermore, in reviewing the approaches used by countries to identify degraded forest, FAO found that "few countries apply quantitative criteria in their definitions" (FAO 2020a).

3.3 The Forest Products Industry's Impact on Global Forest Carbon

3.3.1 Potential Role in Deforestation, Afforestation, and Forest Degradation

The interactions between the forest products industry and global forests are too complex to allow a quantitative estimate of the industry's impact on global forest carbon stocks. The industry's activities can directly affect forest carbon stocks by harvesting, regeneration, and forest management. Some of these activities may decrease forest carbon stocks, while others may increase these stocks. There are also important indirect effects that are even more difficult to characterize. Among the important indirect effects are market-mediated impacts on land use and interactions between the agriculture and forestry sectors. These vary by nation, region, and site and are highly dependent on local legal, regulatory, policy, and governance conditions. Further complicating attempts to characterize the impacts of the forest products industry are the multiplicity of factors affecting forest carbon. These interact in complex ways and often make it impossible to precisely isolate the role of the industry compared to other factors. One can, however, gain insights into the industry's impacts on forest carbon by examining some of the factors known to influence global carbon stocks. Some of the most important of these factors are examined in this section.

Isolating the potential role of the global forest products industry in deforestation is difficult. The FAO report published in 2010, which this report updates, cites a meta-analysis of 152

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[6] The following FAO values are for gross deforestation. They are not offset by gains in forest area via afforestation.

case studies that concludes "The multiple factors intervening in tropical deforestation . . . make it particularly difficult to develop generic and widely applicable policies that best attempt to control the process. Many land-use policies are underlain by simplifications on the drivers of change . . . From the results of the meta-analysis, it is clear that any universal policy or global attempt to control deforestation (e.g., through poverty alleviation) is doomed to failure."(Geist 2001)

A subsequent expanded meta-analysis of 320 deforestation studies (Busch and Ferretti-Gallon 2023) again revealed multiple drivers of deforestation, but "in a change from the previous meta-analysis, timber activity was found to be consistently associated with greater deforestation." Putting this into context, the analysis also found that, "markets that drive deforestation include agriculture, livestock, and, *to a lesser extent, timber*" [emphasis added]. Although "general good governance" was not found to be consistently associated with more or less deforestation, the updated meta-analysis confirmed that increased enforcement of forest laws was consistently associated with less deforestation at the regression level, though not at the study level.[7]

Busch and Ferretti-Gallon also found that "commodity certification programs were associated with less deforestation at the regression level, though not the study level.[7] Certification programs associated with less deforestation included . . . Forest Stewardship Council–certified timber" (Busch and Ferretti-Gallon 2023).

Overall, the new results confirm earlier findings indicating that the factors affecting deforestation trends are complex, and the severity of deforestation varies dramatically from region to region. While demand for timber may be among the factors contributing to forest loss in some areas, the role of timber demand is less important than agriculture and livestock production. Indeed, in some regions, loss of forest area has little to do with commodity demand of any type, being far more related to expansion of developed land area. In the US, for instance, expansion of developed land is projected to account for approximately three-quarters of net forest loss between 2020 and 2070. (See data in table 4-11 of USDA [2023].)

The forest products industry has a large stake in planted forests. FAO estimates that in 2020, planted forests accounted for 46% of global industrial roundwood production (FAO 2022b). Some of this planting is on land that was previously forested (reforestation) while some is on land that was previously used for other purposes (afforestation). Reforestation can involve replanting previously planted forest or planting on land that was converted from naturally regenerating. Major forest certification programs contain requirements to

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[7] The authors note that "For variables that had a consistent association with deforestation at the regression level but not at the study level, we consider the evidence for these variables to be preliminary until confirmed by more studies" (Busch and Ferretti-Gallon 2023).

manage forests to ensure future wood supplies, normally allowing this to be accomplished by either replanting or natural regeneration[8].

Between 1990 and 2020, the global planted forest area increased by 70% (FAO 2022b). FAO indicates that "industrial roundwood production occurs mainly in intensively managed plantation forests" (FAO 2022b). These plantation forests comprised 131 million hectares of the 293 million hectares of planted forests in 2020 (FAO 2020a). In 2000, FAO found that about one-half of forest plantations were designated for industrial use, one-quarter were used for nonindustrial purposes, and the remaining had unspecified uses (FAO 2000). While these facts provide useful context for understanding the importance of planted forests to the forest products industry, the data do not allow the industry's global role in afforestation and reforestation to be quantified.

The potential impacts of the forest products industry on forest degradation are even more difficult to assess than those in deforestation, reforestation, and afforestation. As noted earlier, this is in part due to inconsistent criteria used to identify forest degradation. There is no reason to suspect that the causes of forest degradation, under any set of criteria, are any less complex than those involving deforestation. Given the lack of consistent criteria and data, and the likely complexity of factors affecting forest degradation, no attempt is made in this report to characterize the forest product industry's potential effects on global forest degradation.

4.0 Carbon in Forest Products

Annual harvests of industrial roundwood in 2007 and 2022 contained approximately 428 and 498 million metric tons of carbon, respectively[9]. A significant fraction of this is used as fuel, primarily at forest products manufacturing facilities and, increasingly, in commercial biomass energy production (e.g., by producers of electricity from wood pellets). Most of the carbon removed from the forest, however, is transferred to products that store the carbon for periods ranging from months to centuries.

The stocks and flows of carbon associated with the forest products value chain are shown, in simplified form, in Figure 4.1. Carbon stocks are stored in three places in the value chain, often called carbon pools. These pools are the forest, products in use, and products in landfills. At any point in time, if the total of the carbon stocks in these three pools is increasing, mathematically, the net flow of carbon must be out of the atmosphere and into the value chain (i.e., a net removal of carbon from the atmosphere). Conversely, if the total

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[8] For instance, the Sustainable Forestry Initiative (https://forests.org/wp-content/uploads/2022_SFI_StandardsandRules_section2.pdf) contains a performance indicator calling for "documented reforestation plans," and the FSC standard (https://us.fsc.org/en-us/certification/forest-management-certification) contains a criterion requiring that "the rate of harvest of forest products shall not exceed levels which can be permanently sustained."

[9] Calculated from production data in FAO (2024a) using wood densities of 430 and 560 dry kilogram per cubic meters for coniferous and non-coniferous species, respectively (based on analysis of data in FAO [2020b] and an assumption that dry wood is 50% carbon by weight).

quantity of carbon in these pools is decreasing, there must be a corresponding net transfer of carbon from the value chain into the atmosphere, representing a net emission of biogenic carbon.

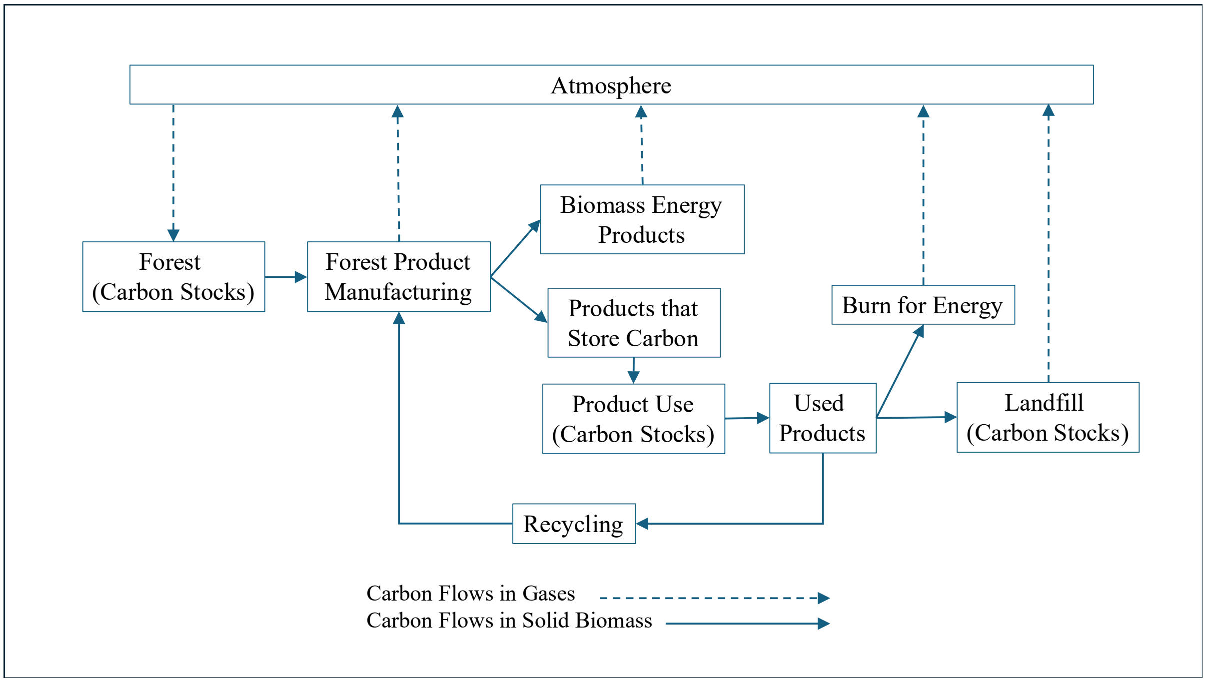

Figure 4.1. Simplified diagram of biomass carbon flows and stocks in the forest industry value chain.

In section 3 of this report, it was observed that over the 10-year period ending in 2020, carbon stocks in global forests declined, albeit at a slower rate than in previous decades. That section also examined the many factors that make it impossible to quantify the overall impact on global forest carbon stocks attributable to the forest products industry value chain. Changes in stocks of carbon in products in use and in landfills, however, occur, by definition, within the industry's value chain and can be calculated.

4.1 Annual Stock Changes in Carbon Stored in Products in Use

For national inventory accounting, changes in stocks of carbon in paper and wood products are often calculated annually based on estimates of annual flows of carbon into, and out of, the pools of carbon in products in use and in landfills. Methods for these calculations are published by IPCC (2006; 2019). Several studies have attempted to calculate the global changes in carbon stocks in paper and wood products. Johnston and Radeloff, for instance, estimated that global stocks of carbon in products in use were growing by 290 million metric tons CO_2e (79 million metric tons carbon) per year in 2007 and 335 million tons CO_2e (91 million metric tons carbon) per year in 2015 (the final year with data) (Johnston and Radeloff 2019). Pan et al. calculated that in the 1990s, 2000s, and 2010s, the stocks of carbon in products in use and in landfills were increasing by 192.6, 193.7, and 211.9 million metric tons carbon per year, respectively (Pan et al. 2024). Pan et al.'s estimates were based on national inventory reports, where available, and where not available, on FAO data. Zhang et al. estimated carbon stocks in products in use for several periods from 1992 to 2015 (Zhang et al. 2020). The increase over this period amounted to 120 million metric tons carbon per year. Pingoud and Soimakallio calculated that annual increases in stock of carbon in products in use varied between 30 and 60 million tons carbon per year between 1960 and 2000 (Pingoud and Soimakallio 2003). For all methods that account for stocks of carbon inherited in 1960, Kayo et al. found that between 1960 and 2020, carbon stocks in products in use varied significantly from year to year but remained between 40 and 100 million metric tons carbon per year, with a general trend toward higher stock changes per year (Kayo et al. 2021).

In this report, estimates of changes in stocks of carbon stored in products in use in 2007 and 2022 were developed using a first-order decay model (IPCC 2019) and forest products production data from 1961 to 2023 (FAO 2024a). Production was assumed to be zero in 1900, and the values between 1900 and 1961 were calculated via linear interpolation. The data on sawnwood, panel, and paper and paperboard production were converted to units of carbon based on the IPCC default conversion factors shown in Table 4.1. Each year, stock change was calculated as the differences between additions (from FAO data) and losses, calculated from the first-order decay model using the half-lives shown in Table 4.1.

The results are shown in Figure 4.2. Because of the short times in use for paper products, the annual changes in stocks of carbon in paper products in use are greatly affected by changes in production. Before 2007, growth in production contributed significantly to the annual net gains in carbon stocks in paper products in use. Since 2007, however, there has been little growth in paper production. As a result, net additions to the pool of paper products in use declined dramatically between 2007 and 2022, as shown in Table 4.2. Also shown in Figure 4.2 are the estimates from Johnston and Radeloff (2019). The analysis by Johnston and Radeloff differs from the analysis performed for this study primarily in (1) the method used to estimate carbon stocks in 1960 and (2) the degree of detail in the analysis, with Johnston and Radeloff using higher resolution with regard to carbon stocks and flows in individual countries. Both analyses show the large variability in stock changes from year to year, resulting from changes in quantities of new production. In addition, both analyses show that, despite these annual fluctuations, the annual changes in stocks of carbon in products in use are generally increasing. The increasing trend is confirmed in the work of Pan et al. (2024). Zhang et al. (2020) found that, based on period averages, annual additions to stocks of carbon in products in use were relatively constant between 1995 and 2015, with the period from 1990 to 1995 showing somewhat higher additions. In all periods examined by Zhang et al. (2020), the net additions to carbon in products in use were higher than found in this study and higher than those indicated in Johnston and Radeloff (2019). Due to the annual swings in production, the analysis performed for this study indicates that net additions to stocks in 2007 were greater than those in 2022 (99.9 million metric tons carbon in 2007 and 83.6 million metric tons in 2022). These values are within the range reported in the literature. Almost all net additions to stocks of carbon in products in use were attributable to wood products, as shown in Table 4.2.

Table 4.1. IPCC default factors for forest products in use.

Product Segment	Half-Life (years)[a]	First-Order *k*	Fraction Remaining in Use at End of Year 100	Conversion Factor to Carbon[b]	Conversion Factor to Metric Tons (Mg)
Paper and paperboard	2	0.3466	Less than 0.000001	0.386 Mg C/Mg	1 Mg/Mg
Wood-based panels	25	0.0278	0.0625	0.269 Mg C/m^3	0.595 Mg/m^{3b}
Sawnwood (lumber)	35	0.0198	0.1380	0.229 Mg C/m^3	0.458 Mg/m^{3b}

[a] See Table 12.3 in volume 4 of IPCC (2019).
[b] See Table 12.1 in volume 4 of IPCC (2019).

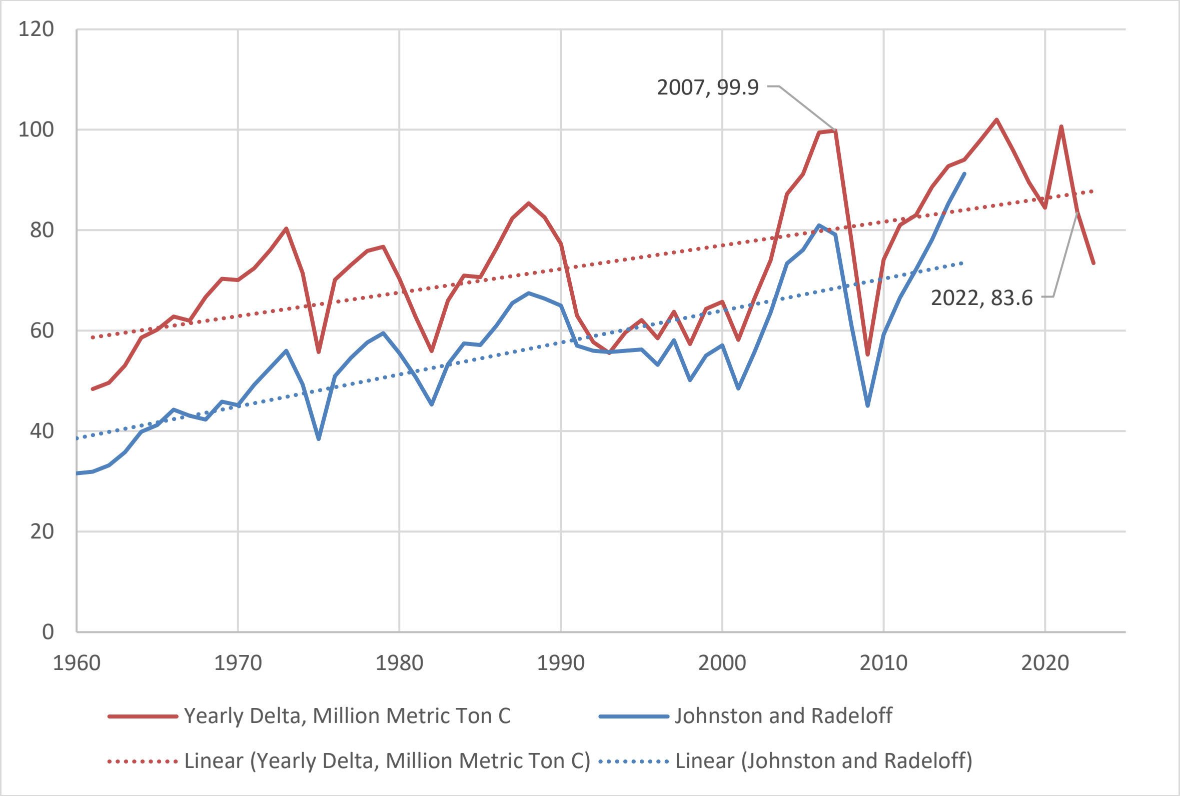

Figure 4.2. Annual changes in stocks of carbon in products in use.

Table 4.2. Net additions to carbon stocks in forest products in use.

	Million Metric Tons CO_2e	
Product	2007	2022
Paper	55.8	7.4
Wood	310	299
Total	366	307

4.2 Annual Stock Changes in Carbon Stored in Landfills

Stock changes associated with landfills reflect the net of (1) additions of forest products to landfills, (2) losses of degradable carbon from landfills due to forest product decomposition, and (3) the addition to landfills of carbon that is nondegradable under the conditions in the landfill receiving the material. Calculating annual changes in landfill carbon stocks, therefore, requires historic data on the annual amounts of various materials landfilled, the design and operation of landfills over time (needed to understand the amount of landfilled material that may permanently store biogenic carbon), and the rate at which degradable carbon is decomposed. Estimates can be developed of quantities landfilled, but information on landfill designs and degradation rates over time do not exist.

The same information is required to estimate methane emissions from landfilled forest products, addressed in section 11 of this report. The key assumptions used in these calculations are as follows:

- Quantities of used products, before recycling, are calculated using the approach described in section 4.1. Specifically, the annual discards are equal to the difference between annual additions and annual stock changes of carbon in products in use. From the quantities discarded are subtracted the quantities of recovered products based on FAO data (FAO 2024a). For the period before FAO data are available (pre-1961), the fraction of paper recovered is held at the value in 1961, reflecting the long-standing practice of recovering paper for recycling, particularly for grades like newsprint and old corrugated boxes. For wood products, in the period before FAO data are available (pre-2017), recovery of wood is assumed to change proportionally to changes in recovery for paper.
- For creating a time series to 1900 (Figure 4.3), all disposed material (i.e., discarded material minus recovered material) is assumed to be sent to landfills or burned. The fraction being burned was estimated using 1996 and 2019 data on national waste management practices published by IPCC (IPCC 2019). The national data on waste management was applied to national -level estimates of discards (see above) to calculate the fraction of non-recovered material being burned rather than being

landfilled in 1996 and 2019. The annual rate of change in this fraction between 1996 and 2019 was used to calculate appropriate fractions for 1997 through 2022. The percentages of paper discards burned in 1996 and 2022 were determined to be 23.4% and 14.9% respectively. For calculations involving years before 1996, the 1996 percentage was used. The percentages were used on discarded paper and wood products. All discards not burned were assumed to be sent to landfills.

- The fraction of organic carbon that decomposes (DOC_f) in the anaerobic regions of landfills is assumed to be 0.5 for paper and paperboard and 0.1 for wood products, which are the IPCC default values (IPCC 2019). Biogenic carbon not contained in anaerobic zones is assumed to degrade to CO_2.
- The fraction of landfilled material subject to anaerobic conditions is calculated using the methane correction factor (MCF). Reflecting the change in the mix of aerobic and anaerobic landfills over time, it is assumed that in 1900 all landfills were unmanaged; hence, an MCF value 0.4 was used, which is the IPCC default for unmanaged, shallow landfills (see table 3.1 in volume 5, chapter 3 of IPCC [2019]). An MCF for 2007 of 0.7 was calculated using information and assumptions from the 2010 FAO report. The MCF of 0.7 is a deposit-weighted average for countries consuming 90% of global forest products in 2007. From 1990 to 2007, this fraction is assumed to increase linearly. From 2007 to 2023, the MCF was held constant at 0.7.
- The first-order degradation rate constant, k, is assumed to be 0.05 yr^{-1}. This is in the midrange of the IPCC default values for paper and wood products (see table 3.3 in volume 5, chapter 3 of IPCC [2019]). A higher degradation rate will yield a lower estimate of stored carbon.

The change in stocks of carbon in landfills, after making these corrections, are shown in Table 4.3. In 2007, the change in landfill carbon stocks equaled 77.1 million metric tons carbon (283 million metric tons CO_2e), while the annual stock change increased to 98.7 million metric tons carbon in 2022 (362 million metric tons CO_2e). Most of the annual increases are due to additions of carbon, which does not degrade under anaerobic conditions. About two-thirds of net additions to landfill carbon stocks are attributable to discarded wood products, as shown in Table 4.3.

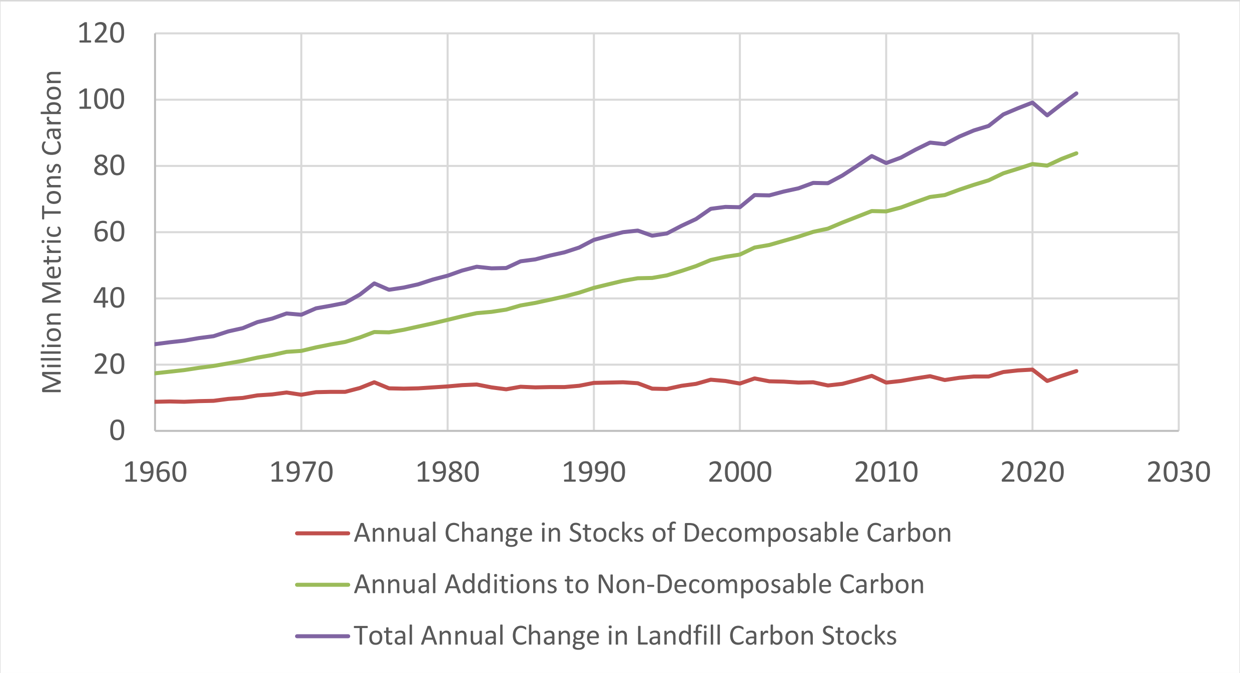

Figure 4.3. Annual carbon stock changes in landfills.

Table 4.3. Net additions to landfill carbon stocks associated with forest products.

Product	Landfill Stock Changes Million Metric Tons CO_2e 2007	2022
Paper	91	94
Wood	191	268
Total	283	362

4.3 Total Annual Changes in Stocks of Carbon in Global Forest Products

Adding the stored carbon quantities calculated in sections 4.1 and 4.2 yields total annual stock changes in global pools of carbon in forest products. The results are shown in Figure 4.4 and Table 4.4. Also shown in Figure 4.4 are estimates from Pan et al. (2024), the only source known to include global carbon stocks in landfills. Total annual changes in stocks of carbon stored in forest products vary with production but have been generally increasing since 1960. Annual increases in global stocks of carbon in forest products in use and in landfills equaled 177 million metric tons carbon in 2007 (649 million metric tons CO_2e) and 182 million metric tons carbon in 2022 (668 million metric tons CO_2e). The annual stock changes are approximately equally divided between products in use and products in landfills, although in both cases, increases in stocks are attributable primarily to wood products (see Tables 4.2 and 4.3). The estimates of Pan et al. (2024) are somewhat larger than those derived in this study. There are large uncertainties associated with any global estimate for carbon in forest products, however, so the differences are not unexpected or surprisingly large. While the estimates of annual changes in carbon stocks in forest products are subject to considerable uncertainty, the estimates derived herein confirm the findings of other studies indicating that these stocks are increasing over time (Johnston and Radeloff 2019; Pan et al. 2024), as do studies performed in countries representing large markets for forest products (e.g., see NCASI [2024]).

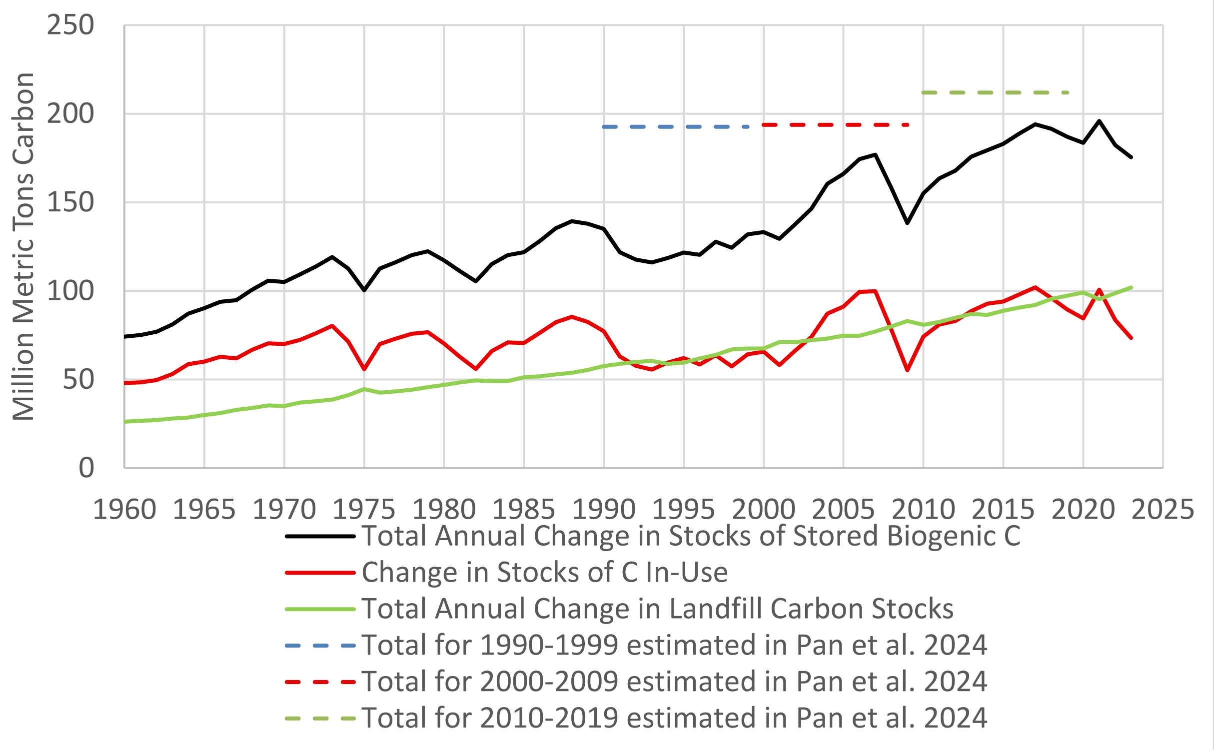

Figure 4.4. Total annual changes of carbon stored in global forest products.

Table 4.4. Total stock changes in products in use and in landfills.

Product	In Use Stock Changes Million Metric Tons CO_2e		Landfill Stock Changes Million Metric Tons CO_2e		Total Stock Changes Million Metric Tons CO_2e	
	2007	2022	2007	2022	2007	2022
Paper	55.8	7.4	91	94	147	102
Wood	310	299	191	268	502	567
Total	366	307	283	362	649	668

5.0 Manufacturing-Related Emissions

5.1 Emissions Associated with Fuel Consumption in Manufacturing and Converting

5.1.1 Pulp and Paper Production

In the 2010 profile (FAO 2010), several sources of data were used to estimate global emissions. The primary source was survey data from the ICFPA. The ICFPA survey obtained data from countries representing 64% of global paper and paperboard production. The remaining countries, except China, were assumed to have the average emissions intensity (emissions per metric ton of production) of these countries. China's pulp and paper industry was assumed to have the same energy intensity as that in the US. To check the results, data from the International Energy Agency (IEA) were also used (IEA 2006). In the case of the IEA data, only Organization for Economic Cooperation and Development (OECD) countries were included. In both cases, the data were extrapolated to global totals using data from FAO (2024a).

For this updated report, direct emissions associated with fuel combustion at pulp and paper mills were again calculated several ways. Updated survey data from ICFPA were obtained, as were energy consumption data from the IEA. For this update, however, a data set was obtained from IEA that extended beyond OECD countries (IEA 2021). Emission factors were obtained from US Environmental Protection Agency (2024). GHG emissions from biomass burning included only methane and nitrous oxide. Improved estimates for China were developed using information in Man et al. (2023). To allow comparison of global emissions estimates with the results of the 2010 FAO report, emissions have been extrapolated from the available data using several methods that were used previously. The results are shown in Table 5.1.

Depending on the approach, the absolute emission changes range from a 6% increase to a 46% decrease compared to data from FAO (2010). On an intensity basis, the changes range from a decrease of 34%–61%. Scope 1 GHG emissions calculated from IEA data for China are suspect (only 15 million metric tons CO_2e to produce 124 million metric tons of paper and paperboard), and Table 5.1 provides a global estimate that includes an improved estimate for China's pulp and paper sector, derived from Man et al. (2023), of 121.1 million metric tons CO_2e.

Table 5.1. Direct GHG emissions (Scope 1) from combustion of fuel at pulp and paper mills.

	Estimate for 2007 (FAO 2010)[a]		Estimate for 2021/2022[b]	
Basis of Calculation	Scope 1 Emissions (metric tons CO_2e)	Scope 1 Emission Intensity (metric tons CO_2e/metric ton)	Scope 1 Emissions (metric tons CO_2e)	Scope 1 Emission Intensity (metric tons CO_2e/metric ton)
ICFPA extrapolation	208 (198 CO_2 +10 CH_4 and N_2O)	0.62	205	0.44
OECD extrapolation	201 (191 CO_2 +10 CH_4 and N_2O)	0.60	156	0.33
IEA World	205[c]	0.61	110	0.24
IEA World with correction to IEA China paper, pulp, and print energy usage[d] (used as the default estimate for purposes of this report)	205[c]	0.61	217	0.47

[a] 2005 production capacity 317.987 million mt (277.597 million metric tons of paper and paperboard + 40.390 million metric tons of market pulp).

[b] 2022 production 466.898 million metric tons (400.881 million mt of paper and paperboard + 65.184 million metric tons market pulp).

[c] Assuming the average of the ICFPA and OECD extrapolation, as was done in NCASI (2007).

[d] Using information from Man et al. (2023), which results in calculated Scope 1 emission for China of 121.1 million mt CO_2e.

To provide context regarding the accuracy of these estimates, Table 5.2 compares GHG emissions calculated from IEA energy data compared to GHG emissions calculated or taken from alternative sources. Differences of 30% among sources are not unexpected. Emission amounts associated with fuel consumption are expected to be the most accurate of the emissions sources and sinks because many countries or regions have long-standing GHG reporting programs in place to collect information on emissions associated with fuel consumption, and these programs incorporate emission validation steps. Because the data are available for the largest number of countries, estimates derived from IEA data (adjusted for China using information from Man et al. [2023]) have been selected to reflect industry performance in this report.

Table 5.2. Comparison of Scope 1 GHG emission amounts calculated from IEA energy data compared to alternative data sources.

Country or Region	IEA 2021 Paper, Pulp, and Print ISIC Divisions 17 and 18 Scope 1 Emissions (metric tons CO_2e)	Alternative Source Scope 1 Emissions (metric tons CO_2e)	Difference (%)	Alternative Source
US	37,227,505	37,874,158	−2	MECS 2018 NAICS 322 paper[a]
		39,383,317	−6	EPA 2021 NAICS 322 paper[b]
CEPI	22,030,978	28,891,964	−31	CEPI 2021[c]
		28,930,000	−31	CEPI 2021[d]
Canada	4,835,618	5,918,931	−22	ECCC 2021 NAICS 322 paper[e]

[a] EIA MECS. https://www.eia.gov/consumption/manufacturing/data/2018/.

[b] EPA GHGRP data. https://www.epa.gov/ghgreporting/data-sets.

[c] Calculated from CEPI Key Statistics energy usage information and considering methane and nitrous oxide emissions from biomass combustion. https://www.cepi.org/wp-content/uploads/2022/07/Key-Statistics-2021-Final.pdf.

[d] Taken directly from CEPI Key Statistics. https://www.cepi.org/wp-content/uploads/2022/07/Key-Statistics-2021-Final.pdf. CEPI does not estimate methane and nitrous oxide emissions from biomass combustion.

[e] Greenhouse Gas Reporting Program (GHGRP)—Facility Greenhouse Gas (GHG) Data. https://open.canada.ca/data/en/dataset/a8ba14b7-7f23-462a-bdbb-83b0ef629823

Emissions intensities of the pulp and paper industry in different countries are shown in Figure 5.1. The total production represented in this figure is 387 million metric tons of paper and paperboard (96% of global production)[10] and 65 million metric tons of market pulp

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[10] 2020 global paper and paperboard production from FAO and is estimated to be 401 million metric tons. https://www.fao.org/forestry/statistics

(87% of global capacity)[11]. The total emissions associated with fuel consumption at pulp and paper facilities in 2021, based on aggregated country information, is 217 million metric tons of CO_2e. The world average emission intensity for paper, pulp, and printing sectors is 0.47 tons CO_2e/ton production[12] for 2021/2022[13]. The large range in country intensities reflects differences in production processes, product types, fuel selection, and energy efficiency.

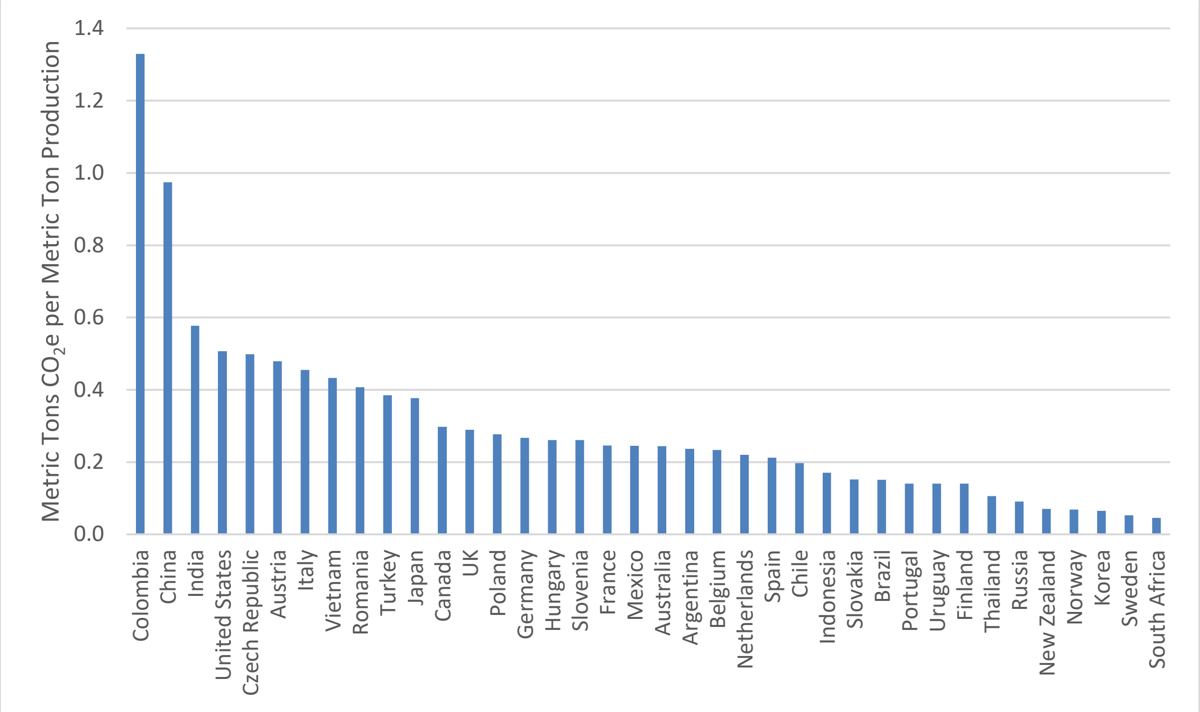

Figure 5.1. Emission intensity associated with fuel consumption by country for the paper, pulp, and printing sector.

5.1.2 Wood Products Production

In the 2010 FAO report, Scope 1 emissions from wood product facilities were calculated from IEA fuel consumption data for OECD countries (IEA 2006), extrapolated to the world using production data for panels and sawnwood from FAO (2024a). In this update, IEA data have also been used, although the data set covers the world (IEA 2021), so no extrapolation was needed. The results are shown in Table 5.3.

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[11] 2020 global market pulp capacity from Hawkins Wright and is estimated to be 75.2 million metric tons. https://industryedge.com.au/wp-content/uploads/ppsr/2021/PPSR21.pdf

[12] Production is represented as paper, paperboard, and market pulp production.

[13] GHG emissions, the intensity numerator, are estimated for 2021, and production, the intensity denominator, is estimated for 2022.

Table 5.3. Direct GHG emissions (Scope 1) from combustion of fuel at wood product facilities.

Scope 1 Emissions Metric	2007	2022	2022 as a Fraction of 2007
Scope 1 emissions, million metric tons CO_2e	25.6	14.4	0.59
Scope 1 emissions intensity, tons CO_2e per ton production	0.074	0.031	0.42

Scope 1 emissions from the global wood products sector decreased by 43% between 2007 and 2022. The decrease in Scope 1 emissions intensity was even greater, with 2022's intensity being 58% lower than 2007's. The large improvement appears to be primarily attributable to a shift from fossil fuels to biomass fuels. While total fuel consumption was approximately the same for the wood products sector in the 2010 profile and this update, consumption of fossil fuels decreased by about 25%, while biomass use increased by almost 15%.

5.1.3 Converting Operations

The process of manufacturing final products from mill output is called converting. In this report, the term *converting* is used broadly, covering everything from making corrugated boxes from containerboard or making furniture from wood to constructing a house from lumber. In the 2010 FAO report, emissions from converting were estimated from a factor, derived from a review of the literature, that suggested that it would be reasonable to multiply Scope 1 and 2 emissions from primary manufacturing facilities by 20% to estimate total Scope 1 and 2 emissions from converting. These were divided equally between Scope 1 and 2 emissions for converting. This resulted in 38.74 million metric tons CO_2e being assigned to Scope 1 converting emissions and 38.74 million metric tons CO_2e being assigned to Scope 2 converting emissions. These represented 16.7% of primary manufacturing Scope 1 emissions and 25% of primary manufacturing Scope 2 emissions. It was acknowledged that the uncertainties associated with these factors were very large.

NCASI revisited this issue in an updated carbon and GHG profile of the US forest products sector (NCASI 2024). That assessment yielded the results shown in Table 5.4. A comparison shows that the 16.7% factor used to calculate Scope 1 converting emissions in FAO (2010) is similar to the factors for pulp and paper converting (16% of primary manufacturing emission) and wood products (13% of primary manufacturing) shown in Table 5.4. However, because the factors for Scope 2 converting emissions in Table 5.4 are quite different from those used in FAO (2010), the factors in Table 5.4 are used in this update for both Scope 1 and 2 emissions. The 2007 estimates have been updated using the new factors, resulting in total converting-related emissions (Scope 1 plus Scope 2) for 2007 being 66% larger than estimated in FAO (2010). The results are shown in Table 5.5.

Table 5.4. Factors for calculating converting-related GHG emissions.

	Converting Emissions as a Fraction of Primary Manufacturing Emissions			
	From FAO (2010)		Updated Factors Used in This Study—Based on Data in NCASI (2024)	
Sector	Scope 1 Emissions	Scope 2 Emissions	Scope 1 Emissions	Scope 2 Emissions[a]
Pulp and paper sector			16%	84%
Wood products sector			13%	10%
Wood and paper products sectors combined	16.7%	25%		

[a] These factors are the ratio of emissions from gross purchases at converting operations as a percentage of emissions from net purchases at primary manufacturing operations as published in NCASI (2024). Net purchases from primary manufacturing are used because converting operations seldom produce electricity, but ratios could have been developed using gross purchases.

Table 5.5. Direct GHG emissions (Scope 1) from converting operations.

	GHG Emissions (Million Metric Tons CO_2e)	
Sector	2007	2022
Pulp and paper sector	32.8	34.8
Wood products sector	3.2	1.9

5.2 Emissions Associated with Purchased Electricity and Steam

5.2.1 Pulp and Paper Production

The pulp and paper industry produces and consumes electricity. In the US, for instance. 42% of electricity demand is self-generated (AF&PA 2014). Much of the electricity generated by the pulp and paper industry is produced using combined heat and power (CHP) systems[14] that first use steam to produce electricity and then use the steam in the production process. This sequential use of steam for multiple purposes makes CHP systems highly efficient. CHP systems convert 75%–90% of fuel energy to useful outputs compared to less than 50% in conventional electricity generation systems (IEA 2011). In the US and Europe, at least 95% of electricity produced on site in the pulp and paper industry is produced using CHP systems (AF&PA 2014; Furzyfer et al. 2022). The emissions associated with self-generated electricity are included in Scope 1 emissions. Scope 2 emissions calculated herein are associated with gross purchased electricity and steam rather than amounts consumed.

As was done by FAO (2010), emissions associated with purchased electricity from the global pulp and paper sector were estimated by extrapolating reported Scope 2 emissions from ICFPA survey data[15]. Scope 2 emissions in non-ICFPA countries were estimated by extrapolating ICFPA emissions based on national production data from FAO (2022a) and adjusting for the difference in the paper production-weighted grid emission factor in non-ICFPA countries compared to ICFPA countries (based on data in IEA [2024]). This is similar to the approach used in the 2010 profile (FAO 2010), except in the earlier calculations, ICFPA data were used to calculate a typical factor for purchased electricity per ton, which was then applied to non-ICFPA countries using production data and grid emissions factors from the same sources as used in this update.

Purchased steam emission factors were based on the approach used by the US Department of Energy (EIA 2007), using energy mix for paper, pulp, and printing by country, thermal efficiencies from EIA for major fuel type (coal, natural gas, fuel oil), GHG combustion emission factor by fuel from the US EPA emission factor hub (US EPA 2024), and a 10% transmission and distribution loss.

The calculations indicate that Scope 2 emissions were 135 million metric tons CO_2e in 2021. Table 5.6 provides a summary of Scope 2 emissions from the global pulp and paper industry for 2021 (assigned to 2022 for purposes of this report) and a comparison to 2007 results from FAO (2010). The 2007 and 2022 estimates are based on global production of 421 and 466 million metric tons of paper, paperboard, and market pulp, respectively, an increase of 11%. The paper production-weighted mean global emission factor for purchased electricity was lower in 2022 than in 2007. Nonetheless, the industry's Scope 2 emissions increased by 28%, resulting in an increase in Scope 2 emissions intensity of 15%. Some of this increase may be due to the change in calculation approach. It is also affected, however, by the fact that most growth has occurred in regions with relatively high emissions associated with purchased electricity. Production in China, for instance, increased by 59% between the two studies, accounting for 19% of global production in the 2007 study and 27% in this update. In this update, the emission factor for purchased electricity in China was 50% higher than the global weighted mean factor. It is also likely that Scope 2 emissions have been impacted by technology trends. IEA has noted, for instance, that "efficiency gains from improved

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[14] Also known as cogeneration systems.

[15] These calculations do not account for emissions credits that may be bought or sold.

technology can be offset by structural changes. For example, higher electricity demand for faster paper machines and strong growth in demand for specialty papers, which are more energy intensive, have masked improvements in electricity efficiency from process and machine advances" (IEA 2007).

Table 5.6. Emissions associated with electricity and steam purchased by pulp and paper mills (Scope 2 emissions).

Metric Elements	2007 (FAO 2010)	2022 This Report	2022 as a Fraction of 2007
Scope 2 emissions (million metric tons CO_2e)			
ICFPA countries		45	
Non-ICFPA countries		90	
World	105.9	135.2	1.28
Production-weighted emission factor for purchased electricity and steam (gram CO_2e per kWh)			
ICFPA countries		288	
Non-ICFPA countries		575	
World	502	416	0.83
Production of paper, paperboard, and market pulp (million metric tons)			
World	421	466	1.11
Scope 2 emissions intensity (metric tons CO_2e per metric ton production)			
ICFPA countries		0.19	
Non-ICFPA countries		0.39	
World	0.25	0.29	1.15

5.2.2 Wood Products Production

In FAO (2010), Scope 2 emissions for the wood products sector were estimated using generic factors for purchased electricity, FAO production statistics (FAO 2024a), and country-specific IEA grid emission factors (IEA 2024). The generic factors for purchased electricity at lumber and panel mills were derived from a review of available literature and data sets (see FAO [2010]).

For this report, instead of using generic factors, IEA global electricity and steam consumption data for the wood products sector are used (IEA 2021). To the extent that CHP systems are used at wood products plants, this overestimates Scope 2 emissions because it

includes the use of self-generated electricity and steam. Self-generation is far less common in the wood products sector, however, than in the pulp and paper sector. In the US, for instance, only about 7% of CHP capacity in the forest products industry is installed at wood products mills (NCASI 2023a), even though the production of paper and paperboard in the US is approximately the same as production of wood products[16]. As a result, electricity consumption approximately equals electricity purchases in the wood products sector.
To convert global electricity consumption data to emissions, a wood products production-weighted average grid emission factor of 386.7 gram CO_2e per kilowatt-hour was developed from FAO sawnwood and panel production data (FAO 2024a) and national grid emission factors from IEA (2024)[17]. Emission factors for purchased steam were derived using the same approach as for pulp and paper mills in section 5.2.1.

The results are shown in Table 5.7. As in the case of pulp and paper mills, emissions increased between 2007 and 2022 by more than production. The reasons are similar. Wood products output has increased rapidly in countries with relatively high grid emission factors. China's 2022 grid emission factor was 60% higher than the global wood products-weighted average emission factor, while its production increased from 15% of global wood products output in 2007 to 25% in 2022. Some of the difference may also be due to the difference in calculation methods between the 2007 study (FAO 2010) and this update.

Table 5.7. Emissions associated with electricity and steam purchased by wood product mills (Scope 2 emissions).

Metric Elements	2007 (FAO 2010)	2022 This Report	2022 as a Fraction of 2007
Scope 2 emissions (million metric tons CO_2e)	48.8	62.9	1.29
Production of wood products (million metric tons)	375	436	1.16
Scope 2 emissions intensity (metric tons CO_2e per metric ton production[a])	0.12	0.14	1.20

[a]FAO statistics have been converted to metric tons using the conversion factors in Table 4.1.

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[16] Paper and paperboard production in the US in 2023 was about 12% greater than wood products production based on FAO (2024a) and conversion factors in Table C.1.

[17] In the cases of Latvia, Belarus, Ukraine, and Maylasia, factors were obtained from IRENA Energy Profiles available at https://www.irena.org/Data/Energy-Profiles.

5.2.3 Converting Operations

As in FAO (2010), GHG emissions associated with converting forest products into final products were calculated using generic factors. The updated analysis, however, uses updated factors shown in Table 5.4. In the case of paper and paperboard products, converting emissions are calculated to be 84% of Scope 2 emissions from primary pulp and paper manufacturing. For wood products, Scope 2 emissions are assumed to be 10% of those associated with primary wood products manufacturing. The results for both wood products and paper and paperboard converting are shown in Table 5.8. The changes from 2007 to 2022 are entirely due to changes in primary manufacturing emissions to which the updated factors are applied.

Table 5.8. Scope 2 emissions from converting operations.

Scope 2 Converting Emissions (million metric tons CO_2e)	2007[a] (FAO 2010)	2022, This Report
Paper and paperboard	89.0	113.6
Wood products	4.9	6.3

[a]Updated using revised factors as described in the text.

6.0 Upstream Emissions Associated with Nonfiber Inputs and Fuels

6.1 Upstream Emissions Associated with Nonfiber Inputs

The manufacturing of forest products requires nonfiber inputs ranging from inorganic fillers for paper to resins for wood panels. These inputs require energy to produce, usually resulting in the release of GHGs. In the 2010 FAO report, these were estimated using factors developed for the Forest Industry Carbon Assessment Tool (FICAT), a model written by NCASI for the International Finance Corporation of the World Bank (NCASI 2023b). These factors reflect generic "recipes" for the chemicals and additives used to produce different forest products, and data from several life cycle databases and studies. The same factors are used in this update. It is likely that there have been emission reductions among suppliers to the industry. This approach, therefore, may overestimate recent emissions associated with nonfiber inputs to the forest products value chain.

6.1.1 Paper and Paperboard

The mix of grades of paper and paperboard shifted significantly between 2007 and 2022. The changes are shown in Figure 6.1 and reflect a large decrease in demand for newsprint as well as printing and writing papers and a large increase in the demand for case materials (also known as containerboard).

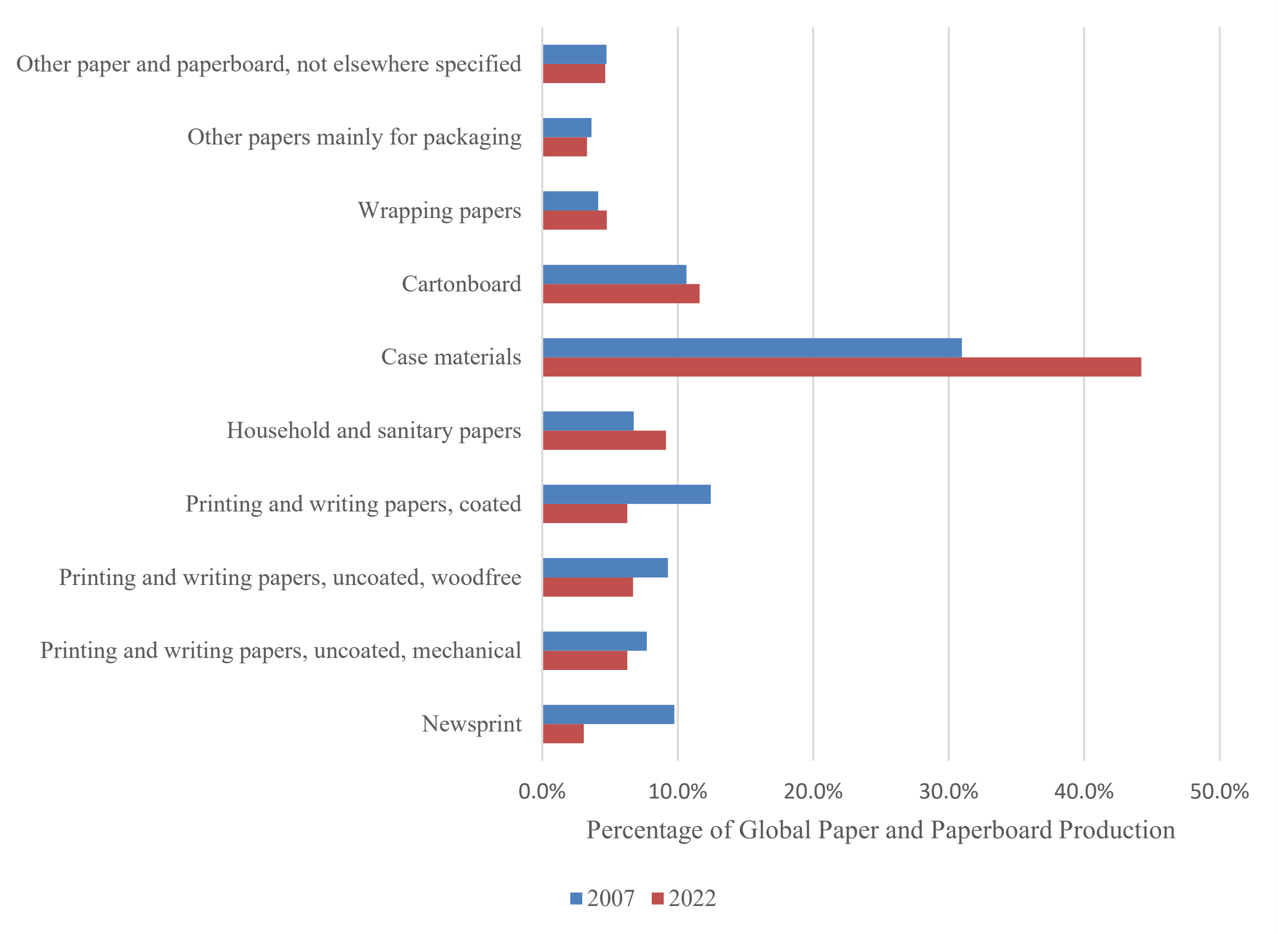

Figure 6.1. Grades of paper and paperboard produced in 2007 and 2022.
[*Source:* FAO (2024a)]

These changes would be expected to affect the types and amounts of nonfiber inputs required by the industry. Therefore, weighted average global emission factors were developed for 2007 and 2022 using FAO production data shown in Figure 6.1 (FAO 2024a). The derivation of these factors is shown in Table 6.1. Note that market pulp is not included because the inputs to market pulp are included in the factors for the resulting paper and paperboard products. Shifts in production in the industry between 2007 and 2022 resulted in a reduction of over 20% in the emissions per metric ton associated with nonfiber, nonfuel inputs to the paper and paperboard sector, dropping from 93.8 kg CO_2e per metric ton to 72.6 kg CO_2e per metric ton. The actual reduction was likely larger than this because this calculation ignores improvements that may have been made by the suppliers to the industry.

The results, shown at the bottom of Table 6.1, reveal that despite industry production increasing by over 5% during this period, emissions associated with nonfiber, nonfuel inputs decreased by 18%, from 36.8 to 30.3 million metric tons CO_2e. The 2007 estimate is close to the estimate of 34.9 million metric tons CO_2e contained in the 2010 FAO report.

Table 6.1. Calculation of upstream emissions associated with nonfiber, nonfuel inputs to the paper and paperboard sector.

FAO Category	FICAT Factor (NCASI 2023b)	Notes	Percentage (%) of Global Production	
	kg CO_2e per Metric Ton Product		2007	2022
Newsprint	75		10	3
Printing and writing papers, uncoated, mechanical	60		8	6
Printing and writing papers, uncoated, woodfree	100		9	7
Printing and writing papers, coated	300	FICAT factor for free sheet	12	6
Household and sanitary papers	50		7	9
Case materials	20	FICAT factor for linerboard	31	44
Carton board	200		11	12
Wrapping papers	20	FICAT factor for packaging and special industrial	4	5
Other papers mainly for packaging	20		4	3
Other paper and paperboard, not elsewhere specified	60	Median of above	5	5
	Emission Calculations			
Weighted average emission factor (kg CO_2e per metric ton production)			93.8	72.6
Metric tons paper and paperboard production (FAO 2024a)			392.5	413.6
Emissions (million metric tons CO_2e)			36.8	30.0

6.1.2 *Wood Products*

In the 2010 FAO report, estimates of emissions associated with nonfiber, nonfuel inputs to the wood products sector were developed only for panels due to an assumption that these emissions would be negligible for sawnwood production. In this update, it is again assumed that untreated sawnwood can be ignored for purposes of estimating emissions related to nonfiber, nonfuel inputs. The same assumption is made for wood pellets. Estimates are extended, however, to include treated sawnwood.

Treated sawnwood production has been estimated based on the assumption that (1) treated sawnwood is predominantly coniferous, (2) it costs 50% more than untreated sawnwood[18], and (3) the global market for treated wood was US$6.21 billion in 2023. Prices for untreated lumber were calculated to be US$516 per cubic meter in 2022, based on import and export data from FAO (2024a). Based on these values, it was estimated that in 2022, treated sawnwood comprised only 3.6% of global sawnwood production, suggesting that errors in this estimate will not have a significant impact on overall industry emissions. This fraction was held constant between 2007 and 2022. Data on the usage of different types of preservatives are not available; therefore, an emission factor was used (300 kg CO_2e per metric ton of treated wood) that is between those for creosote-treated and other-treated wood in FICAT (NCASI 2023b). The emission factor for panels (200 kg CO_2e per metric ton panels) is from FICAT and is the same value as used in the 2010 FAO report. The conversion factors used can be found in Table 4.1.

The results are shown in Table 6.2. The results for 2007 are different from those in the 2010 FAO report, with the difference being due to the earlier use of an unrealistically low value for the density of oriented strand board (OSB). The increase from 2007 to 2022, 35.3 to 46.9 million metric tons CO_2e, is due to a 23% increase in wood products production and the fact that panel production, which is associated with higher emissions, grew even faster (by 34%).

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[18] An examination of retail costs in the US suggests that this is reasonable but may be biased low.

Table 6.2. Calculation of upstream emissions associated with nonfiber, nonfuel inputs to the wood products sector.

Product	FAO Production 2007	FAO Production 2022	Units	Factor to Convert to Metric Tons (see Table 4.1)	Metric Tons Production 2007	Metric Tons Production 2022	Emission Factor (NCASI 2023b), kg CO_2e per Metric Ton	Emissions, Million Metric Tons CO_2e 2007	Emissions, Million Metric Tons CO_2e 2022
Untreated sawnwood	419.7	458.4	10^6 m^3	0.458	192.2	209.9	0	0.0	0.0
Treated sawnwood	15.7	17.1	10^6 m^3	0.458	7.2	7.8	300	2.2	2.4
Panels	278.3	374.0	10^6 m^3	0.595	165.6	222.5	200	33.1	44.5
Pellets	33.4	48.1	10^6 metric t	1	33.4	48.1	0	0.0	0.0
Total								35.3	46.9

6.2 Upstream Emissions Associated with Fossil Fuels used by the Forest Products Industry

The production of fossil fuels results in the release of GHGs. Where fossil fuels are used by the forest products industry, these upstream emissions should be included in the industry's profile. Wood-based fuels are not included here because the emissions associated with wood-based fuels are included in the calculations of forest management–related emissions.

In the 2010 FAO report, upstream emission factors for the production and transport of fuels used by the industry were obtained from FICAT (NCASI 2023b). In this update, the factors are drawn from a more comprehensive analysis in NCASI's Scope 3 GHG Screening Tool, version 1.1a (NCASI 2023c). These factors, which include both production and transport[19] emissions, indicate that upstream GHG emissions associated with natural gas, oil, and coal are 19.8%, 16.1%, and 6.1% of the combustion emissions, respectively. In the 2010 FAO report, the comparable values are calculated to have been 24%, 18%, and 6%, respectively. The newer estimates are close to but somewhat lower than the older estimates. It is not possible, however, to know whether this is due to reductions in fossil fuel production emissions or simply a difference in methodology. Therefore, the newer estimates are used in this update for both 2007 and 2020. Because the most reliable source of data for direct emissions estimates did not identify fuel types (see section 5.1), a fuel-weighted average factor was developed for each scenario based on fuel mix data from IEA (2006; 2007). These were applied to the direct emissions estimates in section 5.1. The converting sector, which was not included in the 2010 FAO report, was assumed to be using only natural gas. The factors and the emission calculation results are shown in Table 6.3. The reductions mirror the reductions in direct emissions associated with fossil fuel use, discussed in section 5.1.

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[19] These transport-related emissions are addressed in this section and not included in those calculated in Section 9, later in this report.

Table 6.3. Upstream emissions associated with the production and transport of fossil fuels.

Sector	Fuel Type	Composition of Fossil Fuel Supply (Based on Heat Content) 2007[a]	Composition of Fossil Fuel Supply (Based on Heat Content) 2022	Upstream Emissions as a Fraction of Total Direct Fossil Fuel Emissions 2007[a]	Upstream Emissions as a Fraction of Total Direct Fossil Fuel Emissions 2022	Upstream Emissions, Million Metric Tons CO_2e 2007	Upstream Emissions, Million Metric Tons CO_2e 2022
Pulp and paper	% Coal	17	20	0.165	0.167	33.8[b]	36.3
	% Natural Gas	56	71				
	% Oil	27	9				
Wood products	% Coal	3	7	0.175	0.180	4.5[b]	2.6
	% Natural Gas	47	62				
	% Oil	50	33				
Converting	% Natural Gas	100	100	0.198	0.198	7.1	7.3
Total						45.5	46.2

[a] Based on 2004 data from IEA (2006).

[b] The estimates in the 2010 FAO report were 30.5 and 4.6 million metric tons CO_2e, respectively. The difference is due to the use of slightly different upstream emission factors.

6.3 Upstream (Scope 3) Emissions Associated with Purchased Electricity

Scope 3 emissions associated with purchased electricity originate in the production and transport[20] of fuel inputs to power plants. These emissions have been calculated using factors for different fuels from the National Renewable Energy Laboratory (NREL) (NREL 2021) adjusted as described in NCASI 2024. These factors, which include transport of fuels, are applied to the fuel mix of the global grid. Data from IEA indicate that between 2010 and 2019, the fractions of global power produced from coal, gas and oil were relatively stable, with approximate ranges being 37% to 42% for coal, 22% to 24% for gas and 4% to 6% for oil (IEA 2020). These changes are small enough to justify the use, in this study, of the same Scope 3 emission factor for 2007 and 2022.

A recent study by NCASI (NCASI 2024) found that in 2005, when the US grid was supplied with approximately 50% coal, 19% gas and 4% oil upstream Scope 3 emissions for fossil fuels supplied to the grid were approximately 7% of the Scope 2 direct emissions from burning these fuels. These values are close to the global grid so, for this report, Scope 3 emissions associated with purchased electricity are calculated using a factor of 7% of Scope 2 emissions. Scope 2 emissions associated with purchased electricity are shown in Section 5.2 and total 248.6 million metric tons CO_2e in 2007 and 318 million metric tons CO_2e in 2022. Using a factor of 7% indicates that Scope 3 emissions associated with the fossil fuels used by electricity producers were 17.4 and 22.3 million metric tons CO_2e in 2007 and 2022, respectively.

7.0 Emissions Associated with Treating Industry Wastes

The treatment of forest product industry wastes often requires inputs of energy. Where this energy is derived from fuels or electricity produced or purchased by the industry, the associated emissions are accounted for in section 5. In some cases, however, treatment of industry wastewaters and disposal of industry solid wastes (e.g., treatment residuals, woody debris) can result in the release of biogenic methane. Specifically, the landfilling of solid wastes can result in the production and release of biogenic methane, and in some cases, wastewater treatment can also produce biogenic methane.

7.1 Emissions from Pulp and Paper Mill Landfills

In the 2010 FAO report, a calculation method was used that yielded an estimate of the ultimate methane emissions associated with mill wastes sent to landfills in 2007. This is different from an annual inventory calculation that would have included all emissions of methane from landfills in 2007 attributable to wastes landfilled in, or before, 2007. The ultimate emission calculation is equal to the annual inventory calculation only if the quantities being landfilled remain constant. If all other aspects of the calculations are unchanged, ultimate emissions will be lower than annual inventory emissions when disposal

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[20] These transport-related emissions are addressed in this section and not included in those calculated in Section 9.0.

quantities are decreasing and higher when quantities are increasing. In section 11 of this report, both types of emissions are calculated for forest products in landfills with ultimate emissions being approximately 1.5 to two times annual inventory emissions.

As a result of the differences in the calculations, it is not appropriate to use the ultimate emissions results to draw judgments about the rates of change in actual landfill emissions. Nonetheless, because it is related to the long-term average annual emissions, ultimate emissions provide a reasonable basis for judging the relative importance of these emissions to the industry's GHG emissions profile.

The following assumptions were made to estimate ultimate methane emissions associated with solid wastes landfilled by pulp and paper mills in 2007:

- Mill solid waste going to anaerobic landfills is equal to 4% of production, a value between those of the European and the US paper industries (AF&PA 2008; CEPI 2008).
- Waste is 25% biomass carbon (value based on NCASI testing [Heath et al. 2010]).
- Approximately 50% of the biomass carbon in mill solid wastes can degrade under anaerobic conditions to gas containing equal amounts (by volume) of methane and CO_2 (the IPCC default for paper products).
- None of the landfills have systems for capturing methane, so the only loss of methane is a 10% oxidation that occurs in the upper layers of the landfill via natural processes (the IPCC default assumption).

Solid waste management practices have changed since 2007. In the US, for instance, between 1995 and 2016, the fraction of wastewater treatment residuals being landfilled dropped from 51% to 36% of the total (NCASI 2024). Global data, however, are sparse. Therefore, this update applies the same assumptions and approach as used in the 2010 FAO report. As a result, the only change in these emissions reflects the increase in global pulp, paper, and paperboard production. Between 2007 and 2022, global production of paper and paperboard increased from 392 to 414 million metric tons, an increase of 5.4%. The emissions calculation result for ultimate emissions from sludge landfills for materials disposed in 2007 was 28.6 million metric tons of CO_2e (FAO 2010) (adjusted from a methane Global Warming Potential [GWP] of 21, used in the 2010 FAO report, to 25 [IPCC 2013], which is used in this report). Increasing this by 5.4% yields an estimate of ultimate emissions from materials disposed of in 2022 of 30.1 million metric tons CO_2e. Again, it should be noted that the change in ultimate methane emissions does not relate directly to the rate of change in actual landfill emissions. Nonetheless, the ultimate methane emissions estimate provides a reasonable measure of the relative importance of annual landfill emissions to the industry's GHG profile.

This estimate does not include potential emissions from other solid wastes from the forest products industry that may be disposed of in landfills. In the US, the US EPA requires the reporting of emissions from the landfilling of boiler ash, recovery area wastes, and miscellaneous wastes, in addition to wastewater treatment sludges (US EPA 2023). Using the default methods and parameter values provided by US EPA, NCASI estimates that wastewater treatment sludges account for only about one-half of GHG emissions from pulp and paper mill landfills (NCASI 2024). The uncertainties in these estimates are very large, however. Furthermore, there is reason to believe that some of the estimates are biased high (see discussion in NCASI [2024]). Therefore, these additional wastes are not included in the estimates developed herein, nor were they included in the 2010 FAO report.

7.2 Emissions from Wood Product Mill Landfills

In the 2010 FAO report, the assumptions made to estimate ultimate methane emissions associated with solid wastes landfilled by wood product mills in 2007 were the same as those for paper mills, shown earlier, with the following exceptions:

- The mill solid waste going to anaerobic landfills is equal to only 1% of production, because most of the waste from wood product plants has high value as fuel and is burned rather than discarded (an assumption with large uncertainty, especially in developing countries where mill solid waste is sometimes disposed of in piles instead of being sent to landfills or burned).
- The waste is 25% biomass carbon, based on awareness that material placed in landfills is often unusable as fuel owing to contamination with soil, rocks, and other debris.

The uncertainty in these emissions is at least as large as that for pulp and paper mill landfills. Therefore, the updated estimate is derived by simply adjusting the 2007 estimate for increased production of wood products. The 2010 FAO report indicated that wood products mill wastes landfilled in 2007 would ultimately release two million metric tons of CO_2e per year (FAO 2010). The global output of wood products in 2007 was 736 million cubic meters, while in 2020 it was 839 million cubic meters, an increase of 14% (FAO 2024a). This suggests that while materials disposed in 2007 will have ultimate emissions of two million tons CO_2e, those disposed in 2020 will have ultimate emissions of 2.3 million metric tons CO_2e.

7.3 Emissions from Wastewater Treatment

Because wood product mills seldom generate significant amounts of wastewater, in the 2010 FAO report, biogenic methane emissions from wastewater treatment were estimated only for pulp and paper mills. Due to lack of global data, an estimate from the US pulp and paper industry was extrapolated to the globe using FAO production data (FAO 2010). The resulting estimate was 1.7 million metric tons of CO_2e. The same approach is used here, but updated estimates for the US pulp and paper industry are used. A report from NCASI (2024) estimates that methane and nitrous oxide emissions associated with US pulp and paper industry wastewater were 1.4 and 0.9 million metric tons CO_2e in 2005 and 2020, respectively[21]. FAO data indicate that the US represented 21% of global paper and paperboard production in 2007 and 16% in 2020. Using these percentages and the US estimates for emissions (using the 2004 estimates for 2007), global emissions associated with pulp and paper industry wastewater treatment are estimated to be 6.7 and 5.6 million metric tons CO_2e in 2007 and 2020, respectively. The uncertainty in these estimates is very large. The difference between the estimate for 2007 shown in the 2010 FAO report and the updated estimate for 2007 developed here is due almost entirely to a change in calculation method.

8.0 Emissions Associated with Growing and Harvesting Wood

In the 2010 FAO report, emissions associated with growing and harvesting wood were estimated using a factor derived from those in FICAT (NCASI 2023b), which is based on a limited set of literature sources. The factor used was in the range of 30 to 50 kg CO_2e per metric ton of wood, depending on the assumed density of harvested logs. For this updated study, additional literature was reviewed suggesting that while the factors used in the 2010 FAO report may be appropriate for high-intensity silviculture, they are too high to be used to represent global practices. The additional analysis indicates that a factor of 15 kg CO_2e per cubic meter of wood is more reasonable as a global value (England et al. 2013; Nakano et al. 2018; NCASI 2024; Oneil 2021; Oneil and Puettmann 2007; Quartucci et al. 2015). This value was multiplied by the quantities of industrial roundwood produced globally in 2007 and 2021 (from FAO [2024a]) to produce estimated emissions for wood growing and harvesting of 26.6 million metric tons CO_2e in 2007 and 30.2 million metric tons CO_2e in 2022.

9.0 Emissions from Transport Operations

The forest products industry value chain includes many transport operations. In the 2010 FAO report, the following transport operations were considered:

- Industrial roundwood (IRW) transport from the forest to the mill;
- Market pulp transport from mill to mill;
- Recovered paper transport from supplier to the mill;
- Product transport to a retail distribution point;
- Final product transport to the consumer;
- Postconsumer paper transport to the recovered paper supplier.

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[21] The values in NCASI (2024) are based on estimates in US EPA's annual inventory of GHG emissions and sinks. The calculated N_2O emissions include emissions from wastewater treatment plants as well as emissions that occur in the environment attributable to the residual nitrogen in industry effluents. NCASI's analysis suggests that because US EPA does not consider several industry-specific factors, its estimates of N_2O emissions from wastewater treatment plants may be high.

Estimated shipment distances and transport modes were based on judgment, and the emissions were calculated using factors from the GHG Protocol (see FAO [2010]).

In this update, the analysis has been modified to make use of published import and export data (UNECE/FAO 2025) and a web-based tool for estimating international shipment emissions (EcoTransIT World 2024)[22]. The additional data have allowed types of shipments to be included that were not part of the 2010 FAO report. In addition, an estimate is developed for emissions associated with transporting nonfuel, nonfiber inputs (e.g., additives) to the global forest products industry value chain. The updated estimates, and changes from earlier estimates, are described later.

9.1 Industrial Roundwood Transport

9.1.1 Domestic Shipments of Industrial Roundwood

Data on 2007 and 2022 global production, global exports, and domestic consumption (determined by difference) were obtained from FAOSTAT (FAO 2024a). The Industrial Roundwood (IRW) domestic one-way haul distance used was 128 km, obtained from an analysis by Karha et al. (2023). The 128-km distance in Karha et al. was for road transport, but for this study, it was assumed that domestic IRW transport was 90% by road and 10% by rail. Production was converted from cubic meters to green metric tons using a factor of 950 kg/m^3 (a reasonable overall value for coniferous and nonconiferous sawlogs and pulpwood from table 2.3.1 in FAO [2020b]). It was assumed that transport vehicles returned to the forest empty, doubling the distance traveled to 256 km. Transport emission factors were obtained from NCASI (2024). For road transport, the 2007 factor was 0.0562 kg CO_2e per metric ton-km, and the 2022 factor was 0.0560 kg CO_2e per metric ton-km. For rail transport, the 2007 factor was 0.0169 kg CO_2e per ton-km and the 2022 factor was 0.0144 kg CO_2e per metric ton-km. These values do not include upstream emissions associated with fuel production and transport, so they were multiplied by 1.161, a factor derived by NCASI to account for upstream emissions associated with oil-based fuels (see section 4.3 in NCASI [2024]). Using these assumptions and data, it was calculated that emissions associated with domestic transport of IRW equaled 24.2 and 27.8 million metric tons CO_2e in 2007 and 2022, respectively. This 15% increase aligns with the 13% increase in global IRW production over this period.

9.1.2 International Shipments of IRW

The origins and destinations for 83.3% (by dollar value) of 2007 global IRW production and 85.7% of 2022 global IRW production were identified using data from UNECE/FAO (2025). These data indicated that it was likely that 67% and 31% of international IRW shipments were by land in 2007 and 2022, respectively. Most of these shipments were within Europe or between adjacent countries (e.g., Russia and China or the US and Canada). The large decrease in the fraction of shipments via land between 2007 and 2022 reflects a large drop in IRW exports from Russia to Europe and China, which represented 33% of international

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[22] Since the estimates in this report were developed, a new version of the calculator has been released.

IRW trade in 2007 but only 7% in 2022. Over the same period, there was a large increase in trans-Pacific transport of IRW, largely to China. Between 2007 and 2022, international wood shipments to China went from 27% of global international shipments to 55%.

For those international shipments expected to occur primarily by land, emissions were calculated using the same approach and assumptions used for domestic shipments. Global emissions associated with this transport were calculated to be 1.3 and 0.5 million tons CO_2e in 2007 and 2022, respectively.

For the remaining international shipments, the EcoTransIT calculator was used to calculate ocean transport emissions (EcoTransIT World 2024). Based on the export and import pairs in the trade data (UNECE/FAO 2025), the distance from New Zealand to China was selected as being representative of ocean shipments in general. This approximation was suitable for IRW because IRW exports represent a relatively small fraction of global IRW production (7.5% in 2007 and 5.5% in 2022) (FAO 2024a). The calculation indicated that ocean transport emissions were 4.5 million tons CO_2e in 2007 and 8.5 million tons CO_2e in 2022. The increase is largely due to the increase in trans-Pacific transport, primarily to China, noted earlier. On each end of the ocean transport, it was assumed that IRW would be transported 128 km by land, using the assumptions applied in calculating emissions for domestic IRW transport. These additional land transport emissions were 0.6 and 1.1 million tons CO_2e in 2007 and 2022, respectively.

Adding ocean and land transport emissions indicates that global emissions from international shipment of IRW were 6.5 and 10. 1 million metric tons CO_2e in 2007 and 2022, respectively.

9.1.3 Total GHG Emissions for Transporting IRW

The results for domestic and international transport of IRW are summarized in Table 9.1. These emissions totaled 30.7 million metric tons CO_2e in 2007 and 38.0 million metric tons CO_2e in 2022. The increase is largely due to the increase in IRW shipments to Asia. It should be noted that the estimate for 2007 is much larger than the corresponding value in the 2010 profile report (7 million metric tons CO_2e) (FAO 2010). This is because the 2010 FAO report did not include the weight of water in green wood and did not include emissions associated with empty return trips. When the 2010 FAO report estimates are corrected for these factors (requiring that the 2010 estimate be multiplied by approximately four), a result is close to the 2007 value shown in Table 9.1.

Table 9.1. Emissions associated with transport of industrial roundwood.

Shipment Type	Million Metric Tons CO_2e 2007	2022
Domestic shipments	24.2	27.8
International shipments	6.5	10.1
Total	30.7	38.0

9.2 Lumber (Sawnwood)

9.2.1 Domestic Shipments of Lumber

Global domestic shipments of lumber were calculated by taking the difference between global production and global exports using data from FAOSTAT (FAO 2024a). Coniferous lumber volume was converted to mass using a conversion factor of 0.45 metric ton dry lumber per cubic meter of lumber, the IPCC default for coniferous (softwood) sawnwood (table 12.1 in chapter 12 of IPCC [2019]). One-way haul distance was assumed to be 500 km, the same assumption as used in the 2010 FAO report. Lumber transport was assigned only one-way transport emissions, assuming that the transport vehicles would be used for another purpose after delivering lumber rather than returning to the sawmill empty. Transport was assumed to be 90% by truck and 10% by rail. The emission factors used were the same as those used for IRW. Extrapolated to the world, the resulting emissions for domestic transport of coniferous lumber were 2.8 and 2.9 million metric tons CO_2e in 2007 and 2022, respectively.

Emissions associated with transport of domestically consumed nonconiferous (hardwood) lumber were assumed to be the same, per ton, after adjusting for densities, i.e., 0.45 and 0.56 dry metric tons per cubic meter for coniferous and nonconiferous lumber, respectively (table 12.1 in chapter 12 of IPCC [2019]). When extrapolated to the world, the resulting emissions for transport of domestically consumed hardwood lumber were 2 and 1.8 million metric tons CO_2e in 2007 and 2022, respectively.

Global emissions associated with all domestically consumed lumber therefore equaled 4.8 and 4.7 million tons CO_2e in 2007 and 2022, respectively.

9.2.2 International Shipments of Lumber

Data from UNECE and FAO were used to identify import-export country pairs and export quantities accounting for 77% and 82% of global exports of softwood lumber in 2007 and 2022, respectively (FAO 2024a; UNECE/FAO 2025). Global results were obtained by extrapolating from these groups.

For transport between the US and Canada (representing 33% and 21% of global international softwood lumber transfers in 2007 and 2022, respectively), transport modes were obtained from Canadian Government statistics (Government of Canada 2024). Transport distances for road and rail were assumed to be 2,000 km. Transport emission factors for truck and rail transport were obtained from NCASI (2024), as described earlier. Emissions for ocean transport from Canada to the US were calculated using the EcoTransIT calculator assuming shipments from Vancouver to Los Angeles (EcoTransIT World 2024). International shipments within Europe were assumed to be associated with the same emissions, per ton, as those from Canada to the US. Shipments from Russia to Europe were assumed to be by rail, with the route beginning in the lumber-producing region of Western Russia and terminating in Frankfurt, Germany. The small quantity of remaining international shipments to Europe were assumed to travel by a mix of 75% road and 25% rail for 1,000 km. For shipments from Russia to China, it was assumed that the lumber was shipped by rail from the lumber-producing regions of Eastern Russia to Wuhan, China. Other international shipments were assumed to use ocean transport between major ports, with the emissions calculated using the EcoTransIT calculator (EcoTransIT World 2024).

Before and after international transport, it was assumed that the lumber was transported 500 km, on each end, to deliver material to the exporting site and to the customer from the importing site. This transport was assumed to be accomplished using 75% road and 25% rail transport. The calculations used the same NCASI factors described earlier (NCASI 2024).

For internationally traded softwood lumber, the total global emissions associated with international shipments described earlier were calculated to be 5.8 and 5.5 million metric tons CO_2e in 2007 and 2022, respectively.

Emissions associated with transport of internationally traded nonconiferous (hardwood) lumber were assumed to be the same, per ton, after adjusting for the difference in densities, i.e., 0.45 and 0.56 dry metric tons per cubic meter for coniferous and nonconiferous lumber, respectively (table 12.1 in chapter 12 of IPCC [2019]). When extrapolated to the world, the resulting emissions for transport of internationally traded hardwood lumber were 1.5 million metric tons CO_2e in both 2007 and 2022.

9.2.3 Total GHG Emissions for Transporting Sawnwood (Lumber)

The results for domestic and international transport of lumber are summarized in Table 9.2. These emissions totaled 12.1 million metric tons CO_2e in 2007 and 11.6 million metric tons CO_2e in 2022. Although production of lumber increased by 1.4%, on a weight basis, between 2007 and 2022, transport emissions decreased slightly. The reductions appear to be related to (1) an increase in the fraction of lumber shipped internationally by ocean and (2) a reduction in emission factors between 2007 and 2022, reflecting improved fuel efficiencies.

The estimate for 2007 is approximately 50% higher than the estimate developed for the 2010 FAO report. This appears to be primarily due to the assumption, in the earlier report, that land transport was accomplished via a 50/50 mix of rail and road. In this update, it is assumed that road transport handles a much larger share. If the updated mix of transport modes is applied to the 2007 data in the 2010 FAO report, a result is obtained that is within 15% of the updated estimate for 2007 shown in Table 9.2. This update also includes land transport associated with moving lumber to and from the place where the international leg of the shipment begins and ends (e.g., from the mill to the export port and from the import port to the customer). This was not included in the 2010 FAO report.

Table 9.2. Emissions associated with transport of sawnwood (lumber).

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic coniferous	2.8	2.9
Domestic nonconiferous	2.0	1.8
International coniferous	5.8	5.5
International nonconiferous	1.5	1.5
Total coniferous	8.6	8.4
Total nonconiferous	3.4	3.2
Total[a]	12.1	11.6

[a] Total may reflect rounding.

9.3 Wood-Based Panels

9.3.1 Domestic Shipments of Wood-Based Panels

Global domestic shipments of wood-based panels were calculated by taking the difference between global production and global exports using data from FAOSTAT (FAO 2024a). Panel volume was converted to mass using a conversion factor of 0.595 metric ton per cubic meter, the IPCC default for panels (aggregate) (table 12.1 in chapter 12 of IPCC [2019]). One-way haul distance was assumed to be 500 km, the same assumption as used in the 2010 FAO report. Panel transport was assigned only one-way transport emissions, assuming that the transport vehicles would be used for another purpose after delivering panels rather than returning empty to the mill. Transport was assumed to be 90% by truck and 10% by rail. The emission factors used were the same as those used for IRW. Extrapolated to the world, the resulting emissions for domestic transport of wood-based panels were 3.6 and 5.1 million metric tons CO_2e in 2007 and 2022, respectively. The large increase was due primarily to the increase in global production of panels over this period.

9.3.2 International Shipments of Wood-Based Panels

Data from UNECE and FAO were used to identify import-export country pairs and export quantities accounting for 69% and 71% of global exports of wood-based panels in 2007 and 2022, respectively (FAO 2024a; UNECE/FAO 2025). Global results were obtained by extrapolating from these groups. Shipment modes, distances, and emissions were calculated using the same approach and data sources as described for international shipments of lumber. The resulting emissions associated with international shipments of wood-based panels were 4.8 and 5.9 million tons CO_2e in 2007 and 2022, respectively. Again, the large increase is due primarily to the global increase in panel production.

9.3.3 Total GHG Emissions for Transporting Wood-Based Panels

The results for domestic and international transport of wood-based panels are summarized in Table 9.3. These emissions totaled 8.5 million metric tons CO_2e in 2007 and 10.9 million metric tons CO_2e in 2022. Global production of panels increased by 34% between 2007 and 2022, while transport emissions increased by 29%.

As was the case for the lumber estimates, the estimate for panel-related transport emissions for 2007 is approximately 50% higher than the estimate developed for the 2010 FAO report. This appears, again, to be primarily due to the assumption, in the earlier report, that land transport was accomplished via a 50/50 mix of rail and road. In this update, it is assumed that road transport handles a much larger share. Also, this update includes land transport associated with moving panels to and from the place where the international leg of the shipment begins and ends (e.g., from the mill to the export port and from the import port to the customer). This was not included in the 2010 FAO report.

Table 9.3. Emissions associated with transport of wood-based panels.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic	3.6	5.1
International	4.8	5.9
Total[a]	8.5	10.9

[a]Difference from sum of above due to rounding.

9.4 Paper and Paperboard

9.4.1 Domestic Shipments of Paper and Paperboard

The approach, data, and calculations for domestic shipments of paper and paperboard were the same as those described earlier for softwood lumber and wood-based panels. The resulting emissions for domestic transport of paper and paperboard were 8.3 and 9.1 million metric tons CO_2e in 2007 and 2022, respectively. Emissions increased by 9% over this period, approximately the same as the increase in consumption of domestically produced paper and paperboard (10%).

9.4.2 International Shipments of Paper and Paperboard

The approach, data, and calculations for international shipments of paper and paperboard were the same as those described earlier for softwood lumber and wood-based panels. The country pairs represented 68% and 63% of global trade in paper and paperboard in 2007 and 2022, respectively. The resulting emissions for international transport of paper and paperboard were 11.3 and 11.1 million metric tons CO_2e in 2007 and 2022, respectively. The slight decrease in emissions is due primarily to a small decrease in international shipments of paper and paperboard over this period.

9.4.3 Total GHG Emissions for Transporting Paper and Paperboard

The results for domestic and international transport of paper and paperboard are summarized in Table 9.4. These emissions totaled 19.6 million metric tons CO_2e in 2007 and 20.2 million metric tons CO_2e in 2022. Global production of paper and paperboard increased by 5% between 2007 and 2022, while transport emissions increased by 3%.

As was the case for the lumber and panel estimates, the estimate for paper and paperboard-related transport emissions for 2007 is approximately 50% higher than the estimate developed for the 2010 FAO report. The reasons are the same as those for differences in lumber and panel plant emissions estimates in the 2010 FAO report.

Table 9.4. Emissions associated with transport of paper and paperboard.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic	8.3	9.1
International	11.3	11.1
Total	19.6	20.2

9.5 Market Pulp

9.5.1 Domestic Shipments of Market Pulp

The approach, data, and calculations for domestic shipments of market pulp were the same as those described earlier for softwood lumber, wood-based panels. and paper and paperboard. The resulting emissions for domestic transport of market pulp were 4.6 and 4.1 million metric tons CO_2e in 2007 and 2022, respectively. Emissions decreased by 11% over this period, essentially the same as the decrease in consumption of domestically market pulp (10%).

9.5.2 International Shipments of Market Pulp

The approach, data, and calculations for international shipments of market pulp were the same as those described earlier for softwood lumber, wood-based panels, and paper and paperboard. The country pairs accounted for 76% and 75% of international shipments of market pulp in 2007 and 2022, respectively. The resulting emissions for international transport of market pulp were 4.5 and 8.5 million metric tons CO_2e in 2007 and 2022, respectively. The large increase (88%) in emissions is due primarily to (1) international shipments of market pulp increasing by 40% over this period and (2) much of the increase being associated with long-distance transoceanic shipments to Asia.

9.5.3 Total GHG Emissions for Transporting Paper and Paperboard

The results for domestic and international transport of market pulp are summarized in Table 9.5. These emissions totaled 9.1 million metric tons CO_2e in 2007 and 12.6 million metric tons CO_2e in 2022. Global production of market pulp increased by 1% between 2007 and 2022, while transport emissions increased by 38%. The discrepancy is due to (1) a drop in domestic consumption of market pulp while market pulp exports grew from 23% of production 2007 to 32% in 2022 and (2) much of the growth in market pulp trade occurring between countries involving long shipment distances.

As was the case for the other estimates of transport-related emissions for 2007, the estimate in Table 9.5 for market pulp is much higher than the estimate of 4.1 million metric tons CO_2e developed for the 2010 FAO report. This is primarily due to the 2010 FAO report lacking emissions associated with domestic transport of market pulp, due to a lack of data.

Table 9.5. Emissions associated with transport of market pulp.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic	4.6	4.1
International	4.5	8.5
Total	9.1	12.6

9.6 Processed Sawnwood

The 2010 FAO study did not include estimates of transport emissions associated with processed sawnwood. Data on processed sawnwood production and trade, however, are available from the UN Comtrade database (United Nations 2025). That database was searched for data on exports of processed sawnwood, focusing on the relevant six-digit

Harmonized System (HS) codes included in the UNECE trade data (UNECE/FAO 2025). These codes and their descriptions are shown in Table 9.6.

Table 9.6. Processed sawnwood HS codes included in estimates of transport emissions.

HS Code	Description
440910	Wood; coniferous (including unassembled strips and friezes for parquet flooring), continuously shaped along any edges, ends, or faces, whether or not planed, sanded, or end-jointed
440922	Wood; coniferous (including unassembled strips and friezes for parquet flooring), continuously shaped along any edges, ends, or faces, whether or not planed, sanded, or end-jointed
440929	Wood; nonconiferous other than bamboo (including unassembled strips and friezes for parquet flooring), continuously shaped along any edges, ends, or faces, whether or not planed, sanded, or end-jointed

The Comtrade database indicated that international trade in processed sawnwood was 2.97 and 2.84 million metric tons in 2007 and 2022, respectively. For developing transport estimates, it was assumed that the ratio of consumption of domestically produced processed sawnwood to imports of sawnwood was the same as for softwood lumber. This yielded estimates of domestic transport quantities of 5.51 and 5.20 million metric tons for 2007 and 2022, respectively.

The emissions per ton for domestic and international shipments were assumed to be the same as for softwood lumber. The results of the calculations are shown in Table 9.7.

Table 9.7. Emissions associated with transport of processed sawnwood.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic	0.2	0.2
International	0.3	0.3
Total	0.5	0.5

9.7 Furniture

The 2010 FAO study did not include estimates of transport emissions associated with finished wood products. Data on furniture production and trade in 2022, however, are available from the UN Comtrade database (United Nations 2025). That database was searched for data on exports of furniture, focusing on six HS codes included in the UNECE trade data (UNECE/FAO 2025). These codes and their descriptions are shown in Table 9.8.

Table 9.8. Furniture HS codes included in estimates of transport emissions.

HS Code	Description
940161	Seats; with wooden frames, upholstered (excluding medical, surgical, dental, veterinary, or barber furniture)
940169	Seats; with wooden frames, not upholstered (excluding medical, surgical, dental, veterinary, or barber furniture)
940330	Furniture; wooden, for office use
940340	Furniture; wooden, for kitchen use
940350	Furniture; wooden, for kitchen use
940360	Furniture; wooden, other than for office, kitchen, or bedroom use

Furniture exports in 2022 equaled 20.97 million metric tons (United Nations 2025). Based on information from Interior Daily, it was assumed that 40% of global furniture production is exported (Interior Daily 2025). This means that consumption of domestically produced furniture in 2022 was 31.46 million metric tons.

Emissions associated with the transport of domestically produced furniture were calculated using the same approach, assumptions, and emission factors as used for domestically consumed paper and paperboard (and most other forest products). The resulting estimate of domestic transport for 2022 is 0.9 million metric tons of CO_2e.

The approach, data, and calculations for emissions related to 2022 international shipments of furniture were the same as those described earlier for softwood lumber, wood-based panels, paper and paperboard, and most other forest products. The country pairs accounted for 80% of international shipments of furniture in 2022. The resulting emissions for international transport of furniture were 2.5 million metric tons CO_2e in 2022.

Corresponding values for 2007 could not be calculated directly because the Comtrade database does not track furniture shipments back that far. Instead, the amounts of furniture shipped domestically and internationally, and the emissions associated with this shipment, were calculated by scaling the 2022 emissions estimate to reflect the change in global GDP between 2007 and 2022. This resulted in an estimate of domestic transport emissions for 2007 of 0.5 million metric tons CO_2e and of international transport emissions of 1.3 million metric tons CO_2e. Emissions associated with furniture transport are summarized in Table

9.9. The significant increase between 2007 and 2022 reflects the assumption that furniture production increased proportionally to global GDP over this period.

Table 9.9. Emissions associated with transport of furniture.

Shipment	Million Metric Tons CO_2e 2007	Million Metric Tons CO_2e 2022
Domestic	0.5	0.9
International	1.3	2.5
Total	1.8	3.4

9.8 Paper and Paperboard Articles

Although not included in the UNECE trade tables (UNECE/FAO 2025), the UN Comtrade database includes trade data for paper and paperboard articles (United Nations 2025). Data are available for HS codes 48 and 49. HS Code 48, “Paper and Paperboard, Articles of Paper Pulp, of Paper or of Paperboard,” includes both unprocessed rolls and sheets and some products manufactured from unprocessed rolls and sheets. Transportation of unprocessed paper and paperboard is addressed in section 9.4 of this report. In this section, we address the transportation of the products in HS Code 48 not addressed in section 9.4 and those in HS Code 49, “Printed books, newspapers, pictures and other products of the printing industry; manuscripts, typescripts and plans.”

Approximately 67 million metric tons of material in these categories were exported globally in both 2007 and 2022. International transport emissions for paper and paperboard articles were calculated by assuming that the emissions were the same, per ton, as for unprocessed paper and paperboard (addressed in section 9.4). These assumptions result in estimates of international transport emissions for paper and paperboard articles of 6.4 and 6.7 million metric tons CO_2e in 2007 and 2022, respectively.

Transport emissions of domestically produced paper and paperboard articles were calculated by applying the ratio of domestic to international emissions calculated for unprocessed paper and paperboard. This approach assumes that (1) the ratio of domestic use to total production is the same for paper and paperboard articles as for unprocessed paper and paperboard, and (2) the trade partners are also the same for articles and unprocessed paper and paperboard. Using these assumptions, domestic emissions for transport of paper and paperboard articles were 4.7 and 5.4 million metric tons in 2007 and 2020, respectively.

Total emissions, shown in Table 9.10, were therefore 11 and 12.1 million metric tons CO_2e in 2007 and 2022, respectively.

Table 9.10. Emissions associated with transport of paper and paperboard articles.

Shipment	Million Metric Tons CO_2e 2007	2022
Domestic	4.7	5.4
International	6.4	6.7
Total[a]	11.0	12.1

[a] May differ from sum of above due to rounding.

9.9 Wood Pellets

Beginning in 2010, FAO began tracking the production and international trade in "wood pellets, briquettes and other agglomerates" (FAO 2024a). In 2022, global production equaled 51.7 million metric tons, while global exports equaled 31.2 million metric tons. The IEA reports that in 2006, global production of pellets was 6 to 7 million tons (IEA 2011b). FAO data indicate that in 2012, approximately one-half of global production was exported (FAO 2024a). For the calculations here, therefore, it is assumed that in 2007, global production of wood pellets and related products was seven million metric tons and that one-half of this was exported.

For domestic shipments, the same assumptions and factors were used as for paper and paperboard and many other forest products in this report. The emissions calculated for domestic shipment of pellets and related products were 0.1 and 0.5 million metric tons CO_2e in 2007 and 2022, respectively.

The UNECE data provide import and export locations for 2022, but there are no data for 2007. It is assumed, therefore, that the shipment routes and modes were the same for 2007 and 2022. The import-export location pairs used for the calculations represented 96% of global shipments. The calculation methods and assumptions were the same as for international shipments of paper and paperboard, among other types of forest products. The resulting estimates of emissions associated with international shipments of pellets and related products are 0.3 and 3.3 million metric tons CO_2e in 2007 and 2022, respectively.

The total emissions attributable to pellet shipments in 2007 and 2022 are shown in Table 9.11. The large increase, from 0.4 to 3.8 million metric tons CO_2e between 2007 and 2022, is due to the rapid increase in pellet production and demand over that period.

Table 9.11. Emissions associated with transport of wood pellets and related products.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic	0.1	0.5
International	0.3	3.3
Total	0.4	3.8

9.10 Recovered Paper and Recovered Fiber Pulp

The UNECE tables do not include trade in recovered fiber. Therefore, domestic and international transport emissions, per ton, were assumed to be the same as for paper and paperboard. This assumes that the import and export countries for recovered fiber and recovered fiber pulp are the same as for paper and paperboard.

Data on recovered paper and recovered fiber pulp production and exports were obtained from FAOSTAT (FAO 2024a). These data indicate that in 2007, 197 million metric tons of recovered fiber (recovered paper and recovered fiber pulp) were produced globally, with 51 million metric tons of this being exported. The corresponding values for 2022 were 240 million metric tons produced and 50 million metric tons exported.

Using the emissions per ton for domestic and international shipment of paper and paperboard yields the results shown in Table 9.12. The increase from 9.3 million metric tons CO_2e in 2007 to 10.7 million metric tons in 2022 is likely due to increased production of recovered fiber over this period, although it may also reflect a change in how recovered fiber pulp is accounted for in FAO statistics. [23]

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[23] FAO data for recovered paper are available for 2007 and 2022. FAO 2022 data also include recovered fiber pulp but 2007 data do not. In 2022, imports and exports of recovered fiber pulp were between 8% and 9% of imports and exports of recovered paper indicating that any error introduced by this difference in coverage for 2007 is likely to be small.

Table 9.12. Emissions associated with transport of recovered paper and recovered fiber pulp.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Domestic	4.4	5.7
International	4.9	5.0
Total	9.3	10.7

9.11 Transport of Nonrecovered Products to End of Life

The methods used to calculate the amounts of used (but not recovered) forest products requiring transport to end of life are described in sections 4 and 11 of this report. Transport emissions for these materials were calculated domestic road transport and a one-way haul distance of 50 km with an empty return (so the material is assigned a 100-km round-trip distance). Transport emission factors were obtained from NCASI (2024). For road transport, the 2007 factor was 0.0562 kg CO_2e per metric ton-km, and the 2022 factor was 0.0560 kg CO_2e per metric ton-km. These values do not include upstream emissions associated with fuel production and transport, so they were multiplied by 1.161, a factor derived by NCASI to account for upstream emissions associated with oil-based fuels (see section 4.3 in NCASI [2024]). The resulting emissions are shown in Table 9.13.

Table 9.13. Emissions associated with transport of discarded, nonrecovered products.

	Million Metric Tons CO_2e	
Shipment	2007	2022
Paper and paperboard	1.2	1.1
Wood products	1.9	2.2
Total	3.1	3.3

9.12 Transport of Nonfiber, Nonfuel Inputs

Earlier in this section, emissions are calculated for transporting roundwood, products, wastes and other materials containing wood fiber. In Section 6, emissions are estimated for transport of fuels used by the industry and by producers of electricity and steam purchased by the industry. Here, we calculate emissions associated with nonfiber, nonfuel inputs to the value chain. These include various manufacturing chemicals and additives needed to make paper and wood products.

In a study of the US forest products industry, it was calculated that emissions from transport of nonfiber, nonfuel inputs were 4% to 5% of those associated with roundwood transport (NCASI 2024). For this study, an estimate of 5% of roundwood transport emissions is used. Thus, these emissions are estimated to have been 1.5 and 1.9 million metric tons CO_2 e in 2007 and 2022 respectively.

9.13 Transport Emissions Summary

The transport-related emissions in the forest products industry value chain are summarized in Table 9.14 and Figure 9.1. Total emissions increased from 106 to 127 million metric tons CO_2e between 2007 and 2022. Global total transport-related emissions are approximately equally divided between those associated with within-country transport of domestic products and transport of exports and imports. When considering specific materials, however, domestic and international transport emissions are sometimes very different. Transport of industrial roundwood, for instance, produces primarily domestic transport emissions, while lumber produces primarily export/import-related emissions.

Table 9.14. Overall transport-related emissions in the global forest products industry value chain.

	2007			2022		
	Million Metric Tons CO_2e			Million Metric Tons CO_2e		
Product	Domestic	Exports	Total	Domestic	Exports	Total
Industrial roundwood	24.2	6.5	30.7	27.8	10.1	38.0
Sawnwood lumber	2.8	5.8	8.6	2.9	5.5	8.4
Hardwood lumber	2.0	1.5	3.4	1.8	1.5	3.2
Panels	3.6	4.8	8.5	5.1	5.9	10.9
Pulp	4.6	4.5	9.1	4.1	8.5	12.6
Paper and paperboard	8.3	11.3	19.6	9.1	11.1	20.2
Processed sawnwood	0.2	0.3	0.5	0.2	0.3	0.5
Nonfiber Inputs	1.2	0.3	1.5	1.4	0.5	1.9
Paper and paperboard articles	4.7	6.4	11.0	5.4	6.7	12.1
Major furniture	0.5	1.3	1.8	0.9	2.5	3.4
Pellets	0.1	0.3	0.4	0.5	3.3	3.8
Recovered paper	4.4	4.9	9.3	5.7	5.0	10.7
Discarded forest products	3.1	0.0	3.1	3.3	0.0	3.3
Total[a]	59.7	48.0	107.7	68.2	60.7	128.9

[a] May reflect rounding.

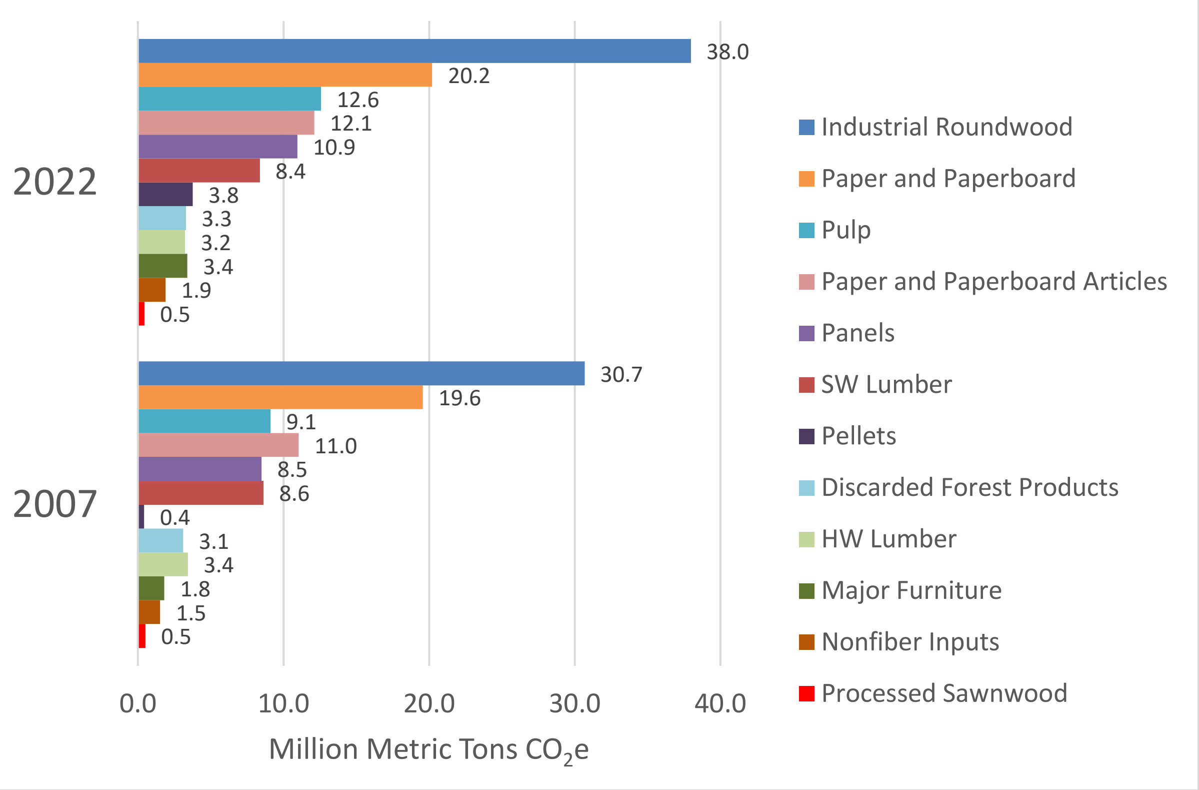

Figure 9.1. Transport-related emissions in the forest products industry value chain: 2007 (bottom) and 2022 (top).

Transport-related emissions attributable to transport of IRW accounted for about 30% of total transport emissions in both 2007 and 2022. The growth in IRW-related emissions is attributable to the increase in global IRW production and the increased share of IRW shipments going to Asia, requiring trans-Pacific transport. The increase in IRW transport emissions accounted for about one-third of the total increase in value chain emissions between 2007 and 2022. Increases in emissions from transport of panels, market pulp, and pellets contributed to between 10% and 20% of the total increase in emissions over this period. Changes in emissions from transport of sawnwood, paper and paperboard, processed sawnwood, paper and paperboard articles, major furniture, recovered paper, and discarded forest products each contributed less than 10% to the overall change from 2007 to 2022.

The total transport-related emissions for 2007 calculated in this update (106 million metric tons CO_2e) are significantly larger than those calculated in the 2010 FAO report (51 million metric tons CO_2e). Most of the difference is due to adjustments in the calculations for shipment of IRW. In addition, this update includes estimates for several processed products not included in the 2010 FAO report, specifically, paper and paperboard articles, major furniture, and processed sawnwood.

10.0 Emissions Associated with Product Use

Forest products seldom emit GHGs during use. The systems in which forest products are used may emit GHGs, but these emissions are usually allocated to the value chain producing the primary product. For instance, GHGs are emitted during transport of a wooden crate containing home furnishings, but the emissions attributable to the transport of the crate are usually assigned to the home furnishings that required transport. An exception to this general rule are GHGs emitted during the use of wood-based fuels. The biogenic CO_2 released during the combustion of wood-based fuels is normally accounted for via inclusion in the calculations of carbon impacts in the forest, an approach called "stock change" accounting. This approach allows biogenic CO_2 emissions to be addressed in a context that also accounts for removal of CO_2 in the forest by growing trees.

Data in section 3 of this report indicate that global forest carbon stocks have been stable since 1990, declining in Africa and South America while increasing elsewhere. This suggests that, on a global scale, biogenic CO_2 emissions are being offset by uptake of CO_2 from the atmosphere by forest growth. Also noted in section 3, however, is the difficulty of attributing specific changes in forest carbon stocks to the forest products industry value chain. The reader is directed to section 3 for more information on this topic. This difficulty precludes the development of global estimates of the net effects of biogenic CO_2 emissions from the forest product value chain.

Here we account for GHGs, other than biogenic CO_2, emitted during the use of wood-based fuels. Emissions associated with other wood-based fuels are not included here because (1) other than pellets, almost all of the industrial use of wood-based fuels is in the forest products sector, and these emissions are accounted for in section 5; and (2) except for pellets, most of the nonindustrial use of wood for fuel is by individual users not associated with the forest products industry value chain[24].

Here, we calculate emissions of nitrous oxide and biogenic methane associated with the combustion of wood pellets. IPCC's default emission factors for "other primary solid biomass" are used (i.e., 30 kg CH_4 and 4 kg N_2O per TJ on a net calorific basis) (IPCC 2006). GWPs of 25 and 298 were used for CH_4 and N_2O, respectively (IPCC 2013). These factors are applied to pellet production of seven million metric tons in 2007 (IEA 2011b) and 51.8 million metric tons in 2022 (FAO 2024a). The heat content of pellets was assumed to be 17 GJ net calorific value per metric ton (Forest Research 2025). The results indicate that in 2007, GHG emissions from burning pellets were 0.1 and 0.1 million metric tons CO_2e of CH_4

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[24] For instance, FAO notes that "Woody biomass, especially fuelwood and charcoal from forests, provides crucial basic energy services for cooking and heating. About 2.3 billion people worldwide (29 percent of the world's population) relied on woody biomass for these purposes in 2021, mostly in sub-Saharan Africa and South Asia."

and N_2O, respectively, for a total of 0.2 million metric tons CO_2e in 2007. For 2022, GHG emissions from burning pellets were 0.7 and 1.0 million metric tons CO_2e of CH_4 and N_2O, respectively, for a total of 1.7 million metric tons CO_2e in 2022.

11.0 Emissions from Forest Product End of Life

After forest products have been used, they are either recycled, landfilled, burned, or otherwise reused or disposed. Transport and manufacturing emissions associated with recycling are accounted for elsewhere in this report. Landfilling and burning can result in the release of methane and nitrous oxide. Biogenic CO_2 is also released, but this is not included in the GHG emissions here for reasons explained in sections 3 and 10.

In the 2010 FAO report, end-of-life emissions were calculated only as ultimate emissions associated with disposal of products manufactured in 2007. This is also done in this update, but we also estimate actual annual emissions from end-of-life operations in 2007 and 2020, attributable to products manufactured in those years and many prior years. Estimates of actual emissions in 2007 and 2022 are more appropriate for use in annual inventories of emissions in 2007 and 2022; therefore, these are used to construct the overall 2007 and 2022 profiles.

The first step is to calculate the amounts of forest products going to end of life. IPCC has published information on the management of municipal solid waste (MSW) around the world in 1996 and 2019 (see table 2A.1 in volume 5, chapter 2 in IPCC [2006] and also IPCC [2019]). Recycling, landfilling, and burning account for end-of-life management of almost all forest products, although this can be difficult to discern in the IPCC default data, because those data do not separately track recycling. As a result, many countries include recycling in the “unspecified” management category (see table 2.A.1 in volume 5, chapter 2 of IPCC [2006] and IPCC [2019]). Indeed, in reviewing the “unspecified” management data, it is clear that most of what is reported in that category is recycling. Therefore, for this report, as in the 2010 FAO report, quantities of used product recovered for recycling have been obtained from FAO data (FAO 2024a). Paper and paperboard recovered for recycling in 2007 and 2020 were obtained from FAO (2024a). The quantities of recovered wood products in 2020 were also obtained from FAOSTAT, but recovered wood products data extend back to only 2017, so linear extrapolation was used to obtain values for 2007. After subtracting the amounts recovered from total discards, it is assumed that all remaining discarded forest products are either landfilled or burned.

Using data published by IPCC (see table 2A.1 in volume 5, chapter 2 in IPCC [2006] and IPCC [2019]), the fraction of discarded forest products sent to landfill and burning in 1996 and 2019 (the years for which there were data in the IPCC reports) were determined, by country, for the set of countries associated with at least 90% of paper and wood products consumption in 2007 and 2020. IPCC’s defaults are for MSW, and it was assumed that nonrecycled forest products are managed using the same practices as for MSW in general. In the case of landfilling, only the fractions going to “landfills,” as reported in table 2.a.1 in volume 5, chapter 2 of IPCC [2006] and IPCC [2019]), were included. The amounts sent to "open dumps" were not considered because the conditions in open dumps do not favor the production of methane or nitrous oxide. IPCC, for instance, points out that "wastes in shallow open dumps generally decompose aerobically and produce little CH_4" (volume 5, chapter 3 in IPCC [2019]). The amounts going to open dumps were allocated either to landfilling or burning according to the ratio of these two in each country. This is expected to increase the estimate of emissions from landfills and burning compared to an analysis where open dumps are considered as a separate fraction. The impact on the results, however, is likely to be small because, according to IPCC defaults, the fractions of MSW going to open dumps is significant only in Africa and South America (table 2.A.1 in volume 5, chapter 2 of IPCC [2019]), regions representing less than 5% of global consumption of forest products (based on data from FAO [2024a]).

Nonrecovered materials were assigned to landfilling or burning according to the ratio of fractions shown in table 2.a.1 in volume 5, chapter 2 of IPCC [2006] and IPCC [2019]). The estimates for these ratios in 2007 and 2020 were obtained by linear interpolation and extrapolation of the 1996 and 2019 values calculated from IPCC (2006; 2019).

11.1 Landfill Emissions

As was the case for calculations of carbon stored in forest products, there are two basic approaches to calculating methane emissions associated with forest products that decompose in landfills. One is to reconstruct a historical record of amounts of material going to landfills to allow an estimate of the actual emissions in one year associated with all products deposited in the past. The second approach is to calculate the future landfill emissions that will be attributable to material generated in one year. In this report, only the first approach is applied.

11.1.1 Landfill Emissions Reflecting Current and Past Year's Production

The approach to calculating annual methane emissions associated with landfill deposits accumulated over time is the same as that needed to calculate year-to-year changes in carbon stocks in landfills, described in section 4.2 of this report. By taking the difference between annual carbon additions to landfills and the annual stock changes in landfilled carbon (see section 4.2), one can calculate the annual losses of carbon from the landfill (i.e., degraded carbon).

Methane only occurs in anaerobic zones of landfills. In the calculations, this fact is addressed by the MCF, which essentially represents the fraction of landfills that are anaerobic. The values for MCF used in this study, and their derivations, are described in section 4.2. For each year, the amount of landfilled carbon was multiplied by the corresponding MCF to calculate the amount of carbon going to anaerobic landfills. One-half of degraded carbon going to anaerobic landfills was assumed to be converted to methane. The degradation was described using a first-order decay model described in section 4.2.

Based on the approach in the 2010 FAO study, described in section 11.1.2 of this report, top-consuming countries were assigned an assumed capture efficiency for methane generated in landfills. A landfill-deposit-weighted average of 20% was calculated for 2007. This value was used for 2007 forward, and for years before 2007, a value between zero and 20% was interpolated. Finally, 10% of the methane not captured was assumed to be oxidized as it travels through the upper layers of the landfill, the default IPCC value (IPCC 2019).

The results of these calculations, shown in Figure 11.1, indicate that methane emissions attributable to accumulated deposits of forest products in landfills were 7.3 million metric tons methane in 2007 and 9.7 million metric tons methane in 2022. Using a GWP for methane of 25 (IPCC 2013), these are equivalent to 182 million metric tons CO_2e in 2007 and 243 million metric tons CO_2e in 2022.

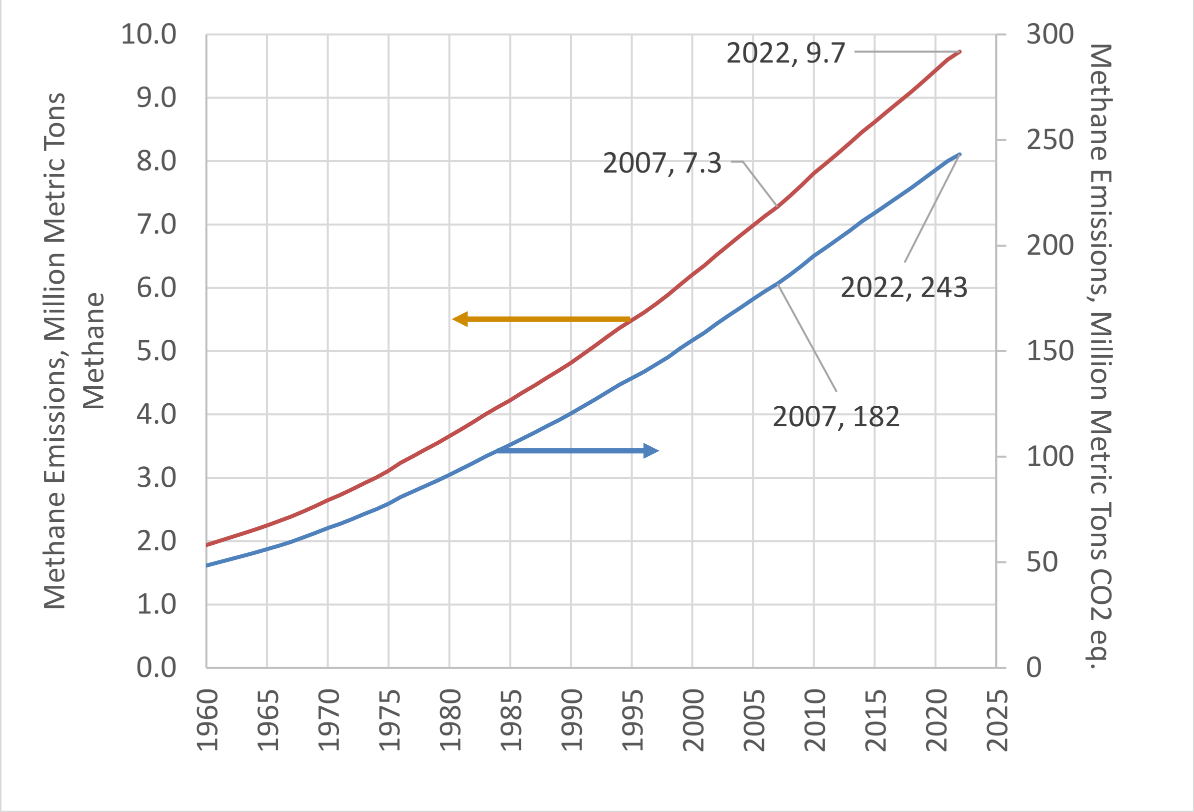

Figure 11.1. Annual global methane emissions from landfills receiving discarded forest products.

[Note: CO_2 equivalents calculated using a GWP of 25]

Methane emissions are compared to annual changes in landfill carbon stocks in Table 11.1. Overall, landfills are a net sink, with annual increases in carbon stocks, in CO_2e, being larger than methane emissions in CO_2e (using a GWP of 25). It should be noted, however, that wood products in landfills have a very different profile than paper and paperboard products. Wood products in landfills are currently a large net sink, while paper and paperboard products are a net source. The net landfill sink for forest products will be maintained only as long as additions to landfills are adequate to offset the methane emissions associated with the deposits to landfills made in years past.

Table 11.1. Comparison of landfill methane emissions and carbon stock changes attributable to forest products disposed in landfills in the inventory year and before.

	Million Metric Tons CO_2e					
	Landfill Stock Changes		Landfill Methane Emissions[a]		Net Emissions	
	2007	2022	2007	2022	2007	2022
Paper	91.3	94.2	142	186	50.7	91.9
Wood	191.3	268	39.9	57.1	−151	−210
Total	283	362	182	243	−101	−119

[a]Methane GWP of 25.

Pan et al., citing IPCC's Six Assessment Report, notes that a loss of 4% of landfilled forest products carbon as methane (at a GWP of 29) is enough to negate the benefits of increasing carbon stocks in landfills (supporting information for (Pan et al. [2024]). The analysis in this report confirms that only a small amount of methane can offset the net removals attributable to increasing landfill carbon stocks. The calculations here, however, suggest a breakeven threshold of approximately 5%, using GWP of 29 or 6% using a GWP of 25.

IPCC has estimated that, between 2000 and 2017, "landfills and waste" were the source of between 53 and 77 million metric tons of methane, globally (table 5.2 in IPCC [2021]). If a value of 65 million metric tons methane (1,625 million metric tons CO_2e using a GWP of 25) is used to represent global landfill emissions in 2022, the estimates derived herein suggest that forest products contribute about 15% of global emissions from landfills and waste treatment. This appears reasonable, as data from IPCC suggest that forest products represent about 16% of MSW and about 28% of the organic waste in MSW (an average of the regional values in table 2.3 in volume 5, chapter 2 of IPCC [2019]). The contribution of forest products to methane generation would be smaller than for other organic materials in MSW because forest products are considerably less degradable. This is evident in IPCC default values for DOC_f, the fraction of biogenic carbon that will degrade under anaerobic conditions, which are 0.7, 0.7, 0.5, and 0.1 for food waste, garden waste, paper and paperboard waste, and wood waste, respectively (see table 3.0 in volume 5, chapter 3 of IPCC [2019]).

11.2 Emissions from Burning Forest Products at End of Life

As for landfill emissions, there are two general approaches to calculating emissions from burning forest products at end of life. One approach calculates the emissions associated with burning discards generated in a specified year, while the other calculates the ultimate emissions associated with burning materials manufactured in a specified year. In this report, only the first approach is used.

11.2.1 Emissions from Burning Forest Products Discarded in 2007 and 2022

The amounts of discarded forest products burned at end of life in 2007 and 2022 were calculated using the methods described in section 4 and at the beginning of section 11. The assumptions for heat content, as well as the emission factors for methane and nitrous oxide, are the same as those used in section 10. The results, shown in Table 11.3, indicate that burning used forest products at end of life produced 1.9 million metric tons CO_2e of emissions in 2007 and 1.8 million metric tons in 2022.

Table 11.2. CH_4 and N_2O emissions from burning forest products discarded in 2007 and 2022.

	Million Metric Tons CO_2e^a	
Sector	2007	2022
Paper and paperboard	0.9	0.8
Wood products	1.0	1.1
Total	1.9	1.8

[a]GWP: CH_4 = 25, N_2O = 298 (IPCC 2013).

12.0 SUMMARY OF THE FOREST PRODUCT INDUSTRY'S GLOBAL PROFILE

The calculations described in this report provide the basis for characterizing the global carbon and GHG profile of the forest products industry in 2007 and 2022. A summary of the profile is provided here. The discussion is divided into GHG emissions, flows of biogenic carbon and biogenic CO_2, and net releases.

12.1 Greenhouse Gas Emissions from the Global Forest Products Industry Value Chain

The emissions calculated in earlier sections of this report are summarized in Table 12.1 and Figure 12.1. The uncertainties associated with different types of emissions vary greatly. In some cases, emission estimates are accurate enough to allow comparisons of 2007 and 2022 performance. In particular, estimates of emissions from the use of fossil fuels in manufacturing and estimates of emissions associated with the production of electricity and steam purchased by the industry can be considered of high quality. This is due to the quality and coverage of the data used in the calculations. In most other cases, the uncertainties in the estimates are large. These other estimates, which are adequate for identifying the parts of the value chain that are most and least significant, should be used with caution when comparing 2007 and 2022 emissions.

Over the 15-year period from 2007 to 2022, the GHG emissions from the forest products industry value chain increased from 1,006 million metric tons CO_2e to 1,175 million metric tons CO_2e. The GHG emissions intensity of the value chain increased slightly, from 1.31 to 1.38 metric tons of CO_2e per metric ton of production.

Figure 12.1 provides a basis for discussing the importance of different types of emissions. It is clear, for instance, that fuel combustion and purchases of electricity are the two most important sources of emissions in the value chain, each representing 23% to 27% of value chain emissions. The quality of the estimates also allows a conclusion that emissions from fuel combustion remained essentially constant between 2007 and 2022, in spite of a 7% increase in paper and paperboard production and a 14% increase in wood products production (FAO 2024a). Emissions associated with purchased power increased by 28% over this period, much faster than the growth in production. As noted in section 5.2, the increase is likely due to (1) faster growth in regions with more GHG-intensive power grids and (2) a trend toward more electricity-intensive technologies.

The data on emissions from product end of life, almost all of which are from landfilling, provide a sound basis for concluding that this represents a significant part of the industry's profile (18% to 21%of gross GHG emissions). The uncertainties in the estimates shown here are large, but they are generally aligned with estimates from other studies.

The only other element contributing 10% or more of the industry's total value chain emissions is transport. Here, again, the estimates are subject to large uncertainty. The data are adequate for confirming that transport is an important contributor to value chain emissions. In addition, it is likely that these emissions increased between 2007 and 2022 because it is likely that production increased more rapidly over this period than could be offset by any emissions reductions per ton-km that would have occurred.

Upstream emissions associated with nonfiber, nonfuel inputs, fossil fuels, treatment of industry wastes, and growing and harvesting of wood each represent between 2% and 7% of the overall gross emissions profile. Emissions associated with product use (i.e., use of wood pellets for fuel) and emissions from burning products at end of life are negligible contributors to the emissions profile.

The value chain emissions intensity increased slightly between 2007 and 2022; from 1.31 to 1.38 tons CO_2e per ton of production in 2007 and 1.32 tons CO_2e per ton of production in 2022. The intensity did not improve due to increases of over 20% in absolute emissions attributable to purchased electricity and steam, transport operations, and methane emissions from industry products in landfills. These increases are explored in more detail in the respective sections describing the calculations.

The emissions of the global forest products industry, expressed in terms of intensity, are shown in Table 12.2. Note that the values in Table 12.2 may differ from those found elsewhere in this report. This is primarily because in Table 12.2, all emissions have been assigned to either paper and paperboard or wood products production. The emissions intensity of the paper and paperboard sector, for instance, includes emissions from the converting sector. Also, the intensity calculation includes emissions from market pulp production, but the denominator in the intensity calculation does not include market pulp. As a result of such factors, the emission intensities for the paper and paperboard sector in Table 12.2 are higher than that shown in section 5 associated with the mills producing paper, paperboard, and market pulp.

Table 12.1. Greenhouse gas emissions from the global forest products industry value chain.

	2007				2022			
	Million Metric Tons CO_2e				Million Metric Tons CO_2e			
Emission Type	Paper and Paperboard	Wood Products	Converting	Total	Paper and Paperboard	Wood Products	Converting	Total
Fossil fuel combustion	205	25.6	36	266.6	217	14.4	36.7	268.1
Purchased electricity and steam	105.9	48.8	93.9	248.6	135.2	62.9	119.9	318
Upstream emissions: nonfiber, nonfuel	36.8	35.3	[a]	72.1	30	46.9	[a]	76.9
Upstream emissions: fossil fuels	33.8	4.5	7.1	45.4	36.3	2.6	7.3	46.2
Upstream Emissions: Scope 3 Electricity	7.4	3.4	6.6	17.4	9.5	4.4	8.4	22.3
Treatment of industry waste[b]	35.3	2	0	37.3	35.7	2.3	0	38.0

(Continued on next page. See notes at end of table.)

Table. 12.1. Continued.

Emission Type	2007 Million Metric Tons CO_2e Paper and Paperboard	Wood Products	Converting	Total	2022 Million Metric Tons CO_2e Paper and Paperboard	Wood Products	Converting	Total
Growing and harvesting wood		26.6		26.6		30.2		30.2
Transport		107.7		107.7		128.9		128.9
Product use		0.2		0.2		1.7		1.7
Product end of life: landfills	142	40	[c]	182	186	57.4	[c]	243
Product end of life: burning	0.9	1.0	[c]	1.9	0.8	1.1	[c]	1.8
Totals				1006				1175

[a] Not calculated.

[b] These emissions are largely from landfills

[c] Included in paper, paperboard, and wood products estimates.

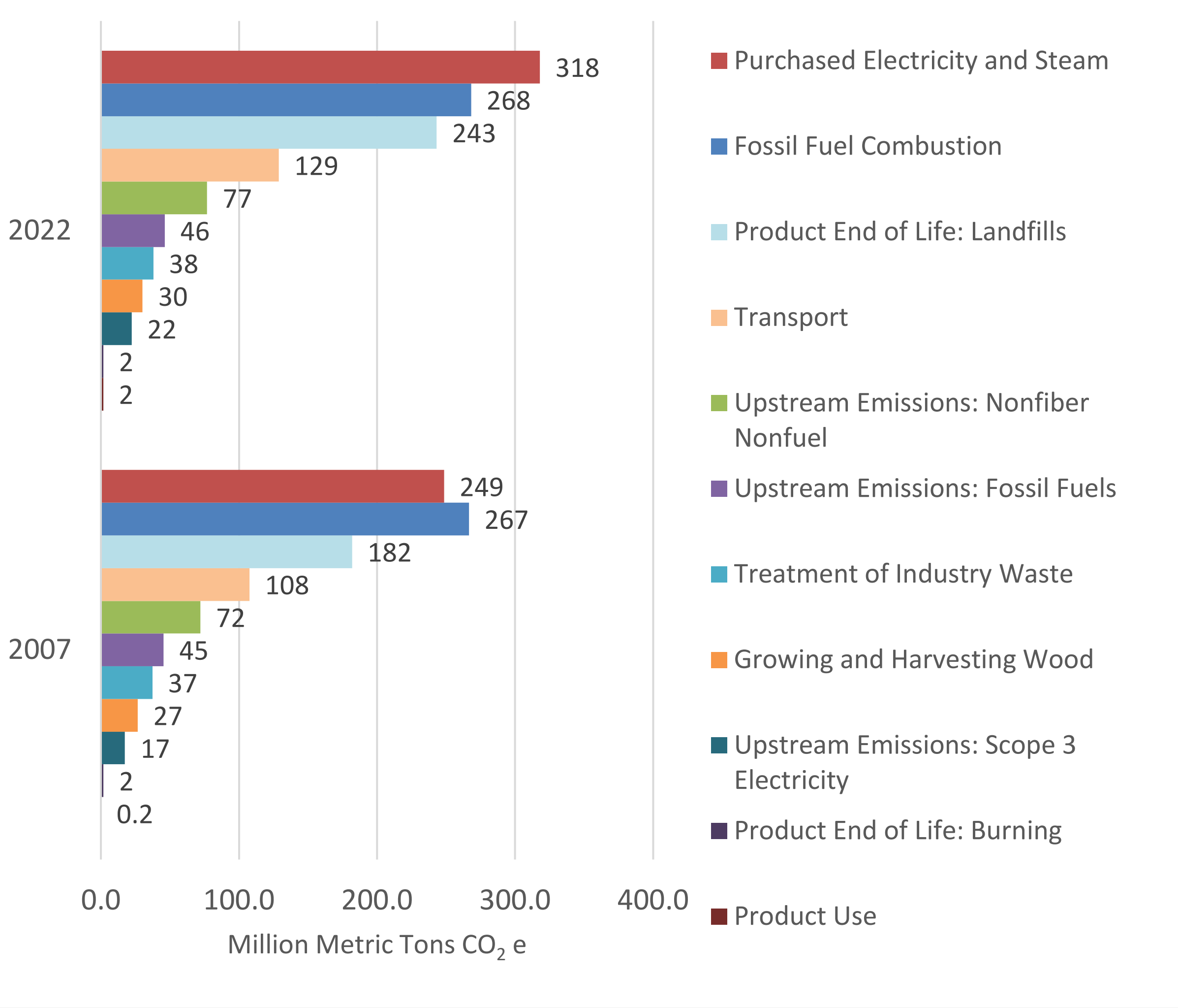

Figure 12.1. Gross greenhouse gas emissions from the global forest products industry value chain: 2007 (bottom) and 2022 (top).

Table 12.2. Emissions intensities[a] in 2007 and 2022.

	Emissions Intensity, Tons CO_2e/Metric Ton Product[b]			
	2007		2022	
Emissions Source	Paper and Paperboard	Wood Products	Paper and Paperboard	Wood Products
Fossil Fuel Combustion	0.606	0.077	0.607	0.037
Purchased Electricity and Steam	0.497	0.143	0.600	0.159
Upstream Emissions: Non-Fiber Non-Fuel	0.094	0.094	0.072	0.108
Upstream Emissions: Fossil Fuels	0.102	0.014	0.104	0.007
Upstream Emissions: Scope 3 Electricity	0.035	0.010	0.042	0.011
Treatment of Industry Solid and Liquid Waste	0.090	0.005	0.086	0.005
Growing and Harvesting Wood	0.035		0.036	
Transport	0.140		0.152	
Product Use	0.000		0.002	
Product End-of-Life: Landfills	0.362	0.107	0.449	0.131
Product End-of-Life: Burning	0.002	0.003	0.002	0.003
Total Forest Products Industry	1.31		1.38	

[a] These may differ from intensity values elsewhere in this report. See text for explanation.
[b] Based on emissions in Table 12.1, production statistics from FAO (2024a) and wood product density values from Table 4.1.

12.2 Stored Carbon in the Forest Products Industry Value Chain

The impacts of biogenic carbon on the atmosphere depend on (1) the net flux of carbon between the atmosphere and the biosphere and (2) the specific GHGs containing the biogenic carbon when it returns to the atmosphere. The impact due to the type of GHG is accounted for in this report by including biogenic methane releases in the totals for fossil fuel–related GHG emissions and applying appropriate factors (GWPs) to account for the warming effect of methane. Accounting for the net flux of biogenic carbon is more difficult. It requires information on the changes in stocks of stored biogenic carbon along the full value chain. These stocks reside, primarily, in forests, forest products in use, and forest products in landfills. If the total carbon in these stocks increases, not only have emissions of biogenic CO_2 been offset by forest growth, but additional carbon has also been removed from the atmosphere beyond that needed to offset biogenic CO_2 emissions. On the other hand, if total stocks of stored biogenic carbon are decreasing, it means that there is a net flow of carbon, almost entirely in the form of biogenic CO_2, to the atmosphere.

In section 3, information was presented indicating that forest carbon stocks have been declining in tropical forests but increasing in boreal and temperate forests. Section 3 also points out, however, that it is not possible to determine how much forest growth should be attributed to the value chain of the forest products industry. As a result, it is not possible to calculate the overall change in forest carbon stocks attributable to, or the net impact of biogenic CO_2 emissions from, the forest products industry value chain.

Carbon stored in forest products, however, is clearly attributable to the forest products industry, and the effects of changes in stocks of carbon in products in use and products in landfills can be characterized. In this report, we calculate annual changes in stocks in 2007 and 2022, attributable to production in those years and earlier.

The results of calculations on the actual year-to-year changes in stocks of forest carbon in use and in landfills, attributable to current and past production, are shown in Table 12.3. The annual change in carbon stocks was about the same in 2007 and 2022, being 649 and 668 million metric tons CO_2e, respectively. Wood products (lumber and panels) contribute about 80% of the total net additions.

Table 12.3. Stock changes in forest products attributable to current and past production

	In Use Stock Changes Million Metric Tons CO_2e		Landfill Stock Changes Million Metric Tons CO_2e		Total[a] Stock Changes Million Metric Tons CO_2e	
Product	2007	2022	2007	2022	2007	2022
Paper	55.8	7.4	91	94	147	102
Wood	310	299	191	268	502	567
Total	366	307	283	362	649	668

[a] May reflect rounding.

The data in Table 12.3 show that these additions to stored carbon represent significant removals of carbon from the atmosphere. While there are uncertainties associated with the estimates, they are within the range of estimates produced by other researchers, as discussed in the sections of this report containing the relevant calculations.

12.3 Overall GHG Emissions and Stock Changes Attributable to the Global Forest Products Industry

Without knowledge of the industry's impact on global forest carbon stocks, removals associated with growth in these stocks should not be netted against the emissions shown in Table 12.1. If it is assumed, however, that the industry's sustainable forest management practices result in stable or increasing forest carbon stocks on the land producing wood for the industry, the values in Table 12.2 can be compared to the emissions in Table 12.1. In this case, the removals associated with net additions to carbon stocks in products represent an offset more than one-half of the industry's value chain emissions (i.e., total of Scopes 1, 2, and 3), and are more than enough to offset all Scope 1 and Scope 2 emissions from the industry[25]. The relative size of these removals compared to the industry's GHG emissions are shown in Figure 12.2. Note that the figure assumes that forest carbon stocks are stable in forests providing wood to the industry. Absent such an assumption, the information in Table 12.2 on its own provides an important indication of the significance of stocks of carbon stored in forest products.

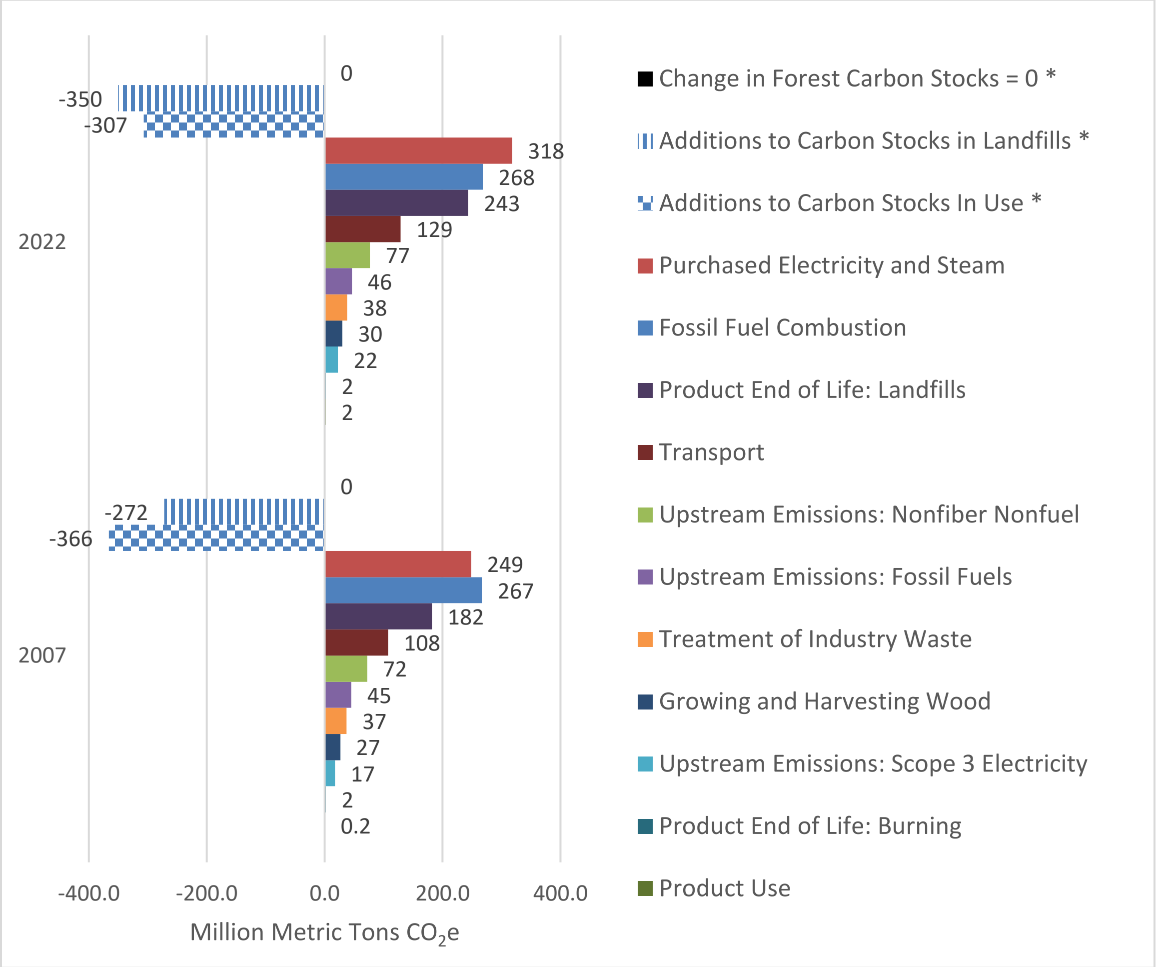

Figure 12.2. GHG emissions and stock changes in the global forest products industry value chain: 2007 (bottom) and 2022 (top).

[Note: The value of zero for change in forest carbon stocks is based on an assumption that carbon stocks are stable on land producing wood for the forest products industry. Asterisks identify the categories used to complete the mass balance of biogenic carbon]

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[25] In this study, Scope 1 emissions are attributable to fuel combustion in forest products manufacturing and converting operating, while Scope 2 emissions are associated with the production of the electricity and steam purchased by the forest products industry.

13.0 CONCLUSIONS

Over the 15-year period from 2007 to 2022, the GHG emissions from the forest products industry value chain increased from 1,006 to 1,175 million metric tons CO_2e. The GHG emissions intensity of the value chain increased slightly, from 1.31 to 1.38 metric tons of CO_2e per metric ton of production.

Fuel combustion (Scope 1 emissions) and purchases of electricity (Scope 2 emissions) represented 23% and 27%, respectively, of value chain emissions in 2022. Emissions from fuel combustion remained essentially constant between 2007 and 2022, despite a 7% increase in paper and paperboard production and a 14% increase in wood products production. Emissions associated with purchased power increased by 28% over this period, faster than the growth in production. The increase is likely due to (1) faster industry growth in regions with more GHG-intensive power grids and (2) a trend toward more electricity-intensive technologies. End-of-life emissions from landfills receiving discarded industry products contributed 21% of total value chain emissions in 2022, while transport-related emissions represented 11%. Upstream emissions associated with nonfiber, nonfuel inputs, fossil fuels, treatment of industry wastes, and growing and harvesting of wood each represent between 2% and 7% of the overall emissions profile in both 2007 and 2022. Emissions associated with product use (i.e., use of wood pellets for fuel) and emissions from burning products at end of life are negligible contributors to the emissions profile.

Data are inadequate to calculate the change in global forest carbon stocks attributable specifically to the forest products industry. As a result, it is not possible to determine the net transfers of biogenic carbon with the atmosphere attributable to the forest products industry. Changes in stocks of carbon in products, however, can be calculated and are important elements of the industry’s carbon and GHG profile. The total annual additions to stocks of stored carbon in products in use and products in landfills are equivalent to a removal of 600 million metric tons CO_2e from the atmosphere per year. This is more than enough to offset the total Scope 1 and 2 emissions from the industry’s value chain. About one-half of the net additions to carbon stocks in products occur in landfills. Increases in carbon stocks in use and in landfills are primarily attributable to wood products. The overall net increases in product carbon stocks are larger than the corresponding methane emissions from decomposing forest products, resulting in landfills currently being a net GHG sink. The net landfill sink for forest products will be maintained, however, only as long as carbon additions to landfills are adequate to offset the methane emissions associated with the deposits to landfills made in years past.

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