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From Source to Sink: Past Changes and Model Projections of Carbon Sequestration in the Global Forest Sector

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ABSTRACT

An economic model of the global forest sector was used to estimate the carbon mitigating potential of the world's forests to 2065 for 180 countries assuming future socioeconomic trends that do not change markedly from historical patterns, consistent with the IPCC-SSP2. Forest carbon pools were broken down into four categories; (i) above-ground and below-ground biomass, (ii) forest soil, (iii) dead wood and litter, and (iv) harvested wood products. Changes in forest carbon storage were driven by the dynamic relationship between endogenously determined timber harvest, wood product consumption, evolving forest biomass stock, forest area change and exogenous demographic and income changes. The results suggested that the forest sector was a net carbon source of approximately 3.6 $GtCO_2e\ yr^{-1}$ in 1992, decreasing to 2.4 $GtCO_2e\ yr^{-1}$ in 2014 (average rate: -0.05 $GtCO_2e\ yr^{-1}$), in general agreement with previous historical assessments. In the projections, the global forest sector achieved a net zero carbon balance by the year 2025, but with large variations by region and country. By 2030, the world's forest sector became a net carbon sink of 1.5 $GtCO_2e\ yr^{-1}$,

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and eventually of 6.8 $GtCO_2e\ yr^{-1}$ by 2065. Uncertainties exist in projecting changes in forest area, including the influence of socioeconomic drivers and climate policy targets, as well as the interplay between forests and climate.

Keywords: Climate change, Forest sector, International trade, Carbon sequestration, Land use, Global Forest Products Model

1 Introduction

To reduce atmospheric concentrations of CO_2, policymakers are increasingly turning to the world's forests. Activities related to land use and forestry were responsible for 24% of global greenhouse gas emissions in 2010, primarily due to deforestation and forest degradation (IPCC, 2014). Yet, at the same time, forests have the ability to remove CO_2 from the atmosphere by sequestering carbon in biomass, dead organic matter, soils, and long-lived wood products, which can turn the forest sector from a net source of CO_2 to a sink (FAO, 2014). Consequently, forests are likely to play a major role in future initiatives to combat climate change.

Yet, the carbon balance of the world's forests is greatly influenced by socioeconomic factors that will determine the economic returns of forest land. Increased population may drive marginal forest land into agriculture to feed a growing population, contributing to deforestation and the release of CO_2 into the atmosphere. Higher levels of income will induce a greater demand for wood products, leading to increased harvest levels and further emissions. Conversely, forest resources used to make long lived wood products that store carbon, will provide an important carbon sink (van Kooten and Johnston, 2016). Differences in production and transport costs will also contribute to comparative advantages of countries in internationally connected markets, thus affecting forest management across countries. Together, these factors will help determine the demand for forest resources, the returns to forest land, and ultimately the future carbon balance of the world's forests and its distribution among countries.

A number of studies have investigated the relationship between the economy, land use, and forestry (see Murray *et al.*, 2009 for a review). Statistical models relate observed levels of land use change, and land based emissions, to other observable factors such as commodity prices, returns to land, and population (e.g., Angelsen and Kaimowitz, 1999; Lubowski *et al.*, 2006). Several models rely on data obtained with Geographical Information System (GIS) to connect social and biological data to land use and emissions data (e.g., Brown *et al.*, 2007; Harris *et al.*, 2008). While these models have great spatial detail, they often assume that market prices are exogenous, ignoring the potential feedback of land use and forest stock on production and commodity prices, land use, and carbon flux.

Approaches that solve for land use and price endogenously include the Forest and Agricultural Sector Optimization Model–Greenhouse Gas version (FASOMGHG) for the United States (Adams *et al.*, 1999; Murray *et al.*, 2004)) and the Global Timber Model (GTM) (Sohngen *et al.*, 1999; Sohngen and Mendelsohn, 2003). These intertemporal spatial equilibrium models endogenously solve for prices, land use and carbon flow in forestry and agriculture, assuming perfect foresight of decision makers.

Due to the complex relationship between social and biophysical systems, integrated assessment models have been applied to derive quantitative projections by marrying together two or more modeling domains. Models that have explicit representations of land use include AIM (Fujimori *et al.*, 2014), GCAM (Wise *et al.*, 2014), IMAGE (Stehfest *et al.*, 2014), MESSAGE-GLOBIOM (Havlík *et al.*, 2014; Riahi *et al.*, 2012) and REMIND/MAgPIE (Popp *et al.*, 2014), and have broadly been applied to investigate the potential future development of land use and greenhouse gas emissions (see Popp *et al.*, 2017; van Vuuren *et al.*, 2017; Rao *et al.*, 2017; Riahi *et al.*, 2017; Fricko *et al.*, 2017).

The Global Forest Products Model (GFPM) used here (Buongiorno *et al.*, 2003)[1] is a recursive dynamic spatial equilibrium model whereby the future depends on the present, but not optimally, thereby avoiding the perfect foresight assumption while reducing the problem size and thus allowing for geographic detail. The current GFPM 2017 covers 180 countries/regions, with 14 forest product groups. Beyond simulating the global market for forest products, the GFPM also tracks, at the country level, annual volumes of timber harvests and changes in forest stock and area.

The objective of this study was to project the carbon sequestration potential of the world's forest sector by expanding the wood supply module of the GFPM to enable a detailed tracking of forest carbon flux. The next section of the paper introduces an international model of wood supply, with dynamic relationships linking timber harvests, forest growth, and forest land use change assuming *middle of the road* socioeconomic development (IPCC-SSP2). The corresponding net carbon flux in biomass, dead organic matter, soil, and harvested wood products were projected in country detail. The following section compares the results from this analysis to other global datasets, and explains discrepancies based on methodological differences in estimates, and scope of coverage followed by a discussion and concluding remarks.

[1] The 2017 version of the GFPM including software, documentation, and data is available freely for research purposes at: http://labs.russell.wisc.edu/buongiorno/welcome/gfpm/

2 Methods and Data

2.1 The Global Forest Products Model (GFPM)

The GFPM is recursive in the sense that the state of the forest sector in a particular year, t, depends on the state in the previous year, $t-1$, and on the predicted exogenous variables at t, principally population and gross domestic product. Each year the model solves a spatial market equilibrium among all countries by maximizing quasi-welfare: the value of end products minus the cost of production and transportation (Samuelson, 1952; Takayama and Judge, 1971). The model represents wood supply for all 180 countries driven by changes in forest area and forest stock (Turner *et al.*, 2006). Successive yearly equilibria are linked dynamically to reflect demographic and economic growth in accord, in this application, with the Intergovernmental Panel on Climate Change's (IPCC's) *middle of the road* Shared Socioeconomic Pathway (SSP); SSP2 (see Popp *et al.*, 2017). Global development is assumed to be consistent with historical patterns, with continued tropical deforestation, although at a slowing rate over time, and low income countries continue to catch up in GDP per capita.

2.2 Roundwood Harvest and Forest Area and Biomass Stock Dynamics

In each year t, the short-run supply (harvest) of roundwood in country i is:

$$H_{it} = H_{it}^r + H_{it}^n + \theta_i H_{it}^f, \tag{1}$$

where H_{it}^r is the harvest of industrial roundwood (to be transformed into sawnwood, wood-based panels, or pulp), H_{it}^n is the harvest of other industrial roundwood, and H_{it}^f is the harvest of fuelwood, for which proportion θ_i comes from the forest. Each harvest component is a function of endogenously determined price, forest area and biomass stock, and other exogenous variables (in this case, GDP and population, projected under SSP2).

A given country's stock of forest biomass, $S_{it} = U_{it}A_{it}$, is a function of forest area, A_{it}, and the stock per unit of area (stock density), U_{it}, and evolves over time according to the following growth-drain equation:

$$S_{i,t+1} = S_{it} + G_{it} - H_{it}, \tag{2}$$

where G_{it} is the annual change in forest biomass stock excluding harvest, obtained from the following equation:

$$G_{it} = S_{it}(g_{it}^a + g_{it}^u). \tag{3}$$

The annual change in forest biomass stock due to forest area change is given by $g_{it}^a S_{it}$, and the annual change in stock due to forest growth or mortality on a given area is given by $g_{it}^u S_{it}$.

Changes in forest area are assumed to be a function of evolving demographics and economic growth, and are linked dynamically according to the equation:

$$A_{i,t+1} = (1 + g^a_{it})A_{it}, \tag{4}$$

where g^a_{it} is the forest area annual growth rate which changes over time according to the following environmental Kuznets curve (Buongiorno, 2015):

$$g^a_{it} = (\alpha_{i0} + \alpha_1 (Y/N)_{it})e^{\alpha_2 (Y/N)_{it}} \cdot \alpha_1 > 0 \text{ and } \alpha_2 < 0. \tag{5}$$

where $(Y/N)_{it}$ is income per capita. With parameter estimates of $\alpha_1 = 0.0014$ (standard error, SE, ± 0.0005) and $\alpha_2 = -0.0898$ (SE ± 0.0327) obtained from historical data, equation (5) predicts negative growth rates of forest area for low income countries, which increase and become positive at higher income, and decrease progressively to zero at the highest income levels. For each country, α_{i0} was calibrated such that in the base year (2014) equation (5) predicted the observed forest area growth rate, g^a_{it}, given the observed level of income per capita, $(Y/N)_{it}$.

The annual rate of change of biomass stock due to tree growth and mortality is inversely related to the forest density (residual stock level, S_{it}, per unit area, A_{it}), according to the equation (Buongiorno, 2015):

$$g^u_{it} = \gamma_{i0} \left(\frac{S_{it}}{A_{it}} \right)^{\sigma}, \tag{6}$$

where σ is a constant elasticity estimated at -0.45 (SE ± 0.12) and γ_{i0} was such that in the base year 2014 the observed growth rate, g^u_{it}, was equal to the growth rate predicted by equation (6). As specified, stock growth per unit area, whose rate is quantified by the latest changes reported by FAO and already contains the effects of recent changes in climate, is assumed to not be additionally affected by continued climate change throughout the projection.

2.3 Forest Sector Emissions

To calculate forest sector carbon flux, we followed the IPCC's Stock-Change Approach which estimates changes in carbon stock in forests of the country in which the wood is grown (i.e., producing country). Changes in the products pool are reported by the country where the products are used (i.e., consuming country). This approach enables a comprehensive temporal estimate of country specific forest carbon flux. Consistent with the GFPM data base, the historical carbon fluxes were estimated for the period from 1992 to 2014, and then projections were made from 2014 to 2065.

In each country the forest carbon pool was broken down into four categories; (i) biomass carbon (above-ground and below-ground), (ii) soil carbon, (iii)

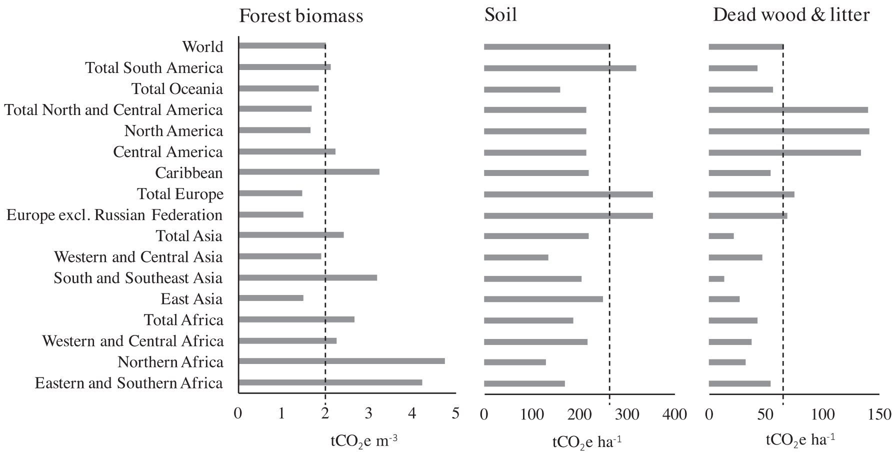

Figure 1: Regional aggregates of emissions factors for forest biomass (above & below ground), soil, and dead wood & litter based upon 180 country-level observations. Data calculated by authors for the year 2010, based on FAO's Forest Resource Assessment FAO (2015).

dead wood and litter (DWL) carbon, and (iv) harvested wood products (HWP) carbon. Changes in forest carbon storage depended on the endogenously determined timber harvest, wood product consumption, evolving forest biomass stock, and forest area changes, ultimately driven by the exogenous changes in population and gross domestic product as projected by IPCC-SSP2.

Annual forest biomass carbon flux was related to changes in biomass stock due to tree growth, mortality, and timber harvests:

$$\Delta c_{it}^{f} = (S_{i,t+1} - S_{it})\phi_i^f, \quad \text{for } f = \text{biomass carbon}, \tag{7}$$

and c_{it}^{f} is the biomass carbon stock, in country i and year t. The regional emission factors[2] is given by ϕ_i^f, where $f \in$ (biomass, soil, dead wood and litter, harvested wood products) as presented as regional aggregates in Figure 1.

Annual changes in the carbon stored in soil and dead wood litter depended on changes in forest area according to the equation:

$$\Delta c_{it}^{f} = (A_{i,t+1} - A_{it})\phi_i^f, \quad \text{for } f = \text{soil, DWL}. \tag{8}$$

[2]Data calculated by authors for the year 2015, based on FAO's Forest Resource Assessment FAO (2015). Regional aggregates of emissions factors for forest biomass (above & below ground), soil, and dead wood & litter are based upon 180 country-level observations, from FAO's Forest Resource Assessment FAO (2015). Above & below ground biomass carbon relied on the reported carbon stock in each respective pool (tonnes), divided by the forest growing stock (m^3). Similarly, in any given country, the forest carbon stock (tonnes) in dead wood, litter, and soil was divided by the forest area (ha). Lastly, where information was insufficient to calculate a regional emissions factor for a given country, it was set to the continental, or sub-continental average for the same year.

The annual change in the carbon stored in harvested wood products was determined by:

$$\Delta c_{it}^{f} = \sum_{j} (\phi_{i,t+1}^{j} - \phi_{it}^{j}), \quad \text{for } f = \text{HWP}, \ \forall j, \tag{9}$$

and $j \in$(other industrial roundwood, sawnwood, structural panels, non-structural panels, paper and paperboard).

Consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[3], the CO_2e stock of the j^{th} harvested wood products pool at the beginning of year t expanded as new products are consumed, and contracted as existing products decayed according to the following equation:

$$\phi_{i,t+1}^{j} = e^{-k}\phi_{it}^{j} + \left[\frac{(1 - e^{-k})}{k}\right] inflow_{it}^{j}, \quad \forall j, \tag{10}$$

where ϕ_t^j was the carbon stored in harvested wood product j in year t, k was a first-order annualized decay constant ($k = ln(2)/HL^j$), and HL^j was product j's half-life (Table 1). Following the IPCCs "product in use" Tier 1 approach for dealing with harvested wood products, the carbon inflow into the j^{th} carbon pool at time t in country i was set equal to the annual apparent consumption defined as domestic production (P) plus imports (IM) minus exports (EX), converted to air dry tonnes of carbon with a carbon factor η^j (Table 1), and converted to tCO_2e with the atomic weight adjustment factor of 44 g of CO_2 per 12 g of carbon:

$$inflow_{it}^{j} = \eta^{j}(P_{it}^{j} + IM_{it}^{j} - EX_{it}^{j})(44/12), \quad \forall j. \tag{11}$$

As recommended by IPCC guidelines, the residual carbon pool in 1992 of products consumed in 1900 was assumed to be nil (i.e., $\phi_{i,1900}^{j} = 0$). Furthermore, since global consumption data were only available for 1961 to 2015 from the FAOSTAT database (FAO, 2017), the last reported data of 1961 were used to back cast the consumption series from 1991 to 1900 (assuming that changes in consumption prior to 1961 were made at the same rate as changes in industrial roundwood production) in order to estimate the carbon pool in harvested wood products with equations (10 and 11) from 1992 to 2014 and then project them from 2014 to 2065 based on the GFPM forecasts of end products consumption.

In sum, the global annual total forest carbon flux in year t was given by:

$$F_t = \sum_{f}\sum_{i} \Delta c_{it}^{f}, \tag{12}$$

[3]Chapter 12 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf).

Table 1: Forest product half-life's, and factors to convert from product units to carbon.

Product j			
Other industrial roundwood, Sawnwood	Structural panels	Non-structural panels	Paper & paperboard
Half-life in use (years); HL^j			
35	30	20	2
Carbon factor ($tC\ m^{-3}$); η^j			
0.225	0.294	0.294	0.450[1]

[1] tC (*air-dry tonne*)$^{-1}$; tC = tonne of carbon.
Data are default recommendations from *IPCC report on GPG- LULUCF (IPCC, 2006)*

for the historical years $t = 1992$ to 2014 and the GFPM projections from 2015 to 2065.

3 Results

The GFPM was used to forecast changes in the global forest sector up to 2065 for 180 individual countries assuming *middle of the road* economic and demographic development consistent with the IPCC-SSP2 scenario. The results depicted the evolution of forest area, stock, and estimated carbon sequestration in the 4 carbon pools; (i) above and below ground biomass carbon, (ii) forest soil carbon, (iii) dead wood and litter carbon, and (iv) harvested wood product carbon. The following results are summarized by major geographic region, with more detailed country level information provided in Appendix Tables A1 to A5.

3.1 Forest Area and Forest Biomass

From 1992 to 2010, the world's forests contracted in size by 116 million ha, and over 6 million m^3 in volume (Figure 2). According to the GFPM, deforestation continued to prevail through 2030, with an additional global forest area loss of about 50 million ha, averaging 3.3 million ha annually. After this period, reinvestments in forest land drove global forest area to return to its 2010 level by 2050, and continued to rise thereafter.

Historically, South America and Africa have experienced the highest levels of deforestation, but this trend was projected to subside over time. South America lost an additional 27 million ha of forests by 2065, primarily in Brazil, and to a lesser extent, Argentina (Table A1). While South America began transitioning land back into forestry by 2045, it took Africa until after 2065 (Figure 3b). During this period, Africa continued losing forest area at an average rate of 1.5 million ha per year.

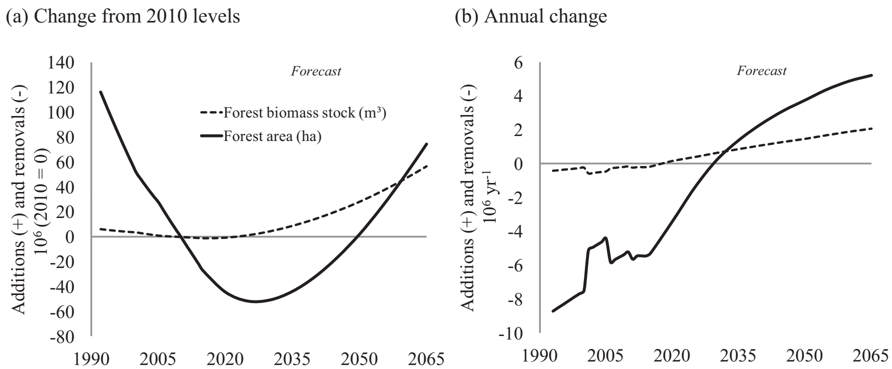

Figure 2: Past and projected global forest biomass stock and area. Historical data (1992–2014) derived from FAO Forest Resource Assessments (FAO 1995 to FAO 2015) and GFPM projections from 2014 to 2065.

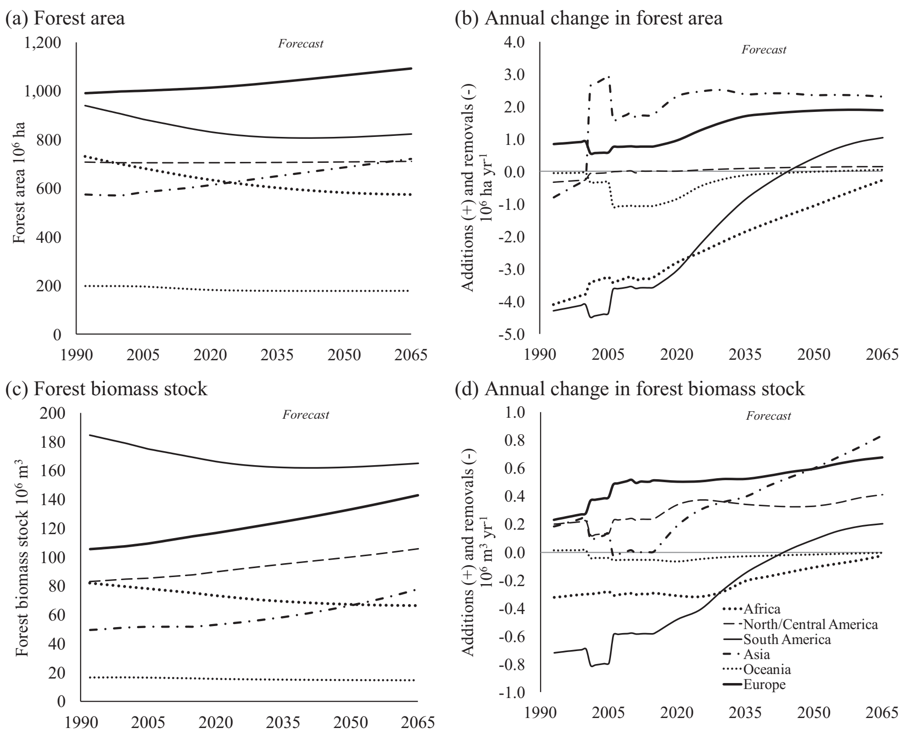

Figure 3: Past and projected regional forest area (a), annual change in forest area (b), forest biomass stock (c), and annual change in forest biomass stock (d). Historical data 1992–2014 derived from FAO Forest Resource Assessments (FAO 1995 to FAO 2015), and GFPM projections from 2014 to 2065.

Oceania was projected to experience modest losses in forest area over the next decade concentrated primarily in Australia, while forest land remained stable in North America through 2065. Meanwhile, forest area continued to expand in Europe, and for the most part, within Russia. During the last two decades, Asia has transitioned from experiencing annual forest losses, to significant gains. From 1992 to 2014, China added 57 million ha of forest land. This trend continued in the future as Asia added an additional 121 million ha of forests in the subsequent 50 years, with 83% of growth occurring in China.

Global forest biomass has declined by over 7 million m^3 since 1992, primarily due to extensive harvesting of timber and land conversion in South America and Africa. The biomass stock in Brazil decreased by 12 million m^3, or about 530 thousand m^3 annually from 1992 to 2014. While this trend started to reverse by around 2040, Brazil was still expected to end up with 2 million m^3less of growing stock in 2065 compared to 2014.

In contrast, North America, Asia, and Europe continued to experience increases in forest biomass stocks through 2065. The United States expanded its stock by 19.5 million m^3, while there was a modest decrease in Canada. China's vast expansions in forest are a resulted in an increase in growing stock biomass of 18.7 million m^3 by 2065. Most other Asian countries experienced minor additions to their growing stock during this period, with the exception of Indonesia where it decreased by2.7 million m^3 from 2014 to 2065. All of Europe experienced a rise in forest biomass over the next 50 years. These regional changes in forest area and forest stock, summarized in Figure 3, were the main drivers in the past and future evolution of carbon emissions in the forest sector.

3.2 Changes in Forest Biomass Carbon

The annual additions or removals of carbon from the above and below ground biomass pool are shown in Figure 4(a) by major geographic region. They resulted from the emissions factors in Figure 1, and the annual changes in forest biomass stock in Figure 3(d). Due to data availability, annual changes begin in 1992 (i.e., change in value from 1992 to 1993). From 1992 to 2014, the global forest biomass, above and below ground, was a net source of CO_2e emissions, but emissions decreased from 1.7 to 1.4 GtCO_2e yr^{-1} (Figure 5(a)). According to the GFPM projections, the emissions from above and below ground forest biomass continued to decrease in the future, and by 2030 it became a net global sink of 0.9 GtCO_2e yr^{-1}, increasing to 4.9 GtCO_2e yr^{-1} by 2065. There were however significant differences in the levels of emissions and their trends across regions (Figure 4(a)) and countries (Table A2).

Historically, South America has been the largest source of emissions from above and below ground forest biomass due to high levels of deforestation,

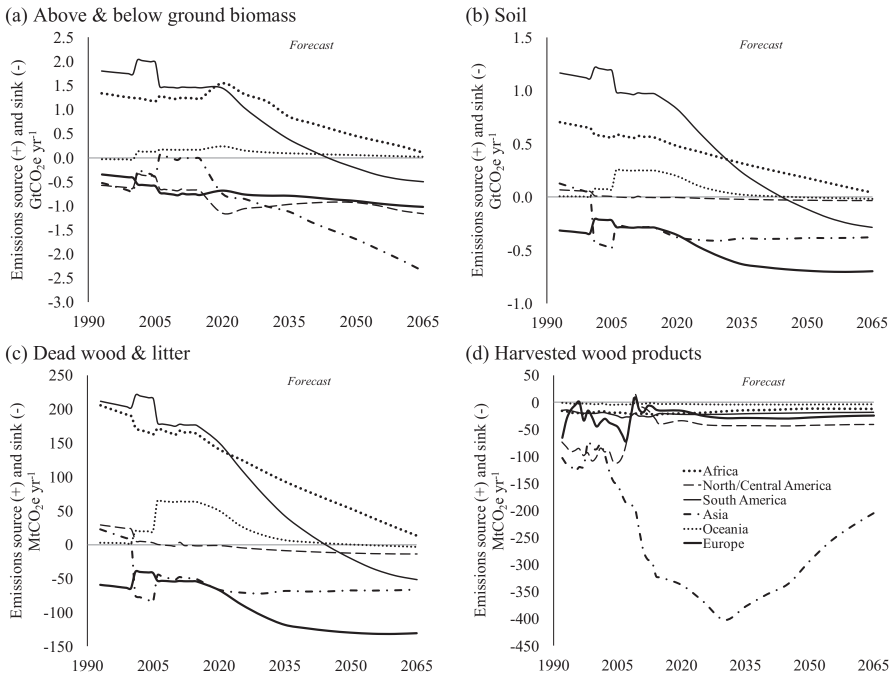

Figure 4: Past and projected regional CO_2e emissions from above & below ground forest biomass (a), soil (b), dead wood & litter (c), and harvested wood products (d). Calculated by authors based on historical data in FAO Forest Resources Assessments (FAO 1995 to FAO 2017), FAOSTAT (FAO 2017) and GFPM projections.

resulting in annual emission of 1.8 $GtCO_2e\ yr^{-1}$ in 1992. With slower rates of deforestation projected with the GFPM (Figure 3), South America's above and below ground forest biomass became a net carbon sink by 2040. Still, Asia became the principal above and below ground biomass carbon sink after 2030, driven by large increases in forest area and growing stock. By 2065, China alone sequestered nearly 0.8 Gt of CO_2e per year (Table A2).

3.3 Changes in Carbon in Forest Soils, Dead Wood and Litter

The carbon stored in forest soil, and dead wood and litter, changed according to changes in forest area (Figure 3(b)) and the emission factors associated with these two carbon pools (Figure 1). The results showed that due to reductions in the rate of deforestation, the global change of CO_2 einforest soils decreased from 1.8 $GtCO_2e\ yr^{-1}$ in 1992, to 1.2 $GtCO_2e\ yr^{-1}$ in 2014 (Figure 5a). By 2065, forest soils became a net carbon sink of 1.4 $GtCO_2e\ yr^{-1}$.

The carbon stored in dead wood and litter followed a similar path, although smaller in magnitude, moving from a net source of 0.4 $GtCO_2e\ yr^{-1}$ in 1992 to a net sink of 0.3 $GtCO_2e\ yr^{-1}$ by 2065. However, as shown in Figure 4 and Table A3, there were large differences in the levels and trends of the changes between regions and countries.

South America has been historically a major source of carbon emissions from forest soils and dead wood and litter, due primarily to forest area losses in Brazil. In 1992, South America lost 1.2 $GtCO_2e\ yr^{-1}$ from forest soils (Table A2), and 0.2 $GtCO_2e\ yr^{-1}$ from dead wood and litter (Table A3). According to projections, both carbon pools became neutral by 2040, and by 2065 they were carbon sinks of 0.3 $GtCO_2e\ yr^{-1}$ in soils and of 0.05 $GtCO_2e\ yr^{-1}$ in dead wood and litter. Africa has also experienced high levels of deforestation leading to losses of carbon stored in forest soils, deadwood and litter. The change in carbon stored in African forest soils which slowly declined from 0.7 $GtCO_2e\ yr^{-1}$ in 1992, to 0.6$GtCO_2e\ yr^{-1}$ in 2014, was projected to continue decreasing past 2065. Due to investments in forest land in Asia, the amount of carbon stored in forest soils has increased at an average rate of 0.2 $GtCO_2e\ yr^{-1}$ from 1992 to 2014. Driven by expanding forest land in France, Germany, Italy, and Russia, Europe is projected to continue on its historical trend of sequestering 0.6 $GtCO_2e\ yr^{-1}$ in soil from 2015 to 2065. Similar trends were projected for dead wood and litter, with Europe storing an estimated 0.1 $GtCO_2e\ yr^{-1}$ during this period.

3.4 Changes in Carbon in Harvested Wood Products

Harvested wood products represent a minor part of the total forest sector sequestration potential (Figure 5(a)). The results suggested that the HWP added 0.3 $GtCO_2e\ yr^{-1}$ to the carbon pool in 1992, increasing to 0.4 $GtCO_2e\ yr^{-1}$ in 2014. The annual removal of atmospheric carbon through the HWP pool peaked globally in 2030 at 0.5 $GtCO_2e\ yr^{-1}$ (Figure 4(d)), driven by the expansion of wood product consumption in China and India (Tables A5

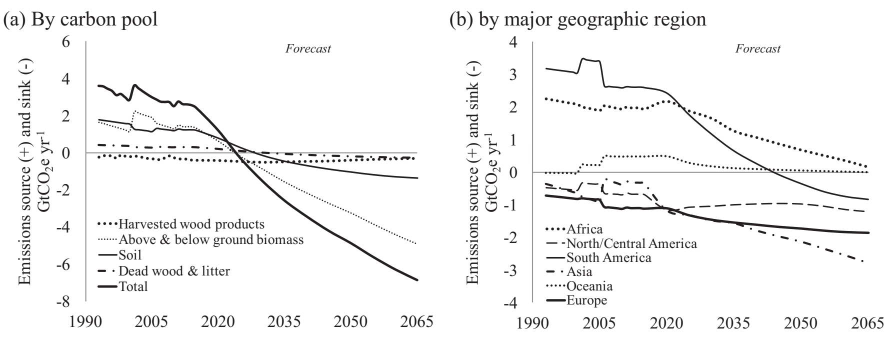

Figure 5: Past and projected forest sector emissions, by carbon pool in the world (a), and in total by region (b). Calculated by authors based on historical data in FAO Forest Resources Assessments (FAO 1995 to FAO 2017), FAOSTAT (FAO 2017), and GFPM projections.

and A6). As the annual rate of consumption growth in Asia decreased after 2030, the decay of previously installed wood products, such as lumber in houses, caused the rate of annual carbon storage in the HWP pool to begin to slow down towards 2065.

The volatility observed in historical HWP carbon sequestration data for North/Central America, and to a lesser extent Europe (Figure 4(d)), was a consequence of the economic recession of 2008–2009. When the sharp drop in consumption caused the carbon stored in newly consumed wood products to be insufficient to offset the decay of previously installed products. Consequently, 2009 was the only year in which harvested wood products were a net source of carbon emissions in North/Central America, and Europe. Based on the GFPM projections conditional on the IPCC-SSP2 economic scenario this pool continued to be a minor carbon sink globally until 2065 (Figure 4(d)).

3.5 Comparison with Other Studies

Although there are few forecasts of carbon sequestration and emissions for the global forest sector, other studies have made an assessment of past levels and trends. These include the latest UNFCCC country reports (UNFCCC, 2017), the FAOSTAT for forest land (FAO, 2017), the IPCC Fifth Assessment Report (AR5) Working Groups (WG) I and III data (IPCC 2013, 2014), and Grassi *et al.* (2017) who also provide a complete review of the available data.

Figure 6 shows how the historical data in previous reports differed from those presented above. While all the data showed similar trends between 1992 and 2010, there were large differences in levels. We estimated that net forest emissions averaged 3.11 (SE $\pm$ 0.33) $GtCO_2e\ yr^{-1}$ between 1992 and 2010, while the IPCC AR5 reports higher (but not significantly different given the standard errors) average emissions of 4.43 (SE $\pm$ 0.92) $GtCO_2e\ yr^{-1}$. The

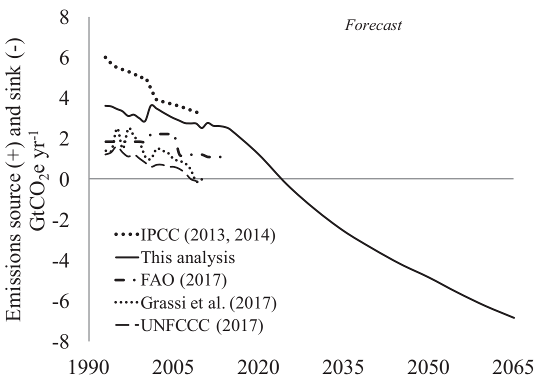

Figure 6: Global forest sector emissions estimated in this study and previous reports.

IPCC AR5 report on emissions through a similar book keeping method based on changes in land cover, forest growth, and some forms of management, but has been criticized for the inconsistent treatment of forest area across countries as well as limitations associated with having to reconcile its data with its own global CO_2 emission estimates (Grassi *et al.*, 2017). The FAOSTAT forest land emissions dataset estimates net carbon stock changes in above and below ground biomass, and forest land converted to other land uses, concluding that net forest emissions average 1.75 ± 0.39 $GtCO_2e\ yr^{-1}$ between 1992 and 2010. This is less than the present study as expected due to the narrower coverage of forest carbon pools, and is not entirely consistent with the implied emissions factors reported by the FAO FRA (2015) used in this study.

The data sets reported by the UNFCCC and Grassi *et al.* (2017) rely on country level reporting. Between 1992 and 2010, the UNFCCC finds that net forest emissions average 0.73 ± 0.51 $GtCO_2e\ yr^{-1}$, while Grassi *et al.* (2017) estimate 1.28 ± 1.15 $GtCO_2e\ yr^{-1}$. Both are less than the present study and significantly so, statistically. However, these low estimates rely on selected countries who self-report land use and forestry related emissions. The latter analyse 68 countries, covering 83% of the global forest area and only 78% of their emissions, while many countries carbon flux was assumed to be zero (Grassi *et al.*, 2017). Beyond the scope of coverage, the higher estimates in this study are also attributable to higher forest land-use emissions provided by FAOSTAT, as compared to those employed in Grassi *et al.*, most notably in developing countries (e.g., Colombia, Liberia, Madagascar, Myanmar, Nigeria, Philippines, and Zimbabwe) and developed ones (e.g., United States and Russia). Furthermore, this study treats forest land based emissions as immediate removals from a forest accounting perspective, while Grassi *et al.* view forest land change as a transfer of carbon stock within the LULUCF sector, resulting in lower land based emission estimates.

3.6 Uncertainty in Future Projections

The results of this study are sensitive to a number of components that are still being debated in the literature. Land-use development assumptions influence projected emissions and mitigation potential for the land-use sector and thus contribute to the overall level of mitigation. Popp *et al.* (2017) predict that afforestation and reduced deforestation are sensitive to not only GDP and population, but also guided assumptions on regulations, demand, productivity, environmental impacts, trade and the degree of globalization of future agricultural and forestry markets. Under a middle-of-the-road SSP2 scenario, Popp *et al.* find that 601 million ha of global forest area were added by 2100 depending on the global climate target, while Fricko *et al.* (2017) predict global wood demand will double causing unmanaged forests and other natural land to be converted to actively managed forests or cropland by 2100.

Meanwhile, Riahi *et al.* (2017) predict that there will be a global loss of 50 to 300 million ha of forest area by 2100 under SSP2, as marginal forest lands are converted to agriculture.

There is increasing evidence that forest area expansion may be most significant under an aggressive climate policy (Popp *et al.*, 2017). Others have argued that the impacts of climate policy are less pronounced, but still noticeable. The demand for biomass based energy, for example, will certainly depend on future climate policy's, and could lead to an increase of land for bio-energy (van Vuuren *et al.*, 2017). At the same time, higher bio energy demand could lead to higher emissions from land use change (Rao *et al.*, 2017).

Additional uncertainty enters this framework through the rapidly expanding body of literature that investigates the inter-relationship between climate change and forest cover. Lindner *et al.* (2014) provide a review, and conclude that while atmospheric CO_2 levels have been increasing over the last century, it remains unclear the degree with which increased CO_2 fertilization affects forest growth and productivity over a long-time horizon. There is also evidence of a circular effect whereby land cover change influences surface air temperature. Alkama and Cescatti (2016) argue that deforestation and afforestation may affect air surface temperatures, which is most pronounced in arid zones, followed by temperate, tropical and boreal. Recent work by Duveiller *et al.* (2018) argue that changes in vegetation cover may lead to net cooling or warming, depending on where the land use change occurs, and whether albedo or evapotranspiration dominate. While there is indeed a relationship between the climate change and forest cover, there is increasing evidence that it is spatially dependent phenomena which is still being debated, and for these reasons, these effects were not considered in the current study.

4 Conclusion

This study estimated the carbon mitigating potential of the world's forests from 1992 to 2065 for 180 individual countries. Results suggested that the forest sector was a net carbon source of approximately 3.6 $GtCO_2e\ yr^{-1}$ in 1992, that decreased to 2.4 $GtCO_2e\ yr^{-1}$ in 2014 (slope of linear trend: -0.05 $GtCO_2e\ yr^{-1}$). Based on projections of area change, forest growth, and production and consumption of forest products obtained with the Global Forest Products Model the world forest sector achieved a net zero carbon balance by the year 2025, it then became a net carbon sink of 1.5 $GtCO_2e\ yr^{-1}$ by 2030, and of 6.8 $GtCO_2e\ yr^{-1}$ by 2065. This analysis appears to fall within the range of previous global datasets for the historical period of 1992 to 2010, although discrepancies seem to be explained, to some extent, by methodological differences and scope of coverage.

Global climate change agreements are moving towards more reliance on forestry to reduce atmospheric CO_2 levels. The 2005 UNFCCC accord for reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (collectively referred to as REDD+) calls for reducing net emissions of greenhouse gases through enhanced forest management in developing countries. In December 2015, at the twenty-first conference of Parties (COP-21), 195 countries ratified the Paris Agreement, strengthening the actions and investments needed to combat climate change. Article 4, paragraph 1(d) of the Convention encourages all parties to conserve and enhances inks and reservoirs of greenhouse gases, including forests, and to take advantage of REDD+ carbon benefits.

The benefits a country receives from reduced forest sector related emissions under the Paris Agreement depend on the estimation of a credible baseline. Countries argue for carbon benefits associated with their Intended Nationally Determined Contributions compared to a business as usual (BAU) baseline. The determination of an accurate emissions baseline in each country is therefore critical for international equity and for achieving a real decrease in atmospheric emissions through forestry. Currently, an acceptable approach for countries that do not report a baseline is a linear extrapolation from recent trends in forest sector emissions.

This analysis provided a new approach to estimate country level BAU baselines, but it also highlighted the discrepancies that may arise due to different methods and data even in the assessment of historical forest sector emissions, let alone in their projections. By providing a future projection of global forest-sector carbon sequestration/emissions, which was lacking so far, this study not only fills an important gap in the global forest sector carbon literature but also reinforces previous findings suggesting that forest sector can play a major role in reducing global CO_2 emissions.

It is clear, however, that more work is needed to clarify definitions, improve data collection, and define plausible future socioeconomic development storylines and data. The simulations we report do not include explicit representations of forest sector policies that may be embodied in plausible future storylines including land use, carbon pricing, taxes, and technological change. While some of the land use and policy related changes are already embodied in the IPCC-SSP2 income and population growth projections that we model, or are contained in the forest area dynamics that are included in the GFPM, we defer specific treatment of these factors to subsequent analyses. In addition, continued research is needed to better understand, country by country, how net forest growth rates may be affected by climate change, as these net growth rates are likely to interact with country and international markets in ways that could add to or subtract from global forest sector related carbon emissions. Furthermore, as fast-growing planted forest growing technologies advance and becomes more widespread, there is added potential to affect timber product markets, potentially altering assessments of the role of forests in affecting atmospheric carbon.

A Appendix

Table A1: Historical and projected annual changes in forest biomass stock and area for select regions and countries. Historical data derived from FAO Forest Resource Assessments (FAO 1995 to FAO 2015) and projections from the GFPM.

	Change in:					
	Forest Stock (10^6 m^3 yr^{-1})			Forest Area (10^3 ha yr^{-1})		
	1992	2014	2065	1992	2014	2065
AFRICA	**−322.0**	**−298.0**	**−24.4**	**−4104.0**	**−3307.0**	**−263.2**
Egypt	0.2	0.0	0.2	1.0	1.0	1.0
Nigeria	−53.1	−48.7	0.0	−437.0	−401.0	−23.2
South Africa	0.0	0.0	17.0	0.0	0.0	32.1
NORTH/CENTRAL AMERICA	**201.0**	**235.0**	**408.8**	**−332.0**	**15.0**	**156.8**
Canada	7.8	−53.6	−16.7	0.0	0.0	5.7
Mexico	−10.6	−9.3	6.7	−359.0	−155.0	110.3
United States of America	251.5	331.4	388.1	385.0	383.0	12.9
SOUTH AMERICA	**−721.0**	**−585.0**	**200.8**	**−4282.0**	**−3573.0**	**1053.0**
Argentina	−17.3	−15.5	0.3	−300.0	−239.0	2.9
Brazil	−573.5	−431.5	167.1	−2927.0	−2190.0	523.9
Chile	7.5	4.9	−12.4	57.0	38.0	30.0
ASIA	**184.0**	**1.0**	**830.0**	**−788.0**	**1720.0**	**2306.0**
China	199.0	191.1	524.1	1927.0	2782.0	1144.0
India	29.7	73.0	153.9	144.0	145.0	471.1
Indonesia	−102.3	−221.3	−24.6	−1997.0	−683.0	193.4
Japan	−0.7	0.9	0.5	−7.0	9.0	3.6
Korea, Republic of	14.2	20.2	86.7	−8.0	−7.0	0.6
Malaysia	91.5	−39.4	52.9	−79.0	−86.0	18.8
OCEANIA	**13.0**	**−56.0**	**−5.2**	**−40.0**	**−1069.0**	**62.4**
Australia	2.7	−58.2	0.1	42.0	−921.0	−2.8
New Zealand	23.3	16.1	−6.8	54.0	−8.0	0.1
EUROPE	**228.0**	**500.0**	**673.2**	**849.0**	**773.0**	**1883.8**
Austria	10.1	−3.5	5.6	6.0	5.0	0.7
Finland	20.7	0.0	−2.2	57.0	0.0	0.4
France	17.6	18.5	44.1	80.0	48.0	0.3
Germany	50.1	61.2	83.6	33.0	0.0	0.8
Italy	21.6	23.0	34.6	76.0	79.0	0.4
Russian Federation	−87.3	145.6	108.7	32.0	60.0	1488.9
Spain	21.3	9.6	8.5	301.0	177.0	7.8
Sweden	1.3	19.3	−3.4	11.0	0.0	0.0
United Kingdom	−0.3	4.5	1.1	18.0	7.0	0.0
WORLD	**−417.0**	**−203.0**	**2083.0**	**−8697.0**	**−5441.0**	**5199.0**

Table A2: Historical and projected annual changes in carbon sequestered in forest biomass and forest soil for select regions and countries. Historical data derived from FAO Forest Resource Assessments (FAO 1995 to FAO 2015) and projections based on the GFPM.

	Change in:					
	Above & below ground biomass (10^3 tCO_2e yr^{-1})			Soil (10^3 tCO_2e yr^{-1})		
	1992	2014	2065	1992	2014	2065
AFRICA	**1333.3**	**1233.9**	**101.0**	**701.2**	**565.1**	**45.0**
Egypt	−0.6	0.0	−0.5	−0.2	−0.2	−0.1
Nigeria	173.7	159.2	0.0	75.2	69.0	4.0
South Africa	0.0	0.0	−75.2	0.0	0.0	−7.4
NORTH/CENTRAL AMERICA	**−572.3**	**−669.1**	**−1163.9**	**69.1**	**−3.1**	**−32.6**
Canada	−12.9	88.4	27.6	0.0	0.0	−1.2
Mexico	16.4	14.3	−10.4	76.9	33.2	−23.6
United States of America	−392.7	−517.4	−605.9	−77.2	−76.8	−2.6
SOUTH AMERICA	**1797.8**	**1458.7**	**−500.6**	**1167.6**	**974.2**	**−287.1**
Argentina	71.5	64.1	−1.3	52.2	41.6	−0.5
Brazil	1287.2	968.5	−375.0	458.1	342.7	−82.0
Chile	−12.4	−8.1	20.5	−10.5	−7.0	−5.5
ASIA	**−521.5**	**−2.8**	**−2352.2**	**129.0**	**−281.6**	**−377.6**
China	−309.4	−297.2	−815.0	−480.5	−693.6	−285.2
India	−55.8	−137.2	−289.2	−29.5	−29.7	−96.5
Indonesia	458.1	990.9	110.2	406.4	139.0	−39.4
Japan	1.1	−1.3	−0.7	1.7	−2.2	−0.9
Korea, Republic of	−23.7	−33.8	−145.2	2.0	1.7	−0.1
Malaysia	−185.7	80.0	−107.5	0.0	0.0	0.0
OCEANIA	**−37.2**	**160.2**	**14.9**	**9.4**	**252.0**	**−14.7**
Australia	−5.0	108.8	−0.2	−6.7	145.9	0.4
New Zealand	−29.8	−20.6	8.6	−18.9	2.8	0.0
EUROPE	**−349.3**	**−766.0**	**−1031.4**	**−314.9**	**−286.7**	**−698.7**
Austria	−12.6	4.3	−7.0	−2.1	−1.8	−0.3
Finland	−25.6	0.0	2.7	−38.2	0.0	−0.3
France	−30.0	−31.5	−75.1	−28.5	−17.1	−0.1
Germany	−59.6	−72.8	−99.5	−8.1	0.0	−0.2
Italy	−36.6	−39.1	−58.7	−22.8	−23.7	−0.1
Russian Federation	128.8	−214.9	−160.4	−11.2	−21.1	−522.5
Spain	−39.2	−17.6	−15.7	−34.5	−20.3	−0.9
Sweden	−1.8	−26.4	4.7	−2.7	0.0	0.0
United Kingdom	0.4	−6.0	−1.5	−15.5	−6.0	0.0
WORLD	**1650.9**	**1414.9**	**−4932.2**	**1761.4**	**1219.8**	**−1365.7**

Table A3: Historical and projected annual changes in carbon sequestered in dead wood & litter, and harvested wood products for select regions and countries. Historical data derived from FAO Forest Resource Assessments (FAO 1995 to FAO 2015) and projections based on the GFPM.

	Change in:					
	Dead wood & litter (10^3 tCO_2e yr^{-1})			Harvested wood products (10^3 tCO_2e yr^{-1})		
	1992	2014	2065	1992	2014	2065
AFRICA	**205.2**	**165.4**	**13.2**	**−16.8**	**−23.9**	**−12.6**
Egypt	0.0	0.0	0.0	−0.9	−4.6	−3.8
Nigeria	30.7	28.2	1.6	−2.3	−1.6	−0.1
South Africa	0.0	0.0	−1.7	0.0	0.2	−1.0
NORTH/CENTRAL AMERICA	**28.7**	**−1.3**	**−13.5**	**−82.4**	**−32.3**	**−41.2**
Canada	0.0	0.0	−0.8	−7.4	−6.7	−6.5
Mexico	48.2	20.8	−14.8	−2.2	−3.8	−3.4
United States of America	−31.6	−31.5	−1.1	−71.1	−20.8	−30.4
SOUTH AMERICA	**211.2**	**176.2**	**−51.9**	**−14.5**	**−23.1**	**−18.8**
Argentina	12.8	10.2	−0.1	−0.9	−1.2	−1.5
Brazil	42.2	31.6	−7.6	−10.4	−12.9	−11.2
Chile	−4.0	−2.6	−2.1	−2.0	−3.6	−2.1
ASIA	**22.7**	**−49.5**	**−66.3**	**−114.7**	**−321.7**	**−204.7**
China	−50.9	−73.4	−30.2	−52.6	−264.0	−148.6
India	−1.2	−1.2	−3.9	−14.5	−8.3	−11.4
Indonesia	26.4	9.0	−2.6	−6.8	−7.8	−9.9
Japan	0.2	−0.2	−0.1	−15.6	9.0	2.8
Korea, Republic of	0.2	0.2	0.0	−4.0	−4.6	−0.8
Malaysia	0.6	0.7	−0.1	−4.6	−3.5	−3.3
OCEANIA	**2.4**	**63.5**	**−3.7**	**−2.0**	**−2.8**	**−3.8**
Australia	−2.4	51.7	0.2	−1.3	−1.2	−2.4
New Zealand	−6.6	1.0	0.0	−0.4	−1.3	−1.1
EUROPE	**−58.9**	**−53.6**	**−130.7**	**−31.6**	**−14.0**	**−24.8**
Austria	−0.4	−0.3	0.0	−2.2	−1.6	−1.0
Finland	−2.5	0.0	0.0	0.3	0.3	−0.5
France	−5.5	−3.3	0.0	−3.0	0.3	−3.2
Germany	−2.4	0.0	−0.1	−5.0	−4.9	−2.8
Italy	−1.8	−1.8	0.0	−4.8	−0.3	−2.1
Russian Federation	−2.5	−4.6	−114.6	1.6	12.7	4.5
Spain	−20.5	−12.1	−0.5	−3.3	0.8	−1.0
Sweden	−0.9	0.0	0.0	−1.1	−2.3	−2.4
United Kingdom	−1.1	−0.4	0.0	−5.4	−3.4	−5.6
WORLD	**411.2**	**300.7**	**−253.0**	**−261.9**	**−417.7**	**−305.9**

Table A4: Historical and projected annual changes in production of fuel wood and industrial roundwood for select regions and countries. Historical data from FAO (2017) projections from GFPM.

	Change in:					
	Fuelwood (10^3 m^3 yr^{-1})			Industrial roundwood (10^3 m^3 yr^{-1})		
	1992	2014	2065	1992	2014	2065
AFRICA	**90127.0**	**7232.0**	**−3776.6**	**2909.0**	**1070.0**	**229.8**
Egypt	331.0	47.0	52.0	2.0	0.0	2.9
Nigeria	1177.0	429.0	0.0	0.0	604.0	0.0
South Africa	400.0	24.0	33.5	−119.0	−878.0	253.3
NORTH/CENTRAL AMERICA	**−10507.0**	**658.0**	**−29.4**	**4129.0**	**2825.0**	**−302.8**
Canada	35.0	314.0	−71.3	6263.0	1074.0	−870.6
Mexico	455.0	6.0	51.7	−1096.0	0.0	−16.7
United States of America	−11497.0	0.0	66.1	−1580.0	1875.0	575.2
SOUTH AMERICA	**1198.0**	**447.0**	**217.4**	**715.0**	**−4476.0**	**−185.2**
Argentina	−410.0	−186.0	5.2	−968.0	−2725.0	3.3
Brazil	1085.0	0.0	176.0	2086.0	−4949.0	163.4
Chile	305.0	0.0	4.0	1177.0	1522.0	−369.9
ASIA	**−9609.0**	**−6104.0**	**−776.4**	**−1294.0**	**−585.0**	**434.2**
China	−8927.0	−3213.0	199.4	5911.0	−6186.0	92.2
India	2767.0	−536.0	−322.4	613.0	0.0	1013.1
Indonesia	−4967.0	−2213.0	46.8	975.0	0.0	−502.1
Japan	−24.0	−4.0	0.0	−1544.0	201.0	−174.2
Korea, Republic of	−53.0	265.0	1.9	61.0	17.0	118.8
Malaysia	−87.0	−45.0	5.1	−7034.0	1038.0	109.6
OCEANIA	**232.0**	**1.0**	**−10.0**	**2672.0**	**3044.0**	**−365.8**
Australia	231.0	0.0	5.0	1005.0	2688.0	−124.3
New Zealand	0.0	0.0	0.0	654.0	192.0	−203.8
EUROPE	**−25546.0**	**1854.0**	**331.4**	**−14746.0**	**21796.0**	**4712.6**
Austria	155.0	102.0	−15.5	−147.0	−403.0	26.9
Finland	1283.0	172.0	4.0	2479.0	−129.0	−85.0
France	−1231.0	191.0	52.8	−2689.0	1299.0	238.7
Germany	0.0	−41.0	22.6	198.0	1191.0	581.3
Italy	−134.0	−161.0	22.7	595.0	51.0	30.6
Russian Federation	−25300.0	618.0	10.6	−27970.0	7921.0	2575.9
Spain	38.0	274.0	4.4	−195.0	562.0	24.0
Sweden	0.0	0.0	−39.6	480.0	3700.0	−115.7
United Kingdom	5.0	245.0	0.0	298.0	118.0	−99.6
WORLD	**45895.0**	**4088.0**	**−4043.2**	**−5615.0**	**23674.0**	**4522.8**

Table A5: Historical and projected annual changes in consumption of sawnwood, and plywood and veneer sheets for select regions and countries. Historical data from FAO (2017). projections from GFPM.

	Change in:					
	Sawnwood (10^3 m^3 yr^{-1})			Plywood + Veneer Sheets (10^3 m^3 yr^{-1})		
	1992	2014	2065	1992	2014	2065
AFRICA	**−731.0**	**1807.0**	**131.8**	**−89.0**	**−41.0**	**123.8**
Egypt	−340.0	1187.0	52.6	−15.0	−80.0	18.5
Nigeria	1.0	−2.0	0.3	−8.0	−50.0	20.0
South Africa	−874.0	271.0	15.8	−32.0	−2.0	2.6
NORTH/CENTRAL AMERICA	**4035.0**	**5057.0**	**511.8**	**219.0**	**−36.0**	**143.2**
Canada	285.0	−917.0	53.3	10.0	−32.0	24.2
Mexico	563.0	11.0	26.9	125.0	−4.0	17.8
United States of America	2719.0	6100.0	421.3	32.0	4.0	92.4
SOUTH AMERICA	**−1052.0**	**−1156.0**	**141.2**	**−7.0**	**−126.0**	**68.2**
Argentina	−479.0	−864.0	17.1	2.0	1.0	1.4
Brazil	143.0	−434.0	102.3	83.0	−310.0	41.3
Chile	204.0	−176.0	−1.7	14.0	192.0	0.8
ASIA	**6912.0**	**7065.0**	**526.6**	**2149.0**	**11720.0**	**−2.8**
China	6621.0	8584.0	175.5	202.0	10673.0	−442.4
India	−10.0	4.0	65.4	1.0	26.0	156.7
Indonesia	−3.0	238.0	32.9	88.0	529.0	139.6
Japan	311.0	−1787.0	26.1	598.0	−85.0	−5.8
Korea, Republic of	137.0	185.0	5.3	174.0	−495.0	−2.3
Malaysia	−25.0	−318.0	17.3	974.0	557.0	25.5
OCEANIA	**304.0**	**706.0**	**39.0**	**−14.0**	**156.0**	**18.8**
Australia	161.0	282.0	26.9	13.0	33.0	5.6
New Zealand	210.0	414.0	10.3	11.0	119.0	8.5
EUROPE	**−17663.0**	**3453.0**	**370.6**	**−904.0**	**466.0**	**46.0**
Austria	−174.0	−177.0	15.5	−16.0	8.0	0.6
Finland	−289.0	169.0	14.6	−26.0	−16.0	1.6
France	−1500.0	−310.0	45.9	−162.0	39.0	7.6
Germany	−2150.0	−68.0	55.4	−105.0	27.0	3.9
Italy	−631.0	10.0	21.6	−19.0	55.0	2.6
Russian Federation	−12962.0	−301.0	16.1	−527.0	−105.0	1.9
Spain	−174.0	502.0	12.8	109.0	45.0	2.2
Sweden	−1183.0	669.0	30.6	−3.0	14.0	2.4
United Kingdom	−455.0	1081.0	53.6	−225.0	15.0	16.3
WORLD	**−8195.0**	**16932.0**	**1721.0**	**1354.0**	**12139.0**	**397.4**

Table A6: Historical and projected annual changes in consumption of non-structural panels, and paper and paperboard for select regions. Historical data from FAO (2017) projections from GFPM.

	Change in:					
	Non-structural panels (10^3 m^3 yr^{-1})			Paper & paperboard (10^3Mt yr^{-1})		
	1992	2014	2065	1992	2014	2065
AFRICA	**−211.0**	**277.0**	**114.8**	**32.0**	**475.0**	**184.0**
Egypt	4.0	62.0	13.1	15.0	94.0	33.4
Nigeria	−10.0	−11.0	33.8	−1.0	37.0	33.7
South Africa	−179.0	241.0	22.3	−90.0	−95.0	30.5
NORTH/CENTRAL AMERICA	**1232.0**	**1894.0**	**299.0**	**2976.0**	**1420.0**	**421.8**
Canada	−129.0	734.0	26.5	532.0	−576.0	31.7
Mexico	−11.0	−64.0	23.1	−193.0	103.0	18.8
United States of America	1385.0	1216.0	246.5	2730.0	1671.0	348.2
SOUTH AMERICA	**347.0**	**−343.0**	**214.2**	**263.0**	**205.0**	**220.4**
Argentina	373.0	−86.0	12.3	0.0	−63.0	18.1
Brazil	−45.0	−59.0	164.2	394.0	−22.0	98.4
Chile	54.0	−121.0	8.1	−26.0	−63.0	40.7
ASIA	**1921.0**	**2927.0**	**10.6**	**3381.0**	**6571.0**	**685.0**
China	1009.0	2390.0	−390.7	2444.0	2962.0	−101.4
India	−10.0	−77.0	29.7	124.0	2777.0	305.5
Indonesia	−80.0	−206.0	30.2	163.0	−113.0	123.0
Japan	481.0	−19.0	−3.1	−205.0	51.0	−1.9
Korea, Republic of	349.0	691.0	−11.9	183.0	101.0	−25.3
Malaysia	56.0	125.0	16.1	−246.0	−301.0	32.7
OCEANIA	**141.0**	**73.0**	**23.0**	**226.0**	**109.0**	**35.0**
Australia	127.0	30.0	19.6	188.0	33.0	29.8
New Zealand	22.0	43.0	2.7	25.0	50.0	4.2
EUROPE	**−813.0**	**1728.0**	**159.6**	**−1525.0**	**60.0**	**400.2**
Austria	−4.0	9.0	1.2	148.0	−107.0	4.0
Finland	−24.0	−45.0	2.0	132.0	−79.0	1.3
France	−130.0	−175.0	30.5	−101.0	54.0	70.0
Germany	461.0	278.0	16.2	−324.0	274.0	45.8
Italy	−307.0	526.0	9.4	−218.0	43.0	45.3
Russian Federation	−1032.0	−281.0	3.5	−2282.0	−93.0	5.0
Spain	−266.0	602.0	9.5	−189.0	−334.0	31.4
Sweden	3.0	−3.0	13.1	−20.0	127.0	10.7
United Kingdom	113.0	345.0	50.2	37.0	−1.0	101.8
WORLD	**2617.0**	**6556.0**	**820.6**	**5353.0**	**8840.0**	**1946.0**

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