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Research article

Projecting global planted forest area developments and the associated impacts on global forest product markets

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ABSTRACT

Planted forests are a rising share of total forests globally and an increasingly important source of timber product output, affecting national and global markets. We estimated econometric models of planted forest area by OECD and non-OECD country groups that control for economic, institutional and environmental policies likely to influence future changes in planted forest area. The models are then used to project planted forest area over next 55 years for 180 countries under five alternative scenarios of global socio-economic changes, represented in shared socioeconomic pathways (SSPs), adjunct products emerging from the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC). By embedding key features of the SSP projections into a global forest sector model, we evaluate how planted forests lead to different global forest product market outcomes for each SSP, compared to corresponding outcomes where planted forests are not considered separately. Projected global planted forest area in 2070 ranges from 379 million ha (Mha) for SSP3 (a relatively poor and unequal world) to 475 Mha under SSP5 (a relatively wealthier and more equal world), representing respective increases of 46% and 66% compared to 2015. SSPs with the highest planted forest area increases have the lowest product prices (down by 12% by 2070, compared to SSP5 without planted forests) and higher global forest products production and consumption quantities (by as much as 3.3% by 2070, compared to SSP5 without planted forests). However, production does not increase in all countries by similar amounts, due to changes in relative advantages in production brought about by reduced product prices.

1. Introduction

Planted forests, defined as forests predominantly composed of trees established through planting and/or deliberate seeding comprising both semi-natural forests and fast-growing plantations (FAO, 2015a), are increasingly considered as providing vital ecosystem services, such as clean air and water, and soil protection. According to one prevailing proposition, planted forests can reduce harvesting pressures on and help conserve natural forests essential for climate change mitigation, biodiversity conservation, and sustainable local livelihood (Sedjo and Botkin, 1997; Leslie, 2005; Bull et al., 2006). While this proposition can be contested (Baral et al., 2016; Pirard et al., 2016), it is apparent that, as planted forest become more widespread, their importance in global wood production, environmental services, and regional development will increase.

According to FAO (2015b), the area of planted forest has risen while that of natural forest has declined in recent decades. Planted forest area increased at an annual rate of about 4.4 million ha (Mha yr^{-1}), 1990 to 2015, while natural forest area declined at a rate of about 9.6 Mha yr^{-1} (Table S1). Although planted forests make up a small fraction of global forest area, they contribute substantially more than that fraction to global industrial roundwood production. As shown in Table S2, planted forests comprised about 7% of global forest area in 2015, but they provided 46% of global industrial roundwood in 2012 (Payn et al., 2015). Regionally, the share of planted forests in total forest area ranged from 2% (South America) to 22% (Asia) but their contribution in total roundwood production was higher, ranging from as low as 37% for Africa to as high as 90% for South America (Table S2). The greater share of removals from planted forests relative to natural forests is not unexpected, in part because the primary management objective of much of the planted forests is to produce timber products. Furthermore, planted forests tend to grow faster than natural forests, due to their

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intensive management. For instance, average productivity from planted forests during 1990–2015 was estimated to be more than 24 $m^3 ha^{-1} yr^{-1}$ in South America (Payn et al., 2015), compared to the estimated global average productivity of natural forests of 3 $m^3 ha^{-1} yr^{-1}$ or less (Paquette and Messier, 2010).

In theory, other factors remaining unchanged, an increased global area of planted forests leads to increased global forest stocks and results in an outward shift of the global timber supply curve, reducing equilibrium product prices and increasing consumption (and production). However, at the individual country level, the reduced price resulting from increased forest stock may alter a country's comparative advantage in the production and trade in timber products, relative to other countries. Consequently, while a reduced product price will tend to increase consumption in every country, the impact on production in each country will depend on how planted forests shift out each country's roundwood supply curve. Differing sizes of supply shifts across countries would tend to rearrange international forest product flows (Buongiorno and Zhu, 2014). This rearrangement is consistent with an endowments-based theory of comparative advantage (Vanek, 1963), as the size of a country's timber stocks is positively related to its relative comparative advantage (Bonnefoi and Buongiorno, 1990; Prestemon and Buongiorno, 1996).

1.1. Past modeling of planted forests and market impacts

Several previous studies have enhanced our understanding of planted forest futures, including their likely expansions and the associated roles in global roundwood production (e.g., Sohngen et al., 1997; Sohngen and Sedjo, 1999, ABARE and Jaakko Pöyry, 1999; Brown, 2000; Carle and Holmgren, 2008; Buongiorno and Zhu, 2014; d'Annunzio et al., 2015). Most of published global outlooks of planted forests and product markets have relied on wood products consumption quantities projected from partial equilibrium models (e.g., Sedjo and Lyon, 1996; Sohngen et al., 1997; Zhu et al., 1998). Among the more recent efforts was by Carle and Holmgren (2008), who projected a substantial increase in roundwood supply from planted forests by 2030, ranging from 1.2 billion m^3 (representing 66% global roundwood production) to 1.9 billion m^3 (representing 80% of global roundwood production by 2030) for their higher productivity scenario.

Using the EFISCEN model (a forest sector model covering Europe, which projects wood supply and forest resource development in response to a given demand for wood), Nabuurs et al. (2014) provided a European perspective on the development of planted forests and projections to 2065. Their simulations of various wood demand scenarios suggested that wood supply growth would not match the rate of growth in wood demand (likely driving up prices to achieve market equilibria), even if 50% of current broadleaved forests in EU27 were converted to coniferous forest plantations.

Other studies considered the importance of forest products market interactions in estimating potential expansion of planted forests. For example, Sohngen and Sedjo (1999), projecting global markets for timber to 2050, simulated the effects of a price-responsive increase in future planted forest area, projecting that most of the increases in timber harvests induced by outward shifts in the demands for various wood products would come from the expansion of plantation area, mostly in subtropical countries. Such plantations were projected to double in area by 2050 compared to observed 1990 levels in their high demand scenario. Similarly, analyzing the effects that expanded planted forests would have on global forest products market equilibria for a single year (2009), Buongiorno and Zhu (2014) reported that global forest products prices would have been as much as 37% lower and that global roundwood and manufactured wood products output would have been 4–14% higher. Analyses by d'Annunzio et al. (2015) projected a decline in global forest area between 2010 and 2030 (a loss of 0.06% per year), the net of natural forest area loss (at 0.19% per year) and planted forest area gain (at 2% per year).

A few studies quantified how comparative advantage may relate to institutional and policy factors behind timber investment attractiveness in a selected set of countries. For example, Cubbage et al. (2014) suggested that the countries with higher returns to plantations, enabled by faster forest growth, lower land costs, and weaker environmental regulations, would likely see more future expansion in planted forests. They reported high financial returns for exotic plantations in almost all of South America and China, followed by South Africa, New Zealand, Australia, Mexico and the United States. Similarly, based on the review of a large set of potential factors affecting planted forest area and data availability, Korhonen et al. (2014) analyzed the statistical relationships between various macroeconomic, institutional, forest-sector related factors and planted forest area development. Relying on econometric analyses using panel data from 1990 to 2010, they found that the statistically most significant determinants of planted forest areas in OECD countries were GDP, tariffs, and industrial production capacity, whereas in non-OECD countries, the level of corruption, GDP, and industrial production capacity were statistically significant explainers of planted forest area.

While past studies have improved our insights into the likely future of planted forest area and its role in global roundwood markets, integrated statistical projections of planted forests under widely accepted economic and demographic futures such as those associated with the Intergovernmental Panel on Climate Change (IPCC) have been lacking. In addition, data show rapid growth in the demand and supply of market pulp and perhaps a shrinkage in the market for solid wood products (FAO, 2018) since the 2007–2009 recession in major producing countries. The recent research advances and market shifts provide a compelling need for a reevaluation of the role of planted forests in the global forest sector. By including specific attention to planted forests in global forest sector models, investors and policy makers can better understand how global comparative advantages in forest products may shift, enabling more precise assessments of the respective economic, social and ecological consequences.

To this end, this study seeks to answer the following research questions: (1) what economic, institutional, and forestry factors influence planted forest area?; (2) how would planted forest area develop under alternative assumptions regarding global economic and demographic changes projected under alternative futures, as indexed by shared socioeconomic pathways (SSP) scenarios (discussed in the methods section)?; and (3) how would projected planted forest area in each SSP affect forest growth, timber stocks, and the associated timber supply, product prices, production, consumption, and trade quantities? To answer these questions, we updated econometric models of planted forest area and incorporated the models into a global partial spatial equilibrium forest sector model, the Global Forest Products Model (GFPM) (Buongiorno et al., 2003). We then projected forest sector outcomes in each SSP scenario, with and without explicit projections of planted forests.

2. Methods

This study involved three primary components: (1) updating the econometric models of planted forest area by OECD and non-OCED countries originally estimated by Korhonen et al. (2014) with new data and revised functional forms; (2) applying the updated econometric models to make projections of planted forest area for 180 individual countries, 2015–2070, under varying socio-economic futures; and (3) quantifying the effects of the planted forest projections on global forest growth and stock and forest products markets. Fig. S1 shows the modeling approach and connections between the planted forest area model and the GFPM in a flow chart. Next, we describe each of the components in detail.

Table 1
Estimated wood productivity in planted and natural forest in major world regions.

Regions	Planted forests[a]	Natural forests	Assumed average growth of stock in planted forests (times higher than natural forests)
	cubic meters per hectare per year		
World	4.6	< 1 (certified)[b]	
World regions			
Africa (east and south)	6.0	1[c]	6
Asia (south and southeast)	6.4	1[c]	6
Europe	3.2	1-3 (intensively managed)[b]	2
North America	7.6	1-3 (intensively managed)[b]	4
Oceania	17.2	2[c]	8
South America	24.0	2[c]	12

[a] Payn et al. (2015).
[b] Paquette and Messier (2010).
[c] Authors' assumption.

2.1. Updating the planted forest area model

Korhonen et al. (2014) reviewed research on the macroeconomic, institutional and forest-sector factors linkages to investment in planted forests and econometrically assessed the importance of these factors in planted forest area establishment. Variables describing the macro-economic factors were represented by (a) GDP per capita (an indicator of market size and investment flows), (b) the volume of bank credit accessible to firms in developing countries, (c) the total value of country level foreign direct investment (an indicator of whether general investment decisions affect the area of planted forests), and (d) the level of country openness and the existence of favorable investment policies (e.g., tariffs). To measure the effects of institutional factors, the authors selected indexed data, allowing for better comparisons across countries, on the level of corruption and unemployment experienced in each country. Finally, the authors included two forestry factors considered to be important in affecting expansion of planted forest area: forest land productivity and the quantity of industrial roundwood output. These data were compiled as a time series-cross sectional panel, at 5 year time steps (except for the first time step which was at 10 years), starting at 1990 and ending at 2010 (Korhonen et al., 2014).

To update the Korhonen et al. (2014) econometric analyses, we made the following changes. First, we added one additional panel data point for 2015, increasing the number of observations. Second, while the original model included policies favoring investments, other policies such as direct or indirect government incentives for plantation activities were not considered, mainly due to the lack of data. To explore the likely effect of such incentives in planted forest area, we examined scatterplots of government expenditures in forestry (FAO, 2015c) (which we consider a proxy for incentives for plantation activities) versus net changes in planted forest area in each country (FAO, 2015c). The scatterplots did not show a strong association between those two variables, so we did not include government expenditure in forestry as an explanatory variable.

Third, we altered how we modeled government involvement in forests. We did this by including dummy variables for countries whose governments were directly involved in encouraging large scale plantations through subsidies or other programs or whose governments own large areas of planted forests, such as Australia, New Zealand, Chile, China, Brazil, and Uruguay. Because time-invariant dummy variables cannot be estimated in the fixed effects model, we estimated only random effects models for the cases where dummies were introduced. The analysis provided no additional value to our best model, so the results only are available on request.

Fourth and finally, we expanded consideration of econometric specifications beyond fixed effects (FE) and pooled ordinary least squares (OLS) to include random effects (RE) specifications. In the latter specification, to control for persistent regional differences, we further introduced regional dummies, intended to capture regionally varying but temporally static institutional, social and natural environmental factors, which we assume are not adequately modeled by individual effects at the country level in the OECD and non-OECD subgroups. While the results indicated some statistically significant differences at the regional level, the statistical testing based on a pooling-test and a Hausman test indicated a better fit for FE model, so we limit our reporting to the results of this functional form (RE model estimates are available upon request). These three model specifications, which were all estimated using logarithmic transformations of continuous variables, were (Greene, 2008):

The pooled OLS model

$$Y_{it} = \alpha + \sum_{k=1}^{K} \beta_k X_{kit} + \varepsilon_{it} \tag{1}$$

The FE model

$$Y_{it} = \alpha_i + \sum_{k=1}^{K} \beta_k X_{kit} + \varepsilon_{it} \tag{2}$$

The RE model

$$Y_{it} = (\alpha + u_i) + \sum_{k=1}^{K} \beta_k X_{kit} + \varepsilon_{it} \tag{3}$$

where:

Y_{it} = area of planted forest for country i at time t
a = constant
β_k = coefficient for the independent variable k (Table 2)
X_{kit} = independent variable k for country i at time t

Table 2
Estimated coefficients and significance levels of planted forest area prediction models by OECD and non-OECD countries.

Variable	Fixed effects model					
	OECD countries			Non-OECD countries		
Intercept	2.988	(1.425)	**	3.749	(3.442)	
GDP per capita	0.230	(0.069)	***	0.381	(0.190)	**
Roundwood production	0.140	(0.082)	*	−0.153	(0.282)	
Banking credit	0.045	(0.050)		−0.693	(0.260)	***
Foreign direct investment	0.020	(0.015)		0.059	(0.093)	
Tariff	−0.029	(0.048)		0.046	(0.232)	
Corruption	−0.380	(0.208)		0.002	(0.619)	
Unemployment	0.068	(0.046)		0.161	(0.274)	
Productivity	0.283	(0.170)	*	1.153	(0.559)	**
Pooling test	18.400	**		46.980	***	
Hausman test	19.040	**		28.530	***	

Note: numbers in parentheses are standard errors; [1] the specified model was a log-log model; hence, estimated coefficients are elasticities; *** statistically significant at 1%, ** at 5%, and * at 10%.

ε_{it} = random error term that varies over country i at time t
u_i = time invariant random individual differences specific to country i (random effect)

2.2. Projecting planted forest area

The projection of planted forest area was made through 2070 for 180 different countries modeled in the Global Forest Product Model (GFPM, described in the following section) by using the fitted models estimated above. Because future projected data for all independent variables were not available, we only projected the changes in GDP per capita and roundwood production as independent variables, keeping all other variables constant at their base year (2015) levels. A match with base year values of planted forest area for each country was achieved by calculating a new intercept value for each country, obtained by using the observed 2015 value of planted forest area (left hand side of the equation) and the observed values and the estimated coefficients of GDP and roundwood production quantities (right hand side of the equation), and solving for the intercept term. Then, the area of planted forests was projected through 2070 for each country for each SSP, using the calibrated intercepts and the estimated coefficients of the predictor variables along with the projected GDP per capita reported in the SSP database (IIASA, 2018) and roundwood productions values projected in this study by GFPM for five SSPs.

The SSPs are narratives of possible world futures that differ among each other on assumed changes in various socioeconomic variables, including projected income, population, international co-operation, fossil fuel use, and effort to mitigate greenhouse gas emissions. Briefly, SSP1 and SSP5 represent a future world that is rich and equal, with SSP1 assuming more sustainable economic growth due to less reliance on fossil fuel. SSP2 represents a world that is similar to the recent economic and demographic trends. Finally, SSP3 and SSP4 represent poorer and more unequal worlds, with SSP4 assuming the largest income inequality among countries. These SSPs were developed in relation to the most recent climate change assessment studies led by the Intergovernmental Panel on Climate Change (IPCC). More detailed narratives of these SSPs can be found in O'Neill et al. (2017).

2.3. Evaluating global forest sector impacts

The market analyses of global forests and the forest products sector was carried out using the GFPM, which is a partial spatial market equilibrium model of global production, consumption and trade of forest products. The objective function of the GFPM maximizes the sum of producer and consumer surplus minus transport costs of the global forest sector (Samuelson, 1952). The full structure of the GFPM is described by Buongiorno et al. (2003) and Buongiorno (2015). To quantify the effects of planted forest area on global forest product market solutions, we compared the baseline GFPM runs, where no separate projections of planted forest area and the associated changes in forest growth and stocks were provided, with alternative runs where the projected baseline forest growth and stocks were adjusted to reflect the projected increase in planted forest area obtained from our updated planted forest area econometric models. In both runs, we relied on GFPM projected total forest area that was based on an Environmental Kuznets Curve (EKC) model, exogenously specified as quadratic function of GDP per capita in all countries (Turner et al., 2006), which did not distinguish between planted and natural forest areas.

To account for higher forest growth and yield associated with the planted forests, we assumed that growth in forest stocks increased as the proportion of planted forest increased in an individual country, as suggested by various studies (e.g., Payn et al., 2015; Paquette and Messier, 2010) (Table 1). Relying on those estimates, we translated our projected increases in planted forest area into corresponding adjustments in forest stock growth rates for each country in GFPM. For instance, stock growth in planted forests in Africa and in Asia were assumed to be 6 times higher than the stock growth in natural forests in these regions, assuming that the average growth in natural forests in these regions are similar to the average productivity of natural forests globally (1 $m^3 ha^{-1} yr^{-1}$, Paquette and Messier, 2010). Similarly, forest growth in planted forests in Europe, North America, Oceania, and South America were respectively assumed to be 2, 4, 8, and 12 times higher than the corresponding stock growth in natural forests, assuming that the average productivity of natural forests in those regions are about 2 $m^3 ha^{-1} yr^{-1}$ (Paquette and Messier, 2010).

It is important to note here that the projected planted forest area from our econometric model does not influence the projected amounts of total forest area in GFPM. However, our projected planted forest area changes the proportion of planted forest area in each country (given GFPM-projected total forest area), which in turn affects projected forest stock growth and resultant changes in prices and quantities of wood produced, consumed, and traded.

The growth rate in total forest stocks (before harvest) in GFPM is estimated as a function of forest stock density (total forest stock divided by total forest area), without distinguishing between planted forests and natural forests, according to equation (4) (Buongiorno and Zhu, 2016). To account for the changes in total forest stock growth, brought about by projected changes in planted forest area separately, we adjusted the growth rate calculated by GFPM in the following manner: First, we extracted the total forest growth rates calculated by the GFPM according to equation (4) (Buongiorno and Zhu, 2016):

$$G_i = (\alpha) * \left(\frac{S_i}{A_i}\right)^{\gamma} \tag{4}$$

where G is the annual rate of total forest stock growth; $\gamma = -0.41$ (used in the current version of GFPM, based on Turner et al. (2006)) is the elasticity of forest stock growth rate with respect to forest stock density, so that a 1% increase in forest stock (S) per unit area (A) decreases G by 0.41%; α is the intercept parameter, which was calibrated so that observed G in the base year is equal to the predicted G in each country.

Next, we calculated the growth rate considering the effect of planted forest area separately, according to equation (5) (Turner et al., 2006):

$$G_i = (\alpha_i + \beta_i * Z_i) * \left(\frac{S_i}{A_i}\right)^{\gamma} \tag{5}$$

where: β is the parameter associated with the proportion of planted forest area (Z); both α and β are calibrated based on the observed growth rate, the observed proportion of planted forests, the observed growing stock density, and the assumed relationship between α and β for the base year such that $\frac{\beta_i}{\alpha_i} = X_i$ and the value of X_i was derived from Table 1, which represents assumption that growth in all planted forest is X times higher than the growth in all natural forests. The differences in forest stock growth values obtained from equations (5) and (4) represents the adjustments needed in the GFPM to account for the changes in forest stock growth resulting from projected changes in planted forest area, which we implemented in the GFPM runs representing planted forest cases.

The assumed increases in total forest growth and stocks due to projected increase in planted forest area allowed an endogenous shift in the wood supply curve, leading to changes in market equilibrium wood products prices, and the resultant changes in consumption, production, and net export quantities of individual countries and world regions. Because all of the bio-economic factors driving forest products production and consumption in both with- and without-planted forest scenarios remained same (except for forest stock), any changes in the market outcome can be attributed to changes in forest stocks resulting from increased planted forest area.

2.4. Model integration

Because roundwood production quantities affect projected planted forest area and vice versa, there was a need to adopt a procedure so that model solutions (all endogenously projected outputs from the GFPM and the amount of planted forest area from planted forest area model) would not change from one run to the other. This procedure involved obtaining the initial projection of planted forest area based on GFPM-projected roundwood production quantities from the baseline runs that did not consider the separate effect of planted forest area. In the next GFPM run, the rate of forest growth was adjusted based on projected changes in proportion of planted forests, producing the updated equilibrium projections of roundwood production quantities for each country and each scenario. The updated roundwood production quantities were then fed into the planted forest area projection model again to provide updated projections of planted forest area for each country, which was further used to obtain the revised proportion of planted forests and to adjust forest stock growth rate in GFPM in the next run. This iterative procedure was continued until the absolute values of the model solutions did not change proportionately by more than 0.0001 from one run to another, at which point the two model were considered to have converged. Such an approach, where outputs are exchanged between model runs to obtain convergent solutions, have been applied in several past studies (e.g., Adams and Haynes, 2007; Nordström et al., 2016; Nepal et al., 2019).

3. Results

3.1. Estimated planted forest area model

After confirming the best fit by the pooling test and the Hausman tests, the estimated coefficients, standard errors, and coefficient statistical significances for the FE-models are summarized in Table 2. (RE specification results are available from the authors upon request). All the variables were estimated using logarithmic transformations, so that the coefficients represent elasticities. For the OECD countries, the FE planted forest area model suggested that coefficients on GDP per capita, roundwood production, and forest productivity were statistically significantly different from zero at 10% or stronger. For the non-OECD countries, the coefficient for banking credit was statistically significant, in addition to those of GDP per capita and forest productivity, all at 5% or stronger. The FE model results suggested a larger effect of per capita income (0.38) and forest productivity (1.15) for the non-OECD countries, compared to the estimated effects of those variables for the OECD countries (0.22, and 0.28, respectively).

3.2. Projected planted forest and total forest area

We report the projections of planted forest area for each country and each scenario through 2070 using the statistically superior FE model (Table 2). Fig. 1 shows projected global planted forest area under five SSPs. The projections show that global planted forest area would expand to 417 Mha by 2070 for the SSP2, the world vision that is similar to the most recent economic trends, representing an increase of 46% compared to the planted forest area of 285 Mha observed in 2015. The projected planted forest areas for other SSPs were consistent with the assumed future trends in GDP per capita growth and the associated levels of roundwood production in each country, with SSP5 resulting in the largest projected increase in global planted forests by 2070 (475 Mha, a 67% increase relative to the 2015 level), SSP3 and SSP4 producing the smallest increases (to 379 Mha and 381 Mha or 33% and 34% increases relative to that of 2015, respectively), and SSP1 showing a 53% increase in planted forests by 2070 (to 435 Mha) compared to 2015.

While we estimated the global level results for all five SSPs, we now only describe for the major world regions and selected countries the results for SSP2, SSP3, and SSP5, given that the projections for SSP4 were very similar to those of SSP3 and that the projections for SSP1 were likewise close to those emerging from SSP5 (Table S3 presents projected development of planted forest area for six world regions and 15 selected countries in next 55 years.). From its 2015 planted forest area of about 15 Mha, Africa was projected to have the smallest increases in planted forest area for the SSP3 (to 18 Mha, increasing by 21%) but substantial projected increases in SSP2 (to 26 Mha, an increase of 74%) and SSP5 (to 35 Mha, an increase of 137%). The next largest percentage increase in planted forest was shown to occur in Asia (compared to its 2015 level of 127 Mha, a 50% increase in SSP3 to a 89% increase in SSP5), mostly in China, India, and Indonesia. After Asia, South America demonstrated the next largest regional changes, where its 15 Mha of planted forests in 2015 were projected to increase by 28% and 68% by 2070 in SSP3 and SSP5, respectively. Europe, Oceania and the North America showed relatively small projected increases in planted forest area for all scenarios, representing 40%, 29%, and 29% increases by 2070 in SSP5, compared to their 2015 levels, respectively.

Independent from our projections of planted forest area, the total forest area projected by GFPM (based on the EKC model alone) showed that the world would see an increase in total forest area ranging from 2% for SSP3 to 4% for SSP5 in 2070, compared to its 2015 level of about 4 billion ha (Fig. 2). While global forest area was projected to increase in all SSPs, regions such as Africa, South America, and Oceania, and several countries within these regions, showed a projected decline in total forest area (Table S4). For instance, a projected decline in total forest area in Africa ranged from 18% in SSP3 to 8% in SSP5, with South America and Oceania showing relatively smaller declines (Table S4). Other regions showed increasing total forest area, with Asia showing the largest increases (20%–24%), followed by Europe (8%–10%). In contrast to the projected trends for other regions, North America showed more or less stable forest area in all SSPs (Table S4).

The projected planted forest area was used to project the proportion of planted forest area in conjunction with the independently projected total forest area from GFPM, which provided the basis for further evaluating the impact of planted forests on forest growth and stock and the resultant impacts on wood products markets. Consistent with projected planted forest and total forest area, the projected increases in global share of planted forest area ranged from 2% for SSP3 to 4% for SSP5 in 2070, relative to the 2015 share of 7% (Table S5). Broken out by region, differences were more variable. North America, South America, Europe and Oceania had the smallest overall increases in the share of planted forests (1–2%), while Asia showed the largest increase in the share, ranging from 5% for SSP3 to 12% for SSP5, while Africa's plantation shares varied from 1% to 4% (Table S5).

Given our assumption that planted forests had higher forest stock growth than natural forests (Table 1), we calculate that global forest stocks were higher by 2% in SSP3 and 5% in SSP5 by 2070, compared to the baseline runs for SSPs that did not separately model planted forests (Fig. 3). In line with findings summarized to the global level, forest stocks for planted forest versions of our projections were also projected to be higher in all regions, ranging from 1.5% higher (e.g., in Europe) to 18% higher (e.g., in Asia), by 2070, compared to the baseline cases without explicit planted forest area consideration (not shown).

3.3. Impacts on wood products price, consumption, production and trade

Because of the outward shifts in wood supply curves brought about by explicit consideration of planted forests, global wood production (roundwood and derivative products) and consumption were projected to increase (Table 3), while world prices were projected to decrease across all product categories (Table 4), compared to the corresponding outcomes in the baseline runs which did not consider projected increase in planted forest area. Consumption and production increases by 2070 ranged from as small as less than half a percent increase (e.g., for paper and various other products in SSP3) to as high as 5% (e.g., for fuelwood in SSP5). The projected world price decreases by 2070 (Table 4) ranged

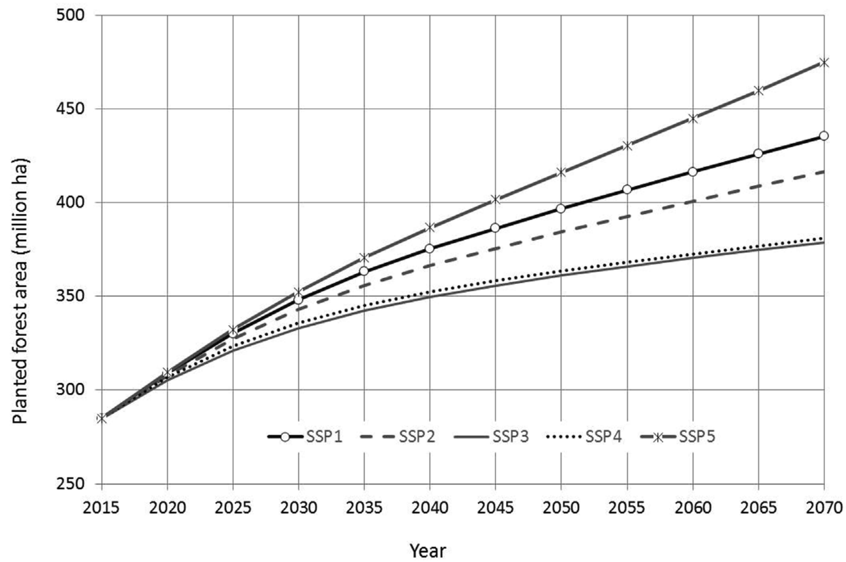

Fig. 1. Projected global planted forest area (million ha) under different shared socioeconomic pathways (SSPs), 2015–2070.

from less than 1% (e.g., for paper product and plywood/veneer in SSP3) to as much as 12% (e.g., for industrial roundwood and fuelwood in SSP5). The relatively smaller effect of reduced product prices compared to consumption quantities was due to price-inelastic demands.

While the projected increase in planted forests led to increased global production of wood products (Table 3), this outcome was not universally the case across all regions (Tables S6-S9), reflecting the varying degree to which planted forests led to differential shifts in relative prices across countries and regions. For instance, although global industrial roundwood production under SSP5 was projected to rise by 89 million m^3 (3.3%) by 2070 compared to model runs without explicit consideration of planted forests, Africa, Asia, and Europe showed industrial roundwood production gains of 146 million m^3 (24.0%), 23 million m^3 (38.3%), and 3 million m^3 (0.3%) respectively. In contrast, North America, South America, and Oceania reduced their industrial roundwood production under SSP5 by 69 million m^3 (9.0%), 8 million m^3 (3.3%), and 6 million m^3 (9.4%), respectively (Table S6) compared to the model runs without explicit consideration of planted forests. Projected fuelwood production increased in all regions and countries, however, relative to the model runs without planted forest consideration (Table S7). Of the projected 63 million m^3 (5%) increase in global fuelwood production in SSP5 by 2070, the majority was shown to increase in Asia (35 million m^3) and Africa (25 million m^3).

Manufactured wood products (sawnwood and panels) showed relatively smaller changes. Most of the projected increases in 2070 (compared to the no-planted forest case), for instance, occurred in North America (26 million m^3), Asia (13 million m^3), and Africa (7 million m^3), with Europe, South America, and Oceania losing production, lower by 15 million m^3, 4 million m^3, and 3 million m^3, respectively, in SSP5 (Table S8). Finally, the projected expansion in planted forest area also had positive but smaller effects on paper and paperboard production for all regions and SSPs, except for South America, where its production declined by about 2% by 2070 in SSP5 compared to the no-planted forest case (Table S9). Of about 9 million metric tonnes (mt) of projected increase in global paper and paperboard production, Asia provided half (4.2 mt), Europe provided a little more than one third (3.3 mt), and North America provided the remaining (1.4 mt).

While the projected reductions in product prices resulting from the projected increase in planted forest area altered the profitability of each region in producing various products, leading to either positive or

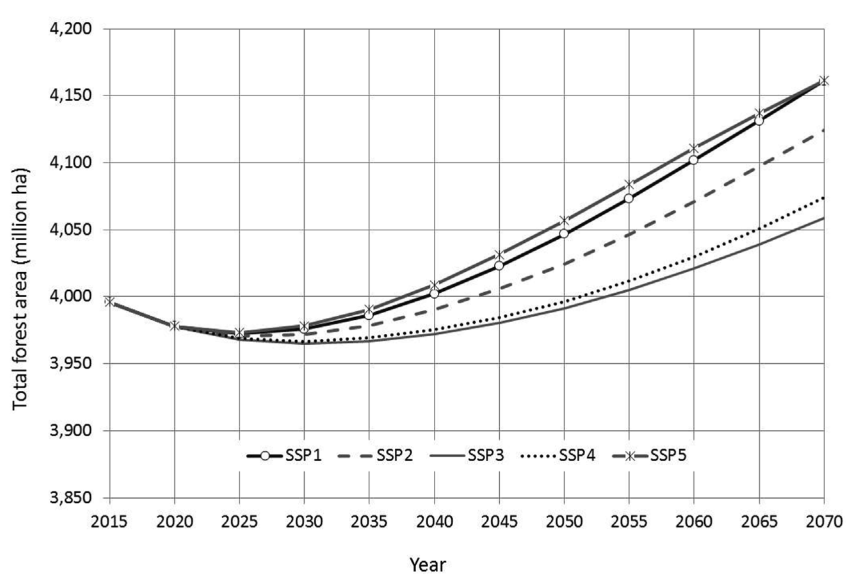

Fig. 2. Projected global total forest area (million ha) under different shared socioeconomic pathways (SSPs), 2015–2070.

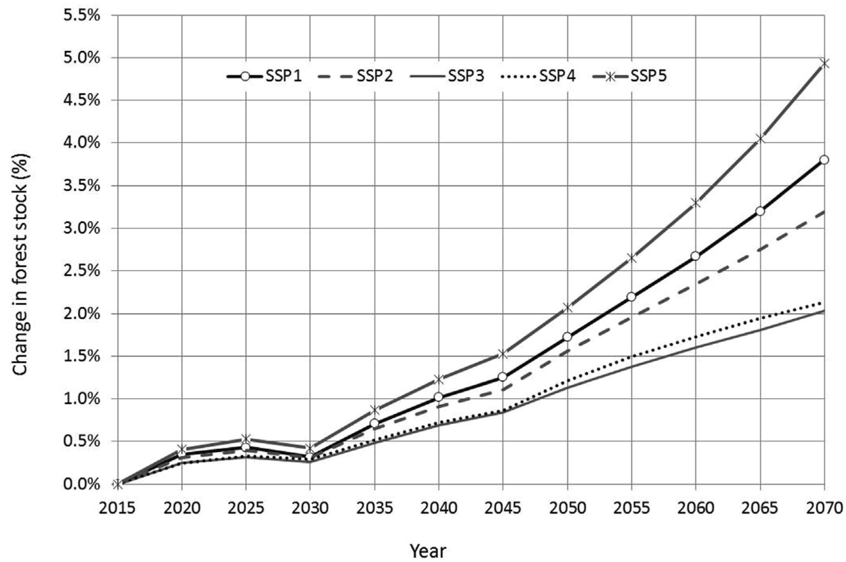

Fig. 3. Projected changes in global forest stocks between the planted forest and no-planted forest cases under different shared socioeconomic pathways (SSPs), 2015–2070.

Table 3
Projected changes in global consumption/production of forest products by 2070 between the planted forest and no-planted forest cases under different shared socioeconomic pathways (SSPs).

Commodity	Changes in 2070 compared to a no planted forest case					
	SSP2		SSP3		SSP5	
	mill. m^3	%	mill. m^3	%	mill. m^3	%
Industrial roundwood	33.5	1.5	17.7	0.9	89.5	3.3
Fuelwood	45.2	3.3	24.0	1.7	63.2	4.7
Sawnwood	5.0	0.9	2.8	0.5	8.3	1.4
Plywood/veneer	2.8	1.0	1.1	0.4	6.6	1.7
Particleboard	1.7	1.1	0.8	0.6	3.6	1.9
Fiberboard	2.2	0.9	1.0	0.5	5.4	1.7
Mechanical pulp	0.9	3.7	0.7	3.5	1.5	4.7
Chemical pulp	1.9	1.3	0.5	0.4	2.6	1.4
Newsprint	0.1	0.3	0.1	0.2	0.3	0.5
Printing & writing paper	1.6	0.8	0.9	0.5	4.3	1.7
Other paper & paper board	1.9	0.5	1.1	0.3	4.2	1.0

Table 4
Projected changes in world prices wood products by 2070 between the planted forest and no-planted forest cases under different shared socioeconomic pathways (SSPs).

Commodity	% changes in 2070 compared to a no planted forest case		
	SSP2	SSP3	SSP5
Industrial roundwood	−9.3	−6.0	−11.8
Fuelwood	−8.1	−5.8	−11.6
Sawnwood	−4.8	−2.9	−6.9
Plywood/veneer	−1.7	−0.8	−3.5
Particleboard	−2.1	−1.1	−3.7
Fiberboard	−1.3	−1.4	−2.4
Mechanical pulp	−3.9	−1.8	−6.6
Chemical pulp	−2.6	−1.6	−3.9
Newsprint	−2.7	−1.7	−5.2
Printing & writing paper	−1.5	−1.0	−2.9
Other paper & paper board	−1.1	−0.7	−2.1

negative effects on forest products productions, their consumption levels were projected to increase unambiguously in all regions and in all SSPs (Table S7–S9). The magnitude of the effect on consumption was relatively smaller than the effect on production because of the more inelastic wood products demands (compared to more elastic wood products supply) with respect to prices.

For regions where production increased, most of those increases were absorbed by increased net exports (shown for industrial roundwood only in Table S6), given relatively smaller changes in consumption. As one example, more than 80% (114 million m^3) of the 146 million m^3 of additional roundwood produced in Asia due to projected increases in planted forests was absorbed by increased net exports, while the remaining 20% was absorbed by increased consumption by 2070 in SSP5. Regions with reduced production were projected to reduce their net exports. For instance, the largest effect was observed in the case of industrial roundwood net exports in North America, which decreased by 124 million m^3 by 2070 in SSP5 compared to the corresponding no-planted forest case, as a result of reduced world (and domestic) prices, manifesting reduced competitiveness of North America in industrial roundwood production.

4. Discussion and conclusions

This research demonstrates that accounting for drivers for new investments in forestry, particularly investments in planted forests, leads to distinctly different projected outcomes for the forest sector in the coming decades compared to previous modeling efforts. Due to a paucity of published statistical models of change drivers of planted forest area at the national level, past projections of planted forest area by country implemented in global forest sector models were mostly based on assumptions of continued trends or of calculated wood needs given projected equilibrium prices and quantities. The econometric results from our study more completely capture underlying economic and demographic drivers involved in planted forest area development, which can form the foundation upon which to build an updated outlook of future global markets.

Our research suggests that the growth in the area of planted forests globally is likely to slow, due in part to recent policy shifts across many countries. Our results show that global planted forest area would grow at a rate of 0.7% per year, 2015–2070, in SSP2, a future tracking recent global trends in incomes and populations, and at 0.9% per year in SSP5, representing a world future of relatively higher rates of economic

Table 5
Estimated changes in industrial roundwood (IRW) production in planted and natural forests for SSP2.

Region	Planted forest share in total forest area in 2015 (%)	Planted forest share in total IRW production in 2015 (%)	Total IRW production in 2070 (million m^3)	Share of planted forests in total forest area in 2070 (%)	Share of planted forests in total RW production in 2070 (%)	IRW production from planted forest in 2070 (million m^3)	Implied IRW production from natural forests in 2070 (million m^3)
Baseline case without considering planted forest area increase							
Africa	2.58	37	51	2.58	37	19	32
Asia	21.18	48	524	21.18	48	252	272
Europe	7.96	33	833	7.96	33	275	558
North America	6.12	36	638	6.12	36	230	408
Oceania	2.33	84	47	2.33	84	39	8
South America	1.77	90	211	1.77	90	190	21
World	7.13	46	2308	7.13	46	1062	1246
Alternative case considering planted forest area increase							
Africa	2.58	37	63	5.21	75	47	16
Asia	21.18	48	601	28.54	65	389	212
Europe	7.96	33	833	9.41	39	325	508
North America	6.12	36	590	7.18	42	249	341
Oceania	2.33	84	47	2.86	103	48	−1
South America	1.77	90	207	2.63	134	277	−70
World	7.13	46	2342	10.10	65	1526	816
Percent change from baseline case							
Africa			24%		102%	149%	−50%
Asia			15%		35%	55%	−22%
Europe			0%		18%	18%	−9%
North America			−8%		17%	8%	−17%
Oceania			0%		23%	23%	−119%
South America			−2%		49%	46%	−431%
World			1%		42%	44%	−35%

growth. These rates of planted forest area growth are lower than the majority of the previously published projections, which were mostly based on expert judgments or assumptions about continuations of past trends (e.g., Brown, 2000; Carle and Holmgren, 2008; d'Annunzio et al., 2015). Yet our findings are plausible, consistent with an expectation, based on recent moves across countries to pull back from government policies and programs fostering forest plantation establishment (Brown, 2000), that planted forest area may not continue to accelerate at increasing rates. However, modest continued planted area growth does appear likely, given rapid growth in the demand for forest products (Brown, 2000; Arezki et al., 2012). This observation is consistent with continued real income growth–hence forest product demand growth—across most countries and regions in the coming decades.

Varying rates of future economic growth and differences in forest productivity and land costs across countries are revealed in the varying projected future of planted forests across countries and regions in our projections. Consistent with higher projected economic growth in most of Africa, Asia, and South America, our projections suggest that these regions would see the largest expansions in planted forests in the future. For instance, in SSP2, Africa, Asia, and South America each showed more than a 45% increase in planted forest area over the next five decades, followed by Europe, North America and Oceania, which each increased by less than 29%.

Despite smaller relative increases in planted forests historically (as seen in Table S1), the tropics have the potential to increase planted forest areas due to relatively greater amounts of available land for tree planting in those regions. For example, of 445 million ha of uncultivated land available for farming and or/planted forests globally, about 201 million ha are reported to be available in sub-Saharan Africa and 123 million ha in Latin America (Arezki et al., 2012). The projected increase in planted forest area in most of the South American countries and China are consistent with higher returns on investments from planted forests in those regions (Cubbage et al., 2014). Assuming that return on investment is an important driver of planted forest expansion, our projections for Oceania and North America apparently run counter to expectations. However, as shown by Cubbage et al. (2014), the inclusion of land costs reduces returns to forest investments substantially, suggesting that the economics of planted forests may not fare better in regions where land is more expensive, such as in most of the western and northern Europe and Oceania. The higher land costs therefore could hinder future growth in planted forest areas in these regions, compared to many African and Asian countries where open lands are relatively cheaper.

Projections reported here also reveal how accounting explicitly for planted forests in a global forest sector model can alter one's perspectives about future forest product market prospects. Our projected changes in forest products prices, consumption, and production due to increased planted forests are substantially smaller in magnitude than those suggested by past studies (e.g., Buongiorno and Zhu, 2014). The increase in forest stocks due to projected increases in planted forest area unambiguously led to increased global timber production, reduced world prices, and increased global consumption of all forest products. However, production did not increase in all countries proportionately, despite increased forest stocks.

This study revealed that planted forests expansion may lead to relatively greater reliance on industrial-style timber management, which could indirectly affect natural forests. For example, our projection results could be used to indirectly estimate the amount of industrial roundwood that could be provided by planted forests and hence reveal changes in production from natural forests (Table 5). Assuming that the current contribution of planted forests in providing industrial roundwood (Table S2) increases proportionately with the projected increase in its share in total forest area (Table S5), we estimated that global roundwood production from planted forests in SSP2 would be higher by 460 million m^3 by 2070, or 44% above levels achieved by 2070 under an SSP2 projection where no explicit accounting for planted forest is made. This higher production of industrial roundwood from planted forests would be accompanied by 35% less production from natural forests (Table 5), supporting analyses offered by Sedjo and Botkin (1997), Leslie (2005), and Bull et al. (2006). However, this greater share of wood produced by planted forests should be interpreted with caution, as the forest type relationships between intensively managed plantations and natural forests have proved to be complicated (Brockerhoff et al., 2008; Malkamäki et al., 2018). Furthermore, currently available data on planted forests do not allow for distinguishing between intensively versus more passively managed planted forests.

Given evidence that planted forests are rising in share relative to natural forests globally, that such forests are increasingly relied upon to produce industrial roundwood, and that they have the potential to alter comparative advantages in forest products, including them directly within global forest sector models has significant value for forest and wood products carbon assessments, market projections, and policy analyses. For instance, the projected increases in global planted forest area leading to increased forest stocks (by 5%) and forest products production (also by 5%) suggest that forests and forest products might sequester a larger share of carbon in the future than previously estimated. The projected effects of planted forests on market variables, including higher overall timber product outputs and wood products consumption but lower prices, imply more substantial changes in producer and consumer welfare than perhaps previously appreciated; however, we leave a detailed discussion of those impacts to future studies. Likewise, the socioeconomic and ecological impacts associated with the spread of planted forests and large-scale plantations on ecosystem services and local livelihoods, particularly in countries characterized by rural poverty and insecure property rights (Malkamäki et al., 2018), may be substantial, affecting as well the production possibilities for a variety of nontimber products. An assessment of those effects are beyond the scope of this study and are also left to other analysts. Nevertheless, we can conclude that planted forest area will likely continue to increase globally and regionally under the range of SSPs considered here, even while trends for natural forests might even be negative in some places. Globally, however, planted forests are shown to affect the forest products sector significantly, leading to a rearrangement in global production, consumption, and trading patterns heretofore not fully appreciated.

Authors declarations of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.03.126.

References

ABARE, Jaakko Pöyry, 1999. Global Outlook for Plantations, ABARE Research Report 99.9. Australian Bureau of Agricultural and Resource Economics, Canberra, Australia. http://data.daff.gov.au/data/warehouse/pe_abarebrs99000431/PC11463.pdf, Accessed date: 13 March 2018.

Adams, D.M., Haynes, R.W., 2007. The challenge of developing models to support forest sector policy analysis. In: Adams, D.M., Haynes, R.W. (Eds.), Resource and Market Projections for Forest Policy Development: Twenty-Five Years of Experience with the U.S. RPA Timber Assessment. Springer Press, New York, pp. 3–18.

Arezki, R., Deininger, K., Selod, H., 2012. The global land rush. Financ. Dev. 49, 47–49.

Baral, H., Guariguata, M.R., Keenan, R.J., 2016. A proposed framework for assessing ecosystem goods and services from planted forests. Ecosyst. Serv. 22, 260–268.

Bonnefoi, B., Buongiorno, J., 1990. Comparative advantage of countries in forest-product trade. For. Ecol. Manag. 36, 1–17.

Brockerhoff, E.G., Jactel, H., Parrotta, J.A., Quine, C.P., Sayer, J., 2008. Plantation forests and biodiversity: oxymoron or opportunity? Biodivers. Conserv. 17, 925–951.

Brown, C., 2000. The Global Outlook for Future Wood Supply from Forest Plantations. FAO Working Paper No. GFPOS/WP/03. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/tempref/docrep/fao/003/X8423E/X8423E00.pdf, Accessed date: 27 June 2018.

Bull, G.Q., Bazett, M., Schwab, O., Nilsson, S., White, A., Maginnis, S., 2006. Industrial forest plantation subsidies: impacts and implications. For. Policy Econ. 9, 12–31.

Buongiorno, J., Zhu, S., Zhang, D., Turner, J., Tomberlin, D., 2003. The Global Forest Products Model. Academic Press, London.

Buongiorno, J., Zhu, S., 2014. Assessing the impact of planted forests on the global forest economy. N. Z. J. For. Sci. 44, S2. http://www.nzjforestryscience.com/content/44/S1/S2.

Buongiorno, J., 2015. Income and time dependence of forest product demand elasticities and 6 implications for forecasting. Silva Fenn. 49, 1395. https://doi.org/10.14214/sf.1395.

Buongiorno, J., Zhu, S., 2016. Using the Global Forest Products Model (GFPM Version 2016 with BPMPD). Staff Paper Series # 85. Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, pp. 37.

Carle, J., Holmgren, P., 2008. Wood from planted forests: a global outlook 2005-2030. For. Prod. J. 58, 6–18.

Cubbage, F., Donagh, P.M., Balmelli, G., Olmos, V.M., Bussoni, A., Rubilar, R., De La Torre, R., Lord, R., Huang, J., Hoeflich, V.A., Murara, M., Kanieski, B., Hall, P., Yao, R., Adams, P., Kotze, H., Monges, E., Pérez, C.H., Wikle, J., Abt, R., Gonzalez, R., Carrero, O., 2014. Global timber investments and trends, 2005-2011. N. Z. J. For. Sci. 44, S7. http://www.nzjforestryscience.com/content/44/S1/S7.

d'Annunzio, R., Sandker, M., Finegold, Y., Min, Z., 2015. Projecting global forest area towards 2030. For. Ecol. Manag. 352, 124–133.

FAO, 2015. FRA 2015 Terms and Definition. Forest Resource Assessment Working Paper 180. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/docrep/017/ap862e/ap862e00.pdf, Accessed date: 6 April 2018.

FAO, 2015. Global Forest Resource Assessment 2015. How Are the World's Forest Changing? Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/a-i4793e.pdf, Accessed date: 11 May 2018.

FAO, 2015. Global Forest Resource Assessment 2015. Desk Reference. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/a-i4808e.pdf, Accessed date: 27 March 2018.

FAO, 2018. FAOSTAT Forestry Production and Trade Database. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/faostat/en/#data/FO, Accessed date: 5 October 2018.

Greene, W.H., 2008. Econometric Analysis, sixth ed. Pearson Prentice Hall, New Jersey.

IIASA, 2018. SSP Database. International Institute for Applied Systems Analysis. https://tntcat.iiasa.ac.at/SspDb, Accessed date: 3 June 2018.

Korhonen, J., Toppinen, A., Cubbage, F., Kuuluvainen, J., 2014. Factors driving investment in planted forests: a comparison between OECD and non-OECD countries. Int. For. Rev. 16, 67–76.

Leslie, A., 2005. What will we want from the forests? ITTO Trop. For. Update 15, 14–16.

Malkamäki, A., D'Amato, D., Hogarth, N.J., Kanninen, M., Pirard, R., Toppinen, A., Zhou, W., 2018. Systematic review of the socio-economic impacts of large-scale tree plantations, worldwide. Glob. Environ. Chang. 53, 90–103.

Nabuurs, G.-J., Schelhass, M.-J., Orazio, C., Hengeveld, G., Tome, M., Farrell, E.P., 2014. European perspective on the development of planted forests, including projections to 2065. N. Z. J. For. Sci. 44, S8. http://www.nzjforestryscience.com/content/44/S1/S8.

Nepal, P., Abt, K.L., Skog, K.E., Prestemon, J.P., Abt, R.C., 2019. Projected market competition for wood biomass between traditional products and energy: a simulated interaction of us regional, national, and global forest product markets. For. Sci. 65, 14–26.

Nordström, E.-M., Forsell, N., Lundström, A., Korosuo, A., Bergh, J., Havlík, P., Kraxner, F., Frank, S., Fricko, O., Lundmark, T., Nordin, A., 2016. Impacts of global climate change mitigation scenarios on forests and harvesting in Sweden. Can. J. For. Res. 46, 1427–1438.

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017. The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Chang. 42, 169–180.

Paquette, A., Messier, C., 2010. The role of plantations in managing the world's forests in the Anthropocene. Front. Ecol. Environ. 8, 27–34.

Payn, T., Carnus, J.-M., Freer-Smith, P., Kimberly, M., Kollert, W., Liu, S., Orazio, C., Rodriguez, L., Sliva, L.N., Wingfield, M.J., 2015. Changes in planted forests and future global implications. For. Ecol. Manag. 352, 57–67.

Pirard, R., Secco, L.D., Warman, R., 2016. Do timber plantations contribute to forest conservation? Environ. Sci. Policy 57, 112–130.

Prestemon, J.P., Buongiorno, J., 1996. Comparative advantage in U.S. interstate forest products trade. J. For. Econ. 3, 207–228.

Samuelson, P.A., 1952. Spatial price equilibrium and linear programming. Am. Econ. Rev. 42 (3), 283–301.

Sedjo, R., Botkin, D., 1997. Using forest plantations to spare natural forests. Environ. Sci. Policy Sustain. Dev. 10, 15–20.

Sedjo, R.A., Lyon, K.S., 1996. Timber Supply Model 96: A Global Timber Supply Model with a Pulpwood Component. Discussion Paper 96-15. Resources for the Future, Washington, DC. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-96-15.pdf, Accessed date: 8 June 2018.

Sohngen, B., Sedjo, R., 1999. The Potential Role of Plantations in Future Timber Supply. Working Paper. Ohio State University, Columbus, Ohio. https://cfaes.osu.edu/sites/aede/files/publication_files/THE%20POTENTIAL%20ROLE%20OF%20PLANTATIONS%20IN%20FUTURE%20TIMBER%20SUPPLY.pdf, Accessed date: 17 April 2018.

Sohngen, B., Mendelsohn, R., Sedjo, R., Lyon, K., 1997. An Analysis of Global Timber Markets. Discussion Paper 97–37. Resources for the Future, Washington DC. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-97-37.pdf, Accessed date: 13 May 2018.

Turner, J.A., Buongiorno, J., Zhu, S., 2006. An economic model of international wood

supply, forest stock and forest area change. Scand. J. For. Res. 21, 73–86.
Vanek, J., 1963. The Natural Resources Content of the United States Foreign Trade, 1870-1955. MIT Press, Massachusetts.
Zhu, S., Tomberlin, D., Buongiorno, J., 1998. Global Forest Products Consumption, Production, Trade, and Prices: Global Forest Products Model Projections to 2010. FAO Working Paper No. GFPOS/WP/01. Food and Agriculture Organization of the United Nations, Rome. Italy.