

Article

U.S. and Global Wood Energy Outlook under Alternative Shared Socioeconomic Pathways

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Abstract: There has been a significant increase in the use of wood pellets for energy in the past decade due in large part to their climate mitigation potential. Because of this, the demand for wood pellets is largely driven by policy, as well as socioeconomic development, making projections of future wood energy markets highly uncertain. The aim of this study is to provide projections of future wood energy market trends under five distinct socioeconomic scenarios based on the assumed future evolution of gross domestic product, population, technological change, trade openness, and bioenergy preferences using the FOrEst Resource Outlook Model. In four out of the five scenarios considered, it is projected that the use of roundwood and mill chips, particles, and residuals will rise in order to produce a growing output of wood pellets in the United States and globally. In terms of international markets, the global dominance of Europe's demand for wood, to help that continent achieve its own climate goals, further explains the sustained and growing supply position of the U.S. South regions to meet that demand. Taken together, the projections suggest emerging bioenergy markets will drive increased competition for inputs with other manufacturers, particularly in the U.S. South regions.

Keywords: wood energy market; wood pellets; forest product markets; bioenergy



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1. Introduction

Forest-based bioenergy could significantly contribute to climate change mitigation [1,2]. In comparison with other solid biofuels, wood pellets offer several unique advantages: high energy content, uniform size, ease of transport and storage, and ability to supply existing energy generating facilities with relatively minor retrofits. Due in part to these reasons, global wood pellets markets have witnessed significant growth for heat and electricity production. Between 2012 and 2020, global wood pellets production increased from 18.1 million tons to 43.7 million tons, with the U.S. being the largest producer, at 19.2% of the total, followed by Canada, with 8.7% [3]. Europe has been the largest consumer of wood pellets, with a consumption of 30.6 million tons of pellets in 2020, of which about a third were imported from the U.S. South [4]. Europe's renewable energy policy is a major factor behind the strong growth in demand for wood pellets [3]. As the EU 2050 net-zero target proceeds, the wood pellets market is likely to continue to grow.

Past and present wood pellets markets have been thoroughly examined, including analysis on the wood pellet market supply chain [5,6], wood pellet market integration [7,8], life cycle emissions and carbon neutrality [9–11], and costs [12]. A few studies dealt with the physical and combustion characteristics of wood pellets' raw materials [13,14]. Given that forest by-products and small-diameter trees are the major sources of raw material for wood pellets, understanding the interactions between wood bioenergy and forest product markets has vital implications for forest industry development [8,15–19] and forest

management [20]. Using the Global Forest Trade Model, Jonsson and Rinaldi [17] found that an increased wood pellet demand in the EU drove up forest biomass feedstock prices and led to lower production and consumption of wood-based panels and pulp. Nepal et al. [18] projected that competition for wood inputs would negatively impact the wood-based panel and pulp and paper sector in the U.S. but have positive effects on softwood lumber by reducing the effective net cost of lumber production through higher-value sales of mill residues. However, the wood energy sector was highly aggregated in their study. Parajuli [19], examining available evidence on markets in the U.S. Southeast, found that the wood pellet industry had driven pine pulpwood prices up in the study region, but the study did not account for the interactions between U.S. regional markets and global timber markets. Increasing wood energy demand not only puts pressure on the forest pulp-based industry but also raises concerns about food security [21] and forest ecosystem services [22]. Recent research has also addressed the potential impacts of wood pellet expansion on land-use change and its implications for net carbon balance [23–25], generally finding that an expanded market for wood energy, including pellets, could affect forestland area and hence net carbon uptake.

Estimates of the future wood energy markets remain highly uncertain, as they significantly rely on social and economic development—which are subject to high levels of uncertainty themselves [26,27]. Several plausible representations of socioeconomic futures have been constructed by the climate change research community over the years, including a new set of scenarios described as the Shared Socioeconomic Pathways (SSPs) [28–30]. These SSPs outline the trajectory of population, urbanization, and economic growth up to 2100. High socioeconomic growth could considerably drive up demand for timber and lead to greater harvested area in the future. Shifting from sustainable development to fragmented socio-economic development may trigger a 60% increase in harvest volumes in the long run [31]. To elaborate specifically on forest sector development, Daigneault et al. [32] developed detailed narratives for how the global forest sector could vary across the five different SSPs, through the development of Forest Sector Pathways (FSPs). However, illustrating the impacts of these FSPs on future wood energy markets is still in its infancy [31], though some attempts have been made (e.g., [25]). Since the U.S. South is the world's largest wood-energy-producing region, there is also a growing need to address the impact of expanded global wood energy demand on the U.S. regional forest product markets.

The aim of this paper is to provide projections of future wood energy market trends under five distinct socio-economic scenarios using a forest sector partial equilibrium model. We extend the previous research on the economic assessment of the fuelwood and wood pellets market in two aspects. First, we investigate the effects of socioeconomic drivers on the production, consumption, and trade of wood energy on a global scale, with an emphasis on the largest wood-pellet-producing region in the world, the United States. Second, we disaggregate the broad category of wood-based bioenergy into two categories—fuelwood and wood pellets—which depend heavily on the production of other primary forest products in a complex manner. In addition, by considering market interactions with other forest products (i.e., sawnwood and pulp and paper), we contribute to the discussion about the potential impacts of growing wood pellet demand on the dynamics of different forest product markets into the future.

The rest of the paper is structured as follows. In Section 2, we introduce the model and detail the scenarios used in the analysis. In Section 3, we present the results of the model. In Section 4, we discuss the results of the model and suggestions for future study. For a detailed mathematical description of the model, one can refer to [33].

2. Materials and Methods

2.1. FOROM

The FOrest Resource Outlook Model (FOROM) is a partial equilibrium model of the world's forest sector that includes forest resources, timber supply, demand for intermediate and final products, and international trade (see [33]). The modelling framework enables investigations into the influence of external shocks and changes in future socioeconomic conditions on the production, consumption, trade, and prices of raw material, intermediates, and final products, controlling for changes in forest land area and forest standing stock. The FOROM was originally designed to provide the outlook of the global and U.S. forest sector for the U.S. Forest Service 2020 Resource Planning Act (RPA) Assessment.

The current version of the FOROM represents the global wood product market in terms of 20 distinct interconnected products (Figure 1; Appendix A, Table A1) across 55 countries and regions of the world (Appendix A, Table A2), although additional regions and products may be included (see [34]). The model tracks the complex relationships between wood products, which is of particular importance to certain product categories, such as wood pellets, which may receive feedstock from various sources including coniferous and non-coniferous industrial roundwood, fuelwood, or chips, particles, and residuals from sawmilling activities.

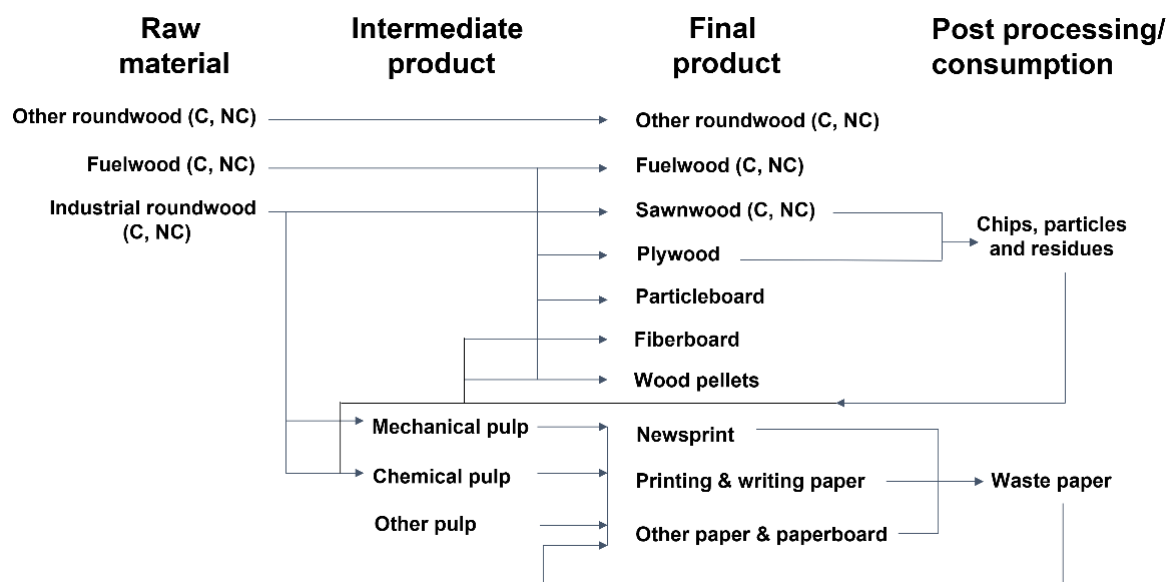


Figure 1. Forest product flow chart in FOROM.

The FOROM consists of solving a series of static equilibria that are connected through dynamic exogenous assumptions. In the static phase, the model maximizes economic welfare for all products in all countries following the law of one price, consistent with the spatial price equilibrium (SPE) framework, where differences in prices between regions are assumed to arise from differences in transport costs (including tariffs and other non-tariff barriers). The most relevant equations of the FOROM model for this study are described below, while the broader modelling framework is presented in Appendix A.

The objective function maximizes the sum of consumers' and producers' surpluses net of transport costs, subject to various constraints related to material balance, resource feasibility, and equilibrium conditions:

$$W = \sum_k \left\{ \sum_j \int_0^{Q_j^k} P_j^k(Q_j^k) dQ_j^k - \sum_i \int_0^{Y_i^k} C_i^k(Y_i^k) dY_i^k - \sum_i \sum_j (t_{ij}^k + \tau_{ij}^k) x_{ij}^k \right\} \quad (1)$$

where P_j^k and Q_j^k refer to the price and quantity of wood product k consumed by region j , while C_i^k and Y_i^k refer to the manufacturing cost and production in region i . The cost of moving product k from region i to j , x_{ij}^k , is a function of the shipping and handling cost, t_{ij}^k , and the associated tariffs, τ_{ij}^k .

The supply of final demand products f from all regions i to region j , including domestic supply, must be greater than or equal to the demand in region j :

$$Q_j^k \leq \sum_i x_{ij}^k \quad (2)$$

where the shadow price gives the demand price, P_j^k .

It follows that the sale of wood products k from region i to all regions j must be no larger than what is produced in region i :

$$Y_i^k \geq \sum_j x_{ij}^k \quad (3)$$

where the shadow price gives the demand price, C_i^k .

Consumers' behavior is represented by a set of constant elasticity demand functions for each final demand product:

$$Q_j^k = \bar{Q}_j^k \left(\frac{\bar{P}_j^k}{P_j^k} \right)^{\eta_j^k} \quad (4)$$

where symbols embellished with a bar indicate benchmark levels, and $\eta_j^k \leq 0$ is the price elasticity of demand. Demand can be linearly approximated by first finding the tangency with the benchmark price and quantity demanded, where small changes in price and quantity are given by:

$$\eta_j^k = \frac{dQ_j^k}{Q_j^k} \frac{P_j^k}{dP_j^k} = \left(\frac{Q_j^k - \bar{Q}_j^k}{\bar{Q}_j^k} \right) / \left(\frac{P_j^k - \bar{P}_j^k}{\bar{P}_j^k} \right) \quad (5)$$

and then rearranged into an inverse constant elasticity of demand curve:

$$P_j^k = \bar{P}_j^k \left(\frac{\eta_j^k - 1}{\eta_j^k} \right) + \left(\frac{\bar{P}_j^k}{\eta_j^k \bar{Q}_j^k} \right) Q_j^k \quad (6)$$

or simply, in reduced form:

$$P_j^k = \alpha_j^k + \beta_j^k Q_j^k \quad (7)$$

Similarly, each supply region i is assumed to have a set of constant elasticity supply curves for each product k , with price elasticity of supply $\mu_i^k \geq 0$:

$$Y_i^k = \bar{Y}_i^k \left(\frac{\bar{C}_i^k}{C_i^k} \right)^{\mu_i^k} \quad (8)$$

which can be linearly approximated in a similar fashion as described for final product demand using benchmark manufacturing costs and quantities:

$$C_i^k = \bar{C}_i^k \left(\frac{\mu_i^k - 1}{\mu_i^k} \right) + \left(\frac{\bar{C}_i^k}{\mu_i^k \bar{Y}_i^k} \right) Y_i^k \quad (9)$$

or simply, in reduced form:

$$C_i^k = a_i^k + b_i^k Y_i^k \quad (10)$$

To satisfy material balance in any given region and product, production plus imports must equal the sum of consumption, exports, and the input of product k required in manufacturing output n , given as a_i^{kn} :

$$Y_i^k + \sum_j x_{ji}^k = Q_i^k + \sum_j x_{ij}^k + \sum_n a_i^{kn} Y_i^n \quad (11)$$

The manufacture of byproducts (i.e., sawmilling byproducts, recycled paper) are a function of primary product manufacturing, represented by:

$$Y_i^b = \sum_n \theta_i^{nb} Y_i^n \quad (12)$$

where θ_i^{nb} is the amount of byproduct $b \subseteq k$ recovered per unit of manufactured output n .

In the static phase, equilibrium prices, quantities, and net trade levels are obtained by solving the problem of maximizing the objective function subject to various economic and engineering constraints. Once a solution for the current period, t , is determined, the model will enter the dynamic phase, in which the parameters of the model are updated based on exogenous drivers (e.g., GDP growth, population growth, changes in productivity, and changes in trade openness) and endogenous variables (e.g., harvest levels, standing stock levels, etc.) in preparation for the next iteration cycle.

Demand is assumed to change over time through exogenous shifts to GDP per capita, $\dot{y}_t$, and translated through the growth rate of per capita GDP, $g_j^{\dot{y}_t}$, and the elasticity of demand with respect to the growth rate of per capita GDP, δ_j^k :

$$\bar{Q}_j^k = Q_j^k \left(1 + \delta_j^k g_j^{\dot{y}_t} \right) \quad (13)$$

Supply of harvestable inputs (i.e., industrial roundwood, fuelwood, other roundwood) are assumed to change over time through exogenous shifts to forest area and forest stock:

$$\bar{Y}_i^k = Y_i^k \left(1 + \varepsilon_i^k g_{i,t}^A + \nu_i^k g_{i,t}^I \right) \quad (14)$$

where $g_{i,t}^A$ is an exogenous change in the growth rate of forest area at time t ; $g_{i,t}^I$ is an endogenously determined growth rate of forest inventory, which changes over time based on the specified nonlinear negative relationship between forest growth and stocking density; and ε_i^k and ν_i^k are elasticities associated with forest area and inventory, respectively.

The main data source for reference prices, quantities, and trade is FAOSTAT (see Table A2). Data on production, import value, import quantity, export value, and export quantity are directly recorded in the database. Consumption is calculated as apparent consumption, equal to production plus import minus export. Data on prices of all 20 forest products are not available in the FAOSTAT database. We follow the method proposed in Buongiorno et al. [35] and choose the unit values of imports or exports (import or export value in US dollars divided by import or export quantity) as the prices. Data on forest areas and stocks are obtained from the FAO's 2010 and 2015 Global Forest Resources Assessments (FRA).

We employ a goal programming approach for reconciling apparently inconsistently reported data (e.g., negative apparent consumption, gaps between total imports and exports) and missing data for the reference year. This approach also re-estimates input–output coefficients and the manufacturing costs for each country/region. The calibrated manufacturing costs are equal to the price of the output minus the cost of wood and fiber input under the zero-profit assumption in each market. The details of the goal programming approach are explained in [33].

The United States is disaggregated into six Resources Planning Act (RPA) Assessment regions (Figure 2) from country-level data, with the primary means of disaggregation based on data from the USDA Forest Service’s Timber Product Output (TPO) program and the United States International Trade Commissions (USITC). These supplemental datasets provided the basis for calculating regional shares, from which FAOSTAT country level data are reconciled.

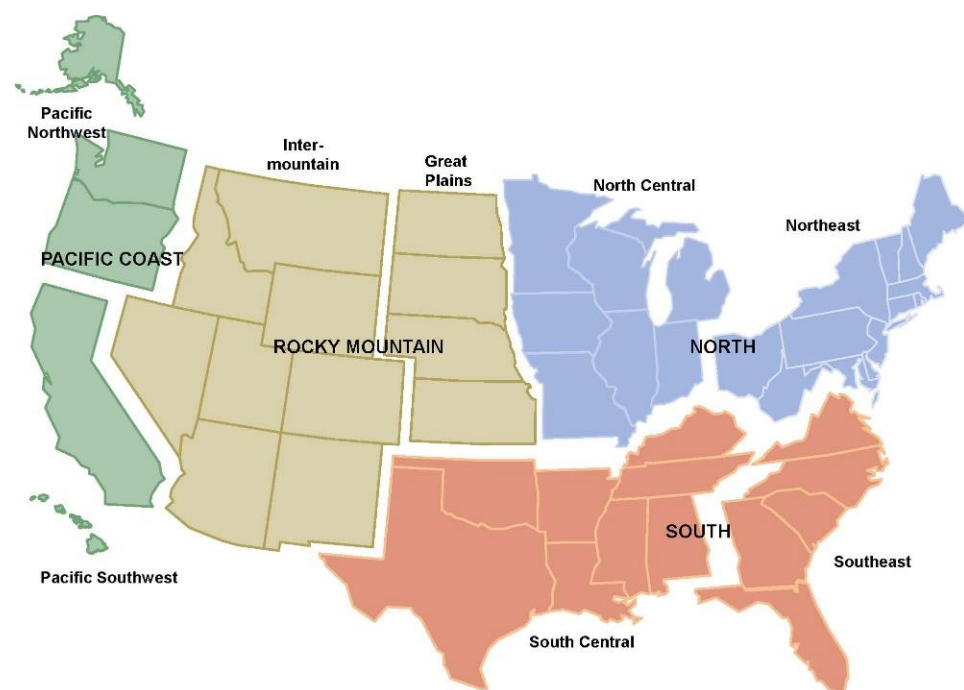


Figure 2. United States Resources Planning Act regions represented in FORUM.

2.2. IPCC Shared Socioeconomic Pathways

The global research community has developed five Shared Socio-economic Pathways (SSPs) describing alternative changes in economic, social, and environmental factors up to 2100 [36,37]. The five broader narratives have been translated into quantitative assumptions in the IIASA SSPs database [35]. Furthermore, as mentioned above, Daigneault et al. [32] developed detailed narratives for how the global forest sector, in particular, could vary across the five SSPs. These narratives serve as key inputs into the modeling process. A brief narrative for each is described follows.

The SSP1 (often referred to as the “Sustainability”) scenario characterizes a more sustainable world where consumption is oriented toward less resource-intensive energy. The world focuses more on low-consumption growth and improved energy efficiency. More sustainable awareness reduces damages to the environment. Land use is strongly regulated. Globalization is developing rapidly. All these factors lead to relatively high economic and urbanization levels, and a moderate level of international trade, but the lowest population level. In this scenario, the world faces low challenges to both mitigation and adaptation.

The SSP2 (“Middle of the Road”) scenario describes a world where social, economic, and technological development will not divert markedly from historical trends. This pathway foresees a moderate growth of the global population and economy. Energy generation continues to rely on fossil fuels at a similar rate as today. The global economy is characterized as semi-open by reduced trade barriers. Land use is incompletely regulated. This scenario faces medium challenges to adaptation and mitigation.

SSP3 (“Regional Rivalry”) describes a world with high challenges to adaptation and mitigation, the opposite of sustainability. This pathway features the lowest economic growth and highest population growth. There is only minor improvement in technologies and energy efficiency. Land use change is hardly regulated. Countries focus on achieving energy objectives within their own region. De-globalization severely restricts international trade, and development becomes fragmented across regions.

The world in the SSP4 (“Inequality”) scenario portrays stagnating economic growth among the poorer countries of the world, leading to a persistent and growing divide in the socioeconomic development prospects of rich versus poor countries. High-income nations have high land use change regulations, while low-income nations have weak land use change regulation. In this divided pathway, the world faces low challenges to mitigation for modest climate targets, but it will be quite difficult to adapt to it.

The SSP5 (“Fossil-fueled Development”) scenario envisions a strongly globalized and fossil-fuel-intensive world with high energy use and greenhouse gas emissions. This pathway features a relatively low growth rate of population but an unconstrained growth in economic output. Accelerated globalization leads to a high level of international trade and market connectivity. Land use change is modestly regulated. This “fossil-fueled development” faces high challenges to mitigation, but low challenges to adaptation.

The SSPs were operationalized within the dynamic phases of FORUM through exogenous changes in gross domestic product (GDP), population, technological development, trade openness, and bioenergy demand preferences (Figure 3 and Table 1). Wear and Prestemon [38] developed a method to jointly downscale national-scale income and population projections to counties within the United States. Technological development implies the degree to which the global forest sector becomes efficient in transforming raw materials into finished products. Trade openness relates to the frictions embedded in the model as it relates to the movement of goods between foreign regions of the model. These later two exogenous drivers are stylized to reflect the storylines of the SSPs, consistent with what is outlined in Daigneault et al. [32].

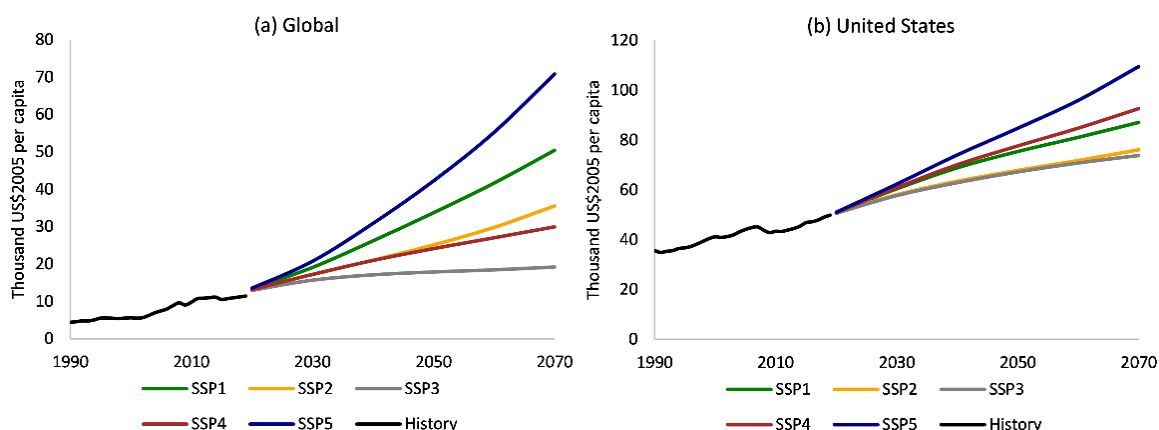


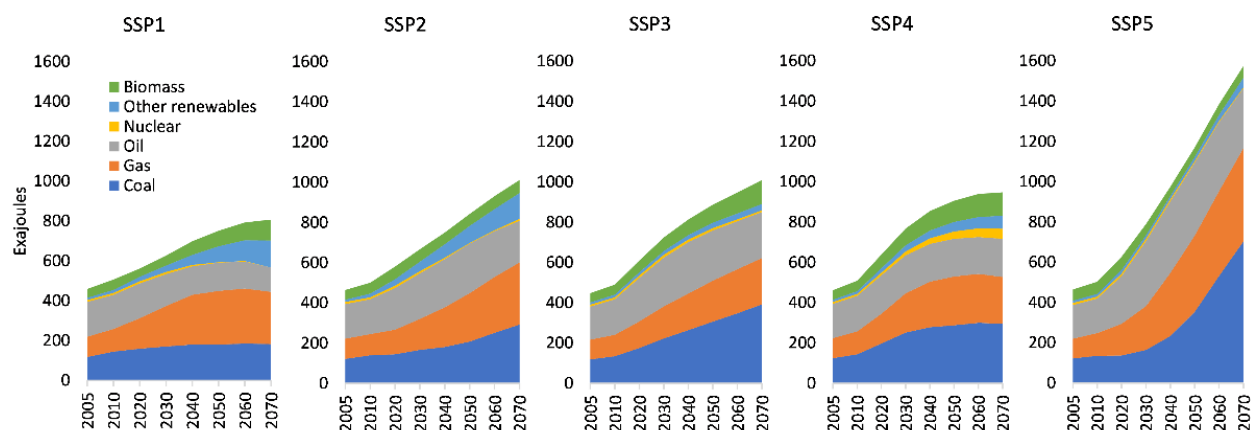
Figure 3. Historic and projected GDP per capita for IPCC Shared Socioeconomic Pathways: (a) global, (b) United States (source: [39]).

Table 1. Key exogenous drivers of global trends in the SSP scenarios *.

Exogenous Driver	Variable	SSP1	SSP2	SSP3	SSP4	SSP5
GDP	$g_j^{y_t}$	High in LICs, MICs; moderate in HICs	Moderate	Low	Low in LICs, moderate in other countries	High
Population	$g_j^{y_t}$	Relatively low	Moderate	Low in OECD, high in other countries	High in LICs, low in other countries	High in OECD, low in other countries
Technological change	a_i^{kn}	High	Moderate	Low	High in HICs, moderate in other countries	High
Trade openness	t_{ij}^k	Moderate	Moderate	Low	Moderate	High
Secondary bioenergy demand	Calibrated to IPCC	High	Moderate	Low	Moderate	High
Fuelwood demand	Calibrated to IPCC	High	Moderate	Moderate	High	Low

* LIC = low-income country; MIC = middle-income country; HIC = high-income country.

The demand for bioenergy in the form of fuelwood as well as wood pellets in FORUM is assumed to be driven not only by economic development assumptions, but also by differences in consumer preference and policy assumptions underpinning the IPCC's shared socioeconomic pathways. For fuelwood demand, FORUM incorporates trends consistent with global primary energy from biomass from the IPCC SSP scenarios (Figure 4). Similarly, the evolution of wood pellet consumption in FORUM is not only driven by changes in GDP per capita, but also constrained using trends in global secondary biomass energy production to capture SSP-related preference and policy differences (Figure 5). Global growth rates of secondary energy were used to scale recent regional growth rates. Secondary energy is energy that has been converted, and in the case of bioenergy, this could represent energy sourced from biomass, including wood pellets.

**Figure 4.** Global primary energy production for IPCC Shared Socioeconomic Pathways (source: [35]).

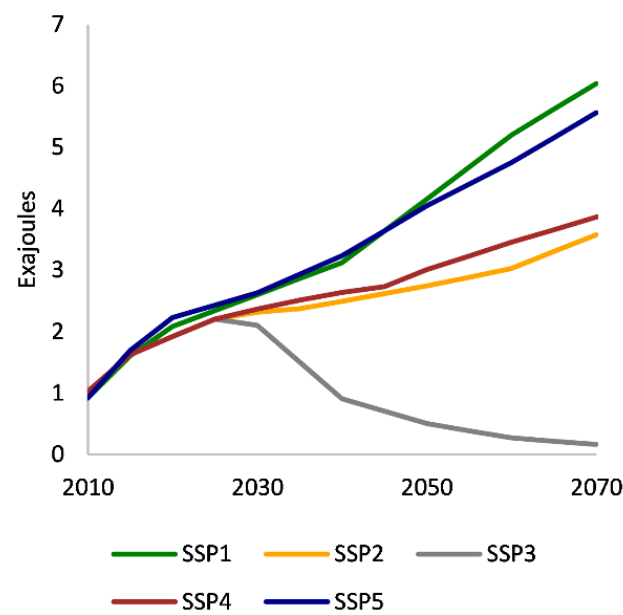


Figure 5. Global secondary energy production for IPCC Shared Socioeconomic Pathways (source: [35]).

3. Results

3.1. Global

Global consumption of fuelwood has increased modestly over the last few decades, from 1833 million m³ in 1990 to 1901 million m³ in 2015 (Figure 6a). By 2070, it is estimated that global fuelwood consumption could reach as high as 2370 million m³ under SSP1 or as little as 1435 million m³ under SSP5. The Middle of the Road scenario, SSP2, projects fuelwood consumption to remain around current levels through the next 50 years, reaching 1858 million m³ by 2070.

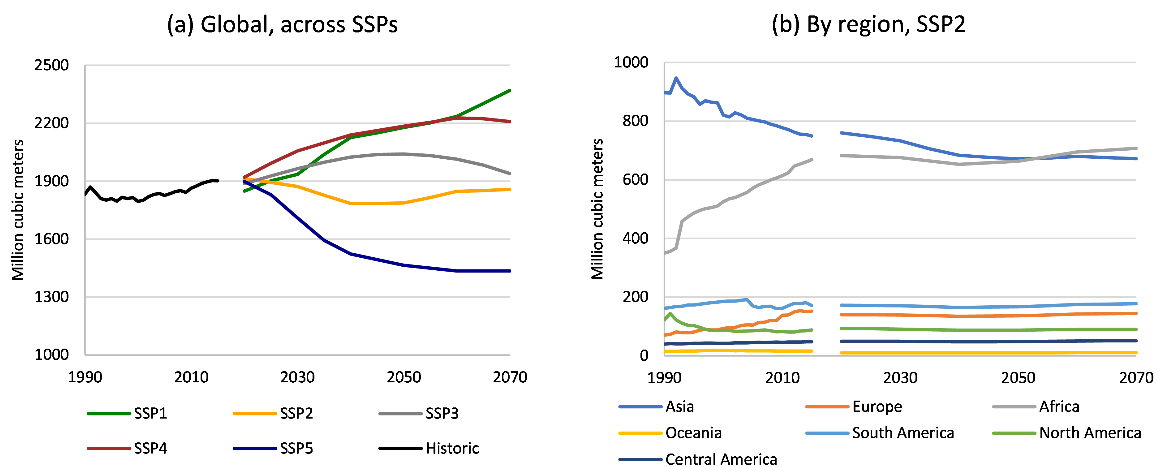


Figure 6. Global consumption of fuelwood (a) across SSPs and (b) by region within SSP2, 1990 to 2015 historic, 2020 to 2070 projections from FORUM.

It is projected that the regional consumption of fuelwood may vary across countries, within a scenario. Figure 6b projects fuelwood consumption by region under SSP2. Here, the consumption of fuelwood in Asia has fallen from nearly 900 million m³ in 1990 to around 785 million m³ by 2015. It is projected that Asia will continue to experience a declining demand for fuelwood under SSP2, reaching a consumption of 750 million m³ by 2070. Part of these losses have been offset by increases in consumption of fuelwood out of Africa over the last few decades. Since 1990, Africa has increased its consumption of fuelwood by nearly 300 million m³. However, it is expected that this increase in consumption will moderate as the African economy further develops, with consumption rising only modestly through to 2070. Country/regional-level historical data and projections are provided in Appendix B (see Tables A3–A6).

The global production of fuelwood has historically relied significantly on hardwood species (Figure 7). Fuelwood from hardwood species comprised 85 percent of total production in 1990, rising to nearly 88 percent of total production by 2015. Under SSP2, this trend is expected to continue, with hardwood fuelwood representing nearly 90 percent of total fuelwood production globally.

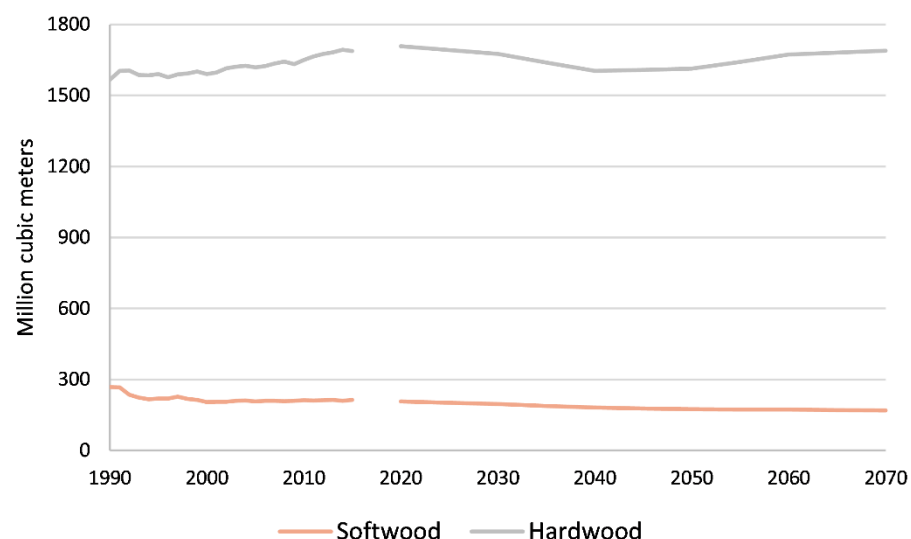


Figure 7. Global production of fuelwood by species type, SSP2, 2012 to 2015 historic, 2020 to 2070 projections from FORUM.

Figure 8 provides the projected path for global fuelwood prices across the five SSPs. This price reflects a weighted average price of both softwood and hardwood fuelwood feedstock. The sustainably minded SSP1 scenario is projected to bring with it the highest prices in fuelwood through 2070. This is driven by strong demand for fuelwood as a primary energy source, as well as demand for wood pellets in secondary energy generation. In contrast, the global average fuelwood price in the SSP5 scenario—a fossil-fuel-dominated world—is expected to decline over time. Driven in large part though declining demand for fuelwood as a sustainable energy source, the price level throughout the simulation is the lowest of the five scenarios.

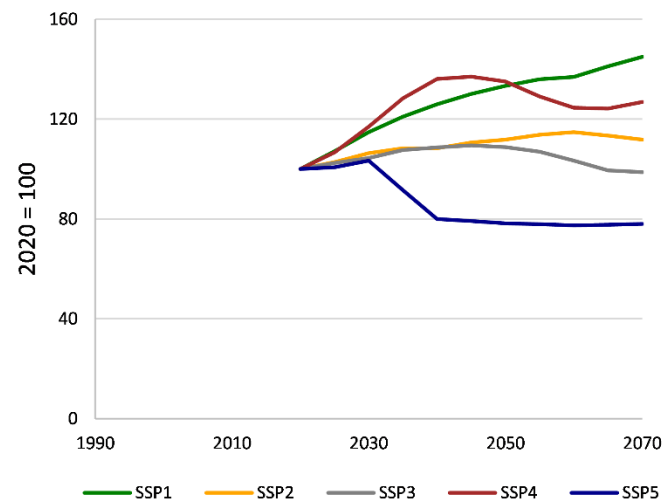


Figure 8. Global average price of fuelwood across SSPs, 2020 to 2070 projections from FORUM.

Global wood pellet consumption data is only available through FAOSTAT since 2012. Yet, since 2012, there is a clear increasing trend in global consumption, rising from 17 million metric tons in 2012 to 27 million metric tons by 2015 (Figure 9a). It is projected that demand for wood pellets will continue to rise through 2070 under all SSPs, except SSP3. Most of the global rise is projected for European countries, especially Germany, Sweden, Belgium, and France. (Other major consumers, including Denmark and the Netherlands, are tallied in the “Rest of Europe” row of the tables in Appendix B. We also note that the United Kingdom is projected under all scenarios to decrease its consumption of wood pellets, the result of a projected pulling back in demand following their withdrawal from the European Union in 2020.) This scenario sees high challenges to adaptation and mitigating climate change and assumes countries do not put significant resources towards sustainability. As a result, wood pellet consumption in SSP3 is projected to decline to around 10 million metric tons by 2070. In contrast, the more sustainably focused pathway of SSP1 projects a large rise in the consumption of wood pellets, reaching 107 million metric tons by 2070.

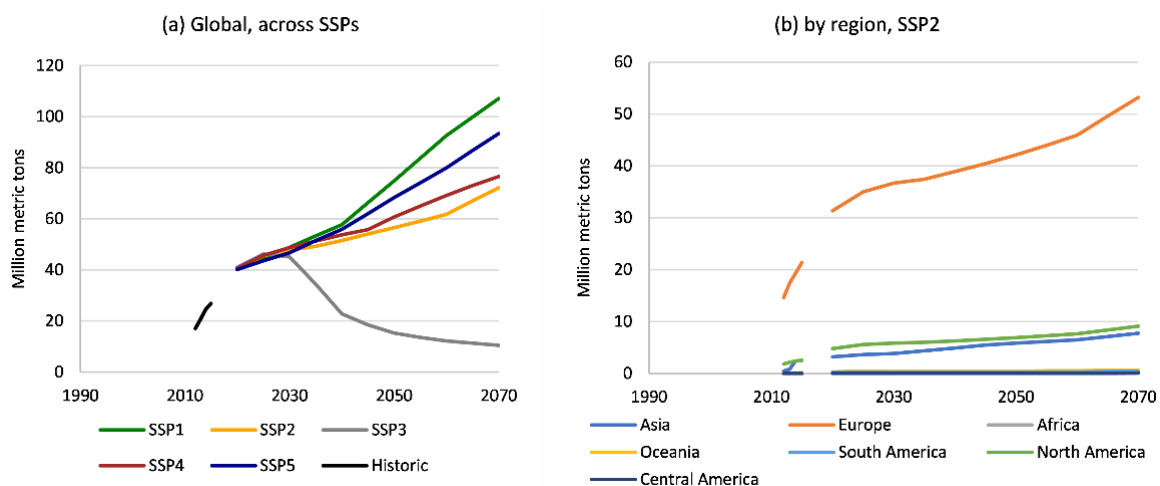


Figure 9. Global consumption of wood pellets (a) across SSPs and (b) by region within SSP2, 2012 to 2070 projections from FORUM.

Demand for wood pellets has historically been dominated by European regions (Figure 9b, and see the appendix for country-level data), supported in part through aggressive policies aimed at climate change mitigation. It is projected that Europe will continue to be the dominant wood-pellet-consuming region under SSP2, with consumption rising from just over 20 million metric tons in 2015 to over 50 million metric tons by 2070. Increases are projected for North America, with consumption projected to more than triple, increasing from 2.6 million metric tons in 2015 to 9.2 million metric tons by 2070. Asia is also projected to contribute to this rising global demand for wood pellets, increasing its consumption from 2.5 million metric tons in 2015 to almost 8 million by 2070.

Since the collection of comprehensive wood pellet market data began in 2012, the market has been dominated by North American exports of wood pellets to European markets (Figure 10). North American net exports of wood pellets doubled between 2012 and 2015, and it is projected that this trend will continue under SSP2, albeit on a slower path. In addition, as Asian economies begin demanding more wood pellets for power and heat generation under this scenario, much of the demand growth is met with imports—driving net exports from positive to negative by mid-century (Figure 10).

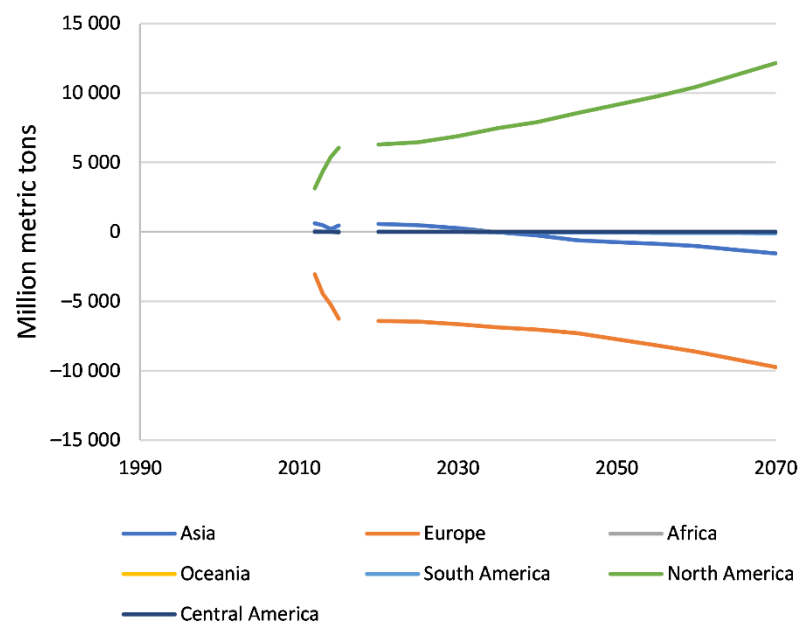


Figure 10. Global net exports of wood pellets, by region, for SSP2, 2012 to 2015 historic, 2020 to 2070 projections from FORUM.

The global average price of wood pellets is presented in Figure 11. Consistent with the projections of pellet consumption provided in Figure 9a, it is projected that the price for wood pellets will continue to rise through 2070 under all SSPs, except SSP3. This scenario describes a world that faces high challenges to adaptation and mitigating climate change and assumes countries do not put significant resources towards sustainability—including wood pellets. As a result, wood pellet consumption in SSP3 is projected to decline substantially over time, driving a nearly 60% decline in the price of pellets by 2070. In contrast, the more sustainably focused pathway of SSP1 projects a large rise in both the consumption and price of wood pellets during this time.

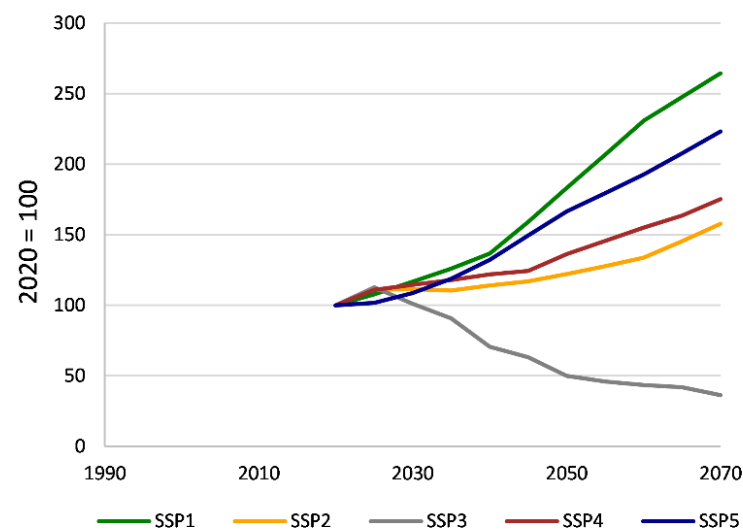


Figure 11. Global price of wood pellets across SSPs, 2020 to 2070 projections from FOROM.

3.2. United States

The vast majority of fuelwood consumed within the U.S. is sourced domestically. Fuelwood production within the U.S. was nearly halved between 1990 and 2000, dropping from over 80 million m³ in 1990 to just over 40 million m³ by 2000 (Figure 12a). Since then, the production of fuelwood within the U.S. has stagnated, hovering around 40 million m³ through to 2015. There is a range of projections of how U.S. fuelwood production may evolve through to 2070 under the SSPs. SSP2 projects a continuation of current trends, with fuelwood production remaining just over 40 million m³ through 2070. Meanwhile, it is projected that U.S. fuelwood production may reach anywhere between 34 and 65 million m³ under SSP5 and SSP1 respectively, by 2070.

The production of fuelwood within the U.S. is largely concentrated east of the Rocky Mountains (Figure 12b). In 2020, it is estimated that 52 percent of national fuelwood was produced in the U.S. South, while another 40 percent originated in the North. These trends are projected to largely continue through to 2070, with the U.S. South increasing its share of production to 54 percent, while the U.S. North remains at 40 percent.

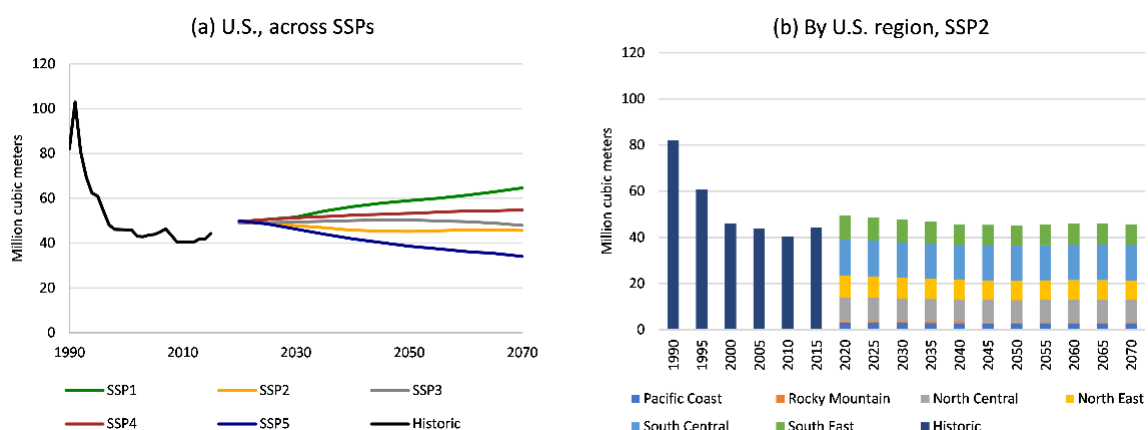


Figure 12. United States production of fuelwood (a) across SSPs and (b) by region within SSP2, 1990 to 2015 historic, 2020 to 2070 projections from FOROM.

The majority of fuelwood within the U.S. is sourced from hardwood forests (Figure 13). Both species groups have experienced similar paths between 1990 to 2015, with a sharp decline from 1990 to 2000, followed by relatively little change in production volumes. In 1990, 81 percent of all fuelwood produced within the United States was sourced from

hardwood species, and by 2070, it is projected that this will rise to 85 percent. While this change is modest, most of this growth originates out of the U.S. South East region, where its share of all hardwood fuelwood production increases from 31 percent in 2020 to 34 percent by 2070 (Figure 13b). The shares of production from other U.S. regions remain similar to their current levels.

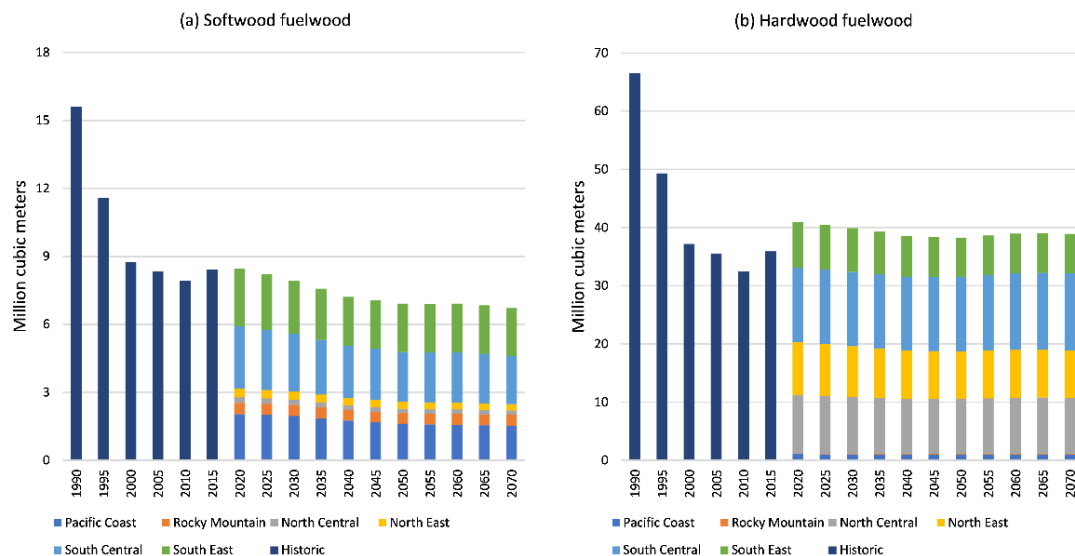


Figure 13. United States production of fuelwood by (a) softwood and (b) hardwood species groups, within SSP2, 1990 to 2015 historic, 2020 to 2070 projections from FOROM.

The production of wood pellets in the United States has risen sharply since the collection of data began in 2012, rising from 3.5 to 6.5 million metric tons by 2015 (Figure 14a). Similar to what was observed at the global level, production levels are projected to be the greatest under the sustainably minded SSP1 scenario, reaching 21 million metric tons by 2070. In contrast, SSP3 projects wood pellet production growth in the U.S. will slow and then reverse, drifting downward to its 2012 level of 3.5 million metric tons by 2070. The Middle of the Road scenario, SSP2, predicts wood pellet consumption in the United States will reach around 15 million metric tons by 2070, driven through a steady increase in the global demand for wood pellets as a secondary energy source.

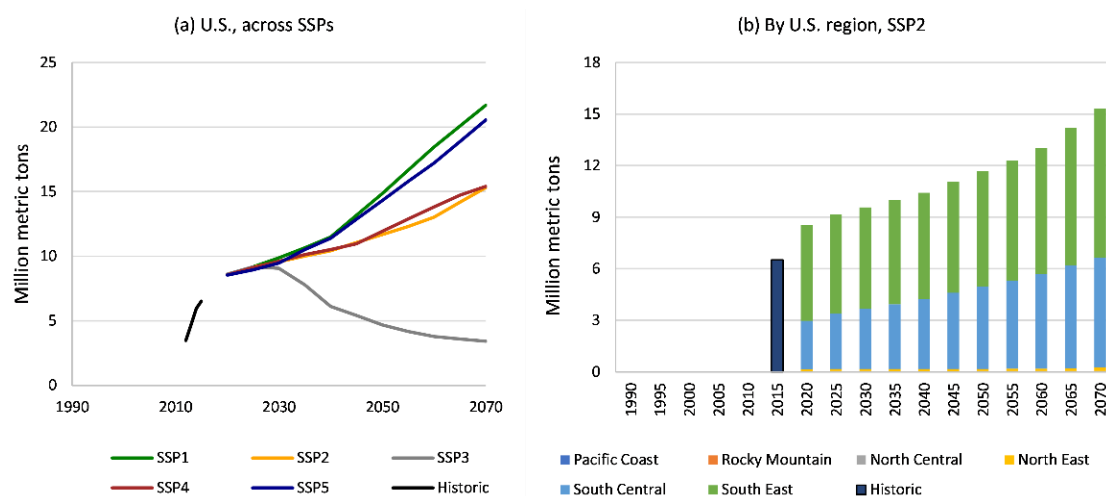


Figure 14. United States production of wood pellets (a) across SSPs and (b) by region within SSP2, 2012 to 2015 historic, 2020 to 2070 projections from FOROM.

Consistent with recent trends, the U.S. South is projected to supply the vast majority of wood pellets within the U.S. (Figure 14b). Growth in production in the U.S. South East is projected to be more rapid than in the South Central region under SSP2; the South East's share of national production rises from 33 percent in 2020 to 42 percent by 2070. Meanwhile, the South East region is predicted to continue to be the main production site within the U.S., producing over 50 percent of all wood pellets within the U.S. throughout the projection.

Within the FORUM model settings, the input for wood pellets can be sourced from six different feedstocks: softwood and hardwood fuelwood and industrial roundwood, as well as chips, particles, and residuals associated with sawmilling activities. It is estimated that while chips, particles, and residuals provide the majority of feedstock for wood pellets throughout the U.S. under SSP2, this may vary across regions (Figure 15). While the Pacific Coast and Rocky Mountain regions source most of their feedstock from softwood industrial roundwood, the production of wood pellets in these regions is negligible when compared to the South regions. Focusing on the South regions, sawmilling residuals are estimated to provide the bulk of feedstock for wood pellet production, followed by hardwood fuelwood, softwood industrial roundwood, and a small amount of softwood fuelwood. It is not projected that increases in domestic production of wood pellets within the U.S. will have to rely on increasing shares of dedicated harvesting, but rather on increased utilization of sawmilling residuals.

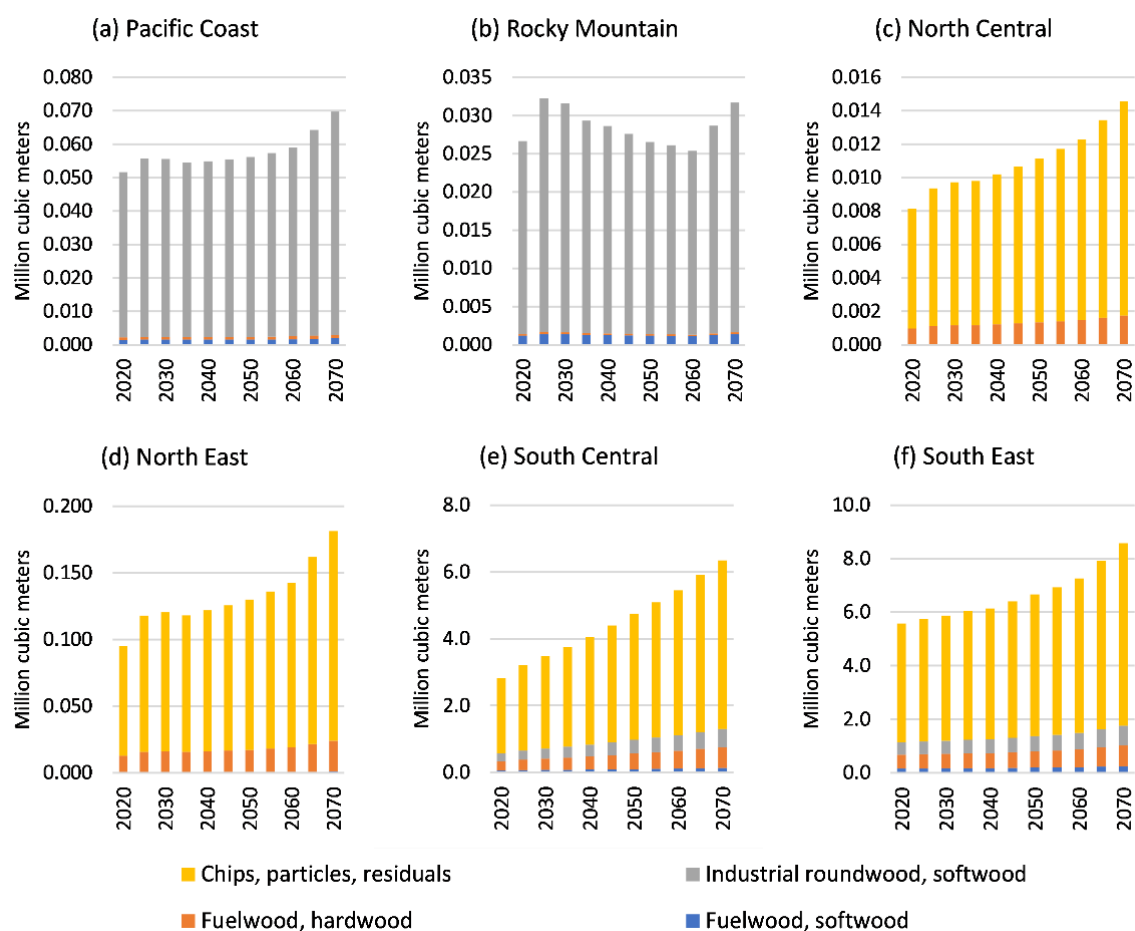


Figure 15. United States wood pellet feedstock by region and type, SSP2, projections from FORUM: (a) Pacific Coast, (b) Rocky Mountain, (c) North Central, (d) North East, (e) South Central, (f) South East.

4. Discussion and Conclusions

Across four out of five scenarios evaluated, we project a rising use of roundwood and mill chips, particles, and residuals to produce a growing output of wood pellets in the United States and globally. The projections show global wood pellet production and consumption tripling or quadrupling by 2070 compared to 2015 under all but the SSP3 scenario. Along with recent historical data on wood pellet production, it is notable that Europe is projected under all scenarios except SSP3 to remain the world's primary wood-pellet-producing region, with their production comprising more than half of global wood pellet output. All of North America is projected in those scenarios to produce less than half the quantity produced in Europe. This result implies that European nations would be faced with continued and rising competition for wood inputs in competing industries—particularly in pulp and paper manufacturing, the dominant consumer of sawmill residues on the continent.

The results on wood pellet production and consumption presented here are in part the outcome of assumptions on pellet demand that were designed in our study to adhere to the storylines embedded in the SSPs. Europe's dominance of global demand for wood pellets, to help that continent achieve its own climate goals, further explains the sustained and growing supply position of the U.S. South regions to meet that demand. Results under SSP3 are one way to judge the overall impact of the European energy policy on global markets, with global consumption in 2070 being less than one-third of the consumption under SSP2 in 2070 (for example).

It also bears mentioning that wood pellet consumption has been and is projected under all scenarios to represent wood quantities that are less than 5% the size of fuelwood. Large portions of the world, particularly in Africa and Asia, have been and are projected to remain reliant on fuelwood as a primary energy source for heating and cooking, even though overall consumption of fuelwood declines under some scenarios.

Wood pellet production and consumption, while small relative to fuelwood, has demonstrated influences in product markets that are projected to continue and grow. Our modeling indicates an eventual slowdown in wood pellet consumption growth across all scenarios compared to the high rates evident in the last decade. Nevertheless, growth is projected to expand under SSP2 by 150% over fifty years, an annualized rate of just under 2%. Although North American (including U.S.) and Asian consumption growth is projected to be vigorous even with SSP2, the absolute consumption quantity growth in both continents would be one-fifth that of Europe's. With the United States demonstrating substantial new wood pellet production capacity growth in the last decade and continuation of capacity growth in the projected future, the trade implications of these divergent trends are not unsurprising: the United States is projected under most scenarios to remain the world's largest net exporter for the next five decades, while Europe remains import dependent.

This study, unlike Nepal et al. [18] or others, offers a picture of the U.S. regional geographic distribution of wood pellet production growth into the future across multiple future economic and demographic change scenarios, providing industry decision makers with a range of possible futures beyond the business-as-usual case. We find that, just as market factors help to determine the spatial distribution of individual producers of wood pellets [40], market factors define the likely overall national distribution of wood pellet manufacturing and the market competition facing composite panel and pulp and paper mills in the United States in the coming decades. Consistent with recent historical experience, we project only small changes in fuelwood use in the United States, a continued dominance of the U.S. South in national wood pellet markets, and primary reliance on mill residues in pellet manufacturing. The results on the dominance of U.S. South regions in wood pellet production mirror similar analyses carried out by Nepal et al. [18]. Although wood pellet producers in the U.S. West have historically sourced, and are projected to continue to source, most of their wood input from industrial roundwood as their output rises until 2070 under most scenarios, industry growth in the West is projected to be limited

compared to the South, which is responding primarily to quickly growing European demand, ensuring that industrial roundwood sourcing will play an overall minor role in the growth of the wood pellet industry.

Wood pellets are projected under SSP1, 2, 4, and 5 to more than double in output and thereby consume an increasing share of total wood production in the US, rising from about 2% to 3.5%, likely resulting in pressure on input prices. That result, consistent with other projections (e.g., [18]) and recent observations (e.g., [41]), would be the result of projected increasing direct competition for those materials with composite mills and pulp and paper manufacturers, in the South regions especially. Although softwood industrial roundwood is not projected under most scenarios to represent the majority of wood pellet manufacturing input volume overall in the United States, that input category also is projected to rise in total volume, implying rising competition that puts upward pressure on softwood industrial roundwood prices (e.g., [19]).

5. Disclaimers

The findings and conclusions in this publication are those of the authors and should not be construed to represent any official U.S. Department of Agriculture or U.S. Government determination or policy.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Structure and Mathematical Formulations of the Forest Resource Outlook Model (FOROM)

Table A1. Wood product categories represented in FOROM.

Name	Description	Units
Industrial roundwood	Sawlogs and veneer logs; pulpwood, round and split; and other industrial roundwood.	m ³
Fuelwood	Roundwood that will be used as fuel for purposes such as cooking, heating, or power production.	m ³
Other roundwood	Industrial roundwood (wood in the rough) other than sawlogs, veneer logs, and/or pulpwood.	m ³
Sawnwood	Wood that has been produced from both domestic and imported roundwood, either by sawing lengthways or by a profile-chipping process, and that exceeds 6 mm in thickness.	m ³

Table A1. *Cont.*

Name	Description	Units
Plywood	A panel consisting of an assembly of veneer sheets bonded together with the direction of the grain in alternate plies, generally at right angles. Thin sheets of wood of uniform thickness, not exceeding 6 mm, rotary cut (i.e., peeled), sliced or sawn.	m ³
Particleboard	A panel manufactured from small pieces of wood or other ligno-cellulosic materials (e.g., chips, flakes, splinters, strands, shreds, shives, etc.) bonded together by the use of an organic binder together with one or more of the following agents: heat, pressure, humidity, a catalyst, etc. The particle board category is an aggregate category. It includes oriented strandboard (OSB), medium-density particle board (MDP), waferboard, and flaxboard.	m ³
Fiberboard	A panel manufactured from fibres of wood or other ligno-cellulosic materials with the primary bond deriving from the felting of the fibres and their inherent adhesive properties (although bonding materials and/or additives may be added in the manufacturing process). It includes fibreboard panels that are flat-pressed and moulded fibreboard products. In JQ1 and JQ2, it is an aggregate comprising hardboard, medium/high-density fibreboard (MDF/HDF), and other fibreboard.	m ³
Mechanical pulp	Wood pulp obtained by grinding or milling pulpwood or residues into fibres, or through refining chips or particles.	t
Chemical pulp	Wood pulp obtained by subjecting pulpwood, wood chips, particles, or residues to a series of chemical treatments. It includes sulphate (kraft) wood pulp; soda wood pulp and sulphite wood pulp.	t
Other pulp	Pulp manufactured from recovered paper or from fibrous vegetable materials other than wood and used for the manufacture of paper, paperboard, and fibreboard.	t
Newsprint	Paper mainly used for printing newspapers. It is made largely from mechanical pulp and/or recovered paper, with or without a small amount of filler.	t
Printing and writing paper	Paper, except newsprint, suitable for printing and business purposes, writing, sketching, drawing, etc. Made from a variety of pulp blends and with various finishes.	t
Other paper and paperboard	Other papers and boards for industrial and special purposes.	t
Wood pellets	Agglomerates produced either directly by compression or by the addition of a binder in a proportion not exceeding 3% by weight.	t
Chips, particles, and residuals	Wood that has been reduced to small pieces and is suitable for pulping, for particle board, and/or fibreboard production, for use as a fuel, or for other purposes.	m ³
Waste paper	Waste and scraps of paper or paperboard that have been collected for re-use or trade.	t

Note: Adapted from FAOSTAT definitions. <http://www.fao.org/forestry/34572-0902b3c041384fd87f2451da2bb9237.pdf>, accessed on 27 April 2022.

Table A2. Countries and regions represented in FOROM in the current study.

Africa	Asia	Europe	Central America	North America	Oceania	South America	World
Nigeria	China	Austria	Rest of Central America	Canada	Australia	Argentina	Rest of World
South Africa	India	Belarus		Mexico	New Zealand	Brazil	
Rest of Africa	Indonesia	Belgium		United States	Rest of Oceania	Chile	

Table A2. Cont.

Africa	Asia	Europe	Central America	North America	Oceania	South America	World
	Japan	Estonia		North Central		Uruguay	
	Malaysia	Finland		North East		Rest of South America	
	Myanmar	France		Pacific Coast			
	Russian Federation	Germany		Rocky Mountain			
	Thailand	Latvia		South Central			
	Turkey	Norway		South East			
	Vietnam	Poland		Rest of North America			
	Rest of Asia	Portugal					
		Romania					
		Russian Federation					
		Slovakia					
		Spain					
		Sweden					
		Ukraine					
		United Kingdom					
		Rest of Europe					

Appendix B. Detailed Projections of Fuelwood and Wood Pellets by Country and Region

Table A3. Fuelwood consumption (million m³), 1990 to 2015 historic, 2070 projections from FOROM.

Region/Country	1990	2015	2070				
			SSP1	SSP2	SSP3	SSP4	SSP5
AFRICA	349.5	658.1	905.4	695.4	674.8	800.9	551.5
Nigeria	50.9	65.3	94.6	72.8	68.5	71.0	55.7
South Africa	11.8	13.2	18.5	14.5	14.2	16.8	11.7
Rest of Africa	286.7	579.6	792.2	608.0	592.0	713.0	484.1
ASIA	897.0	784.6	902.8	750.1	812.1	876.1	605.2
China	287.3	219.0	122.5	146.9	222.4	179.5	124.0
India	276.2	305.7	426.5	329.5	322.4	386.6	262.4
Indonesia	126.0	48.3	67.5	51.8	50.4	61.0	41.1
Japan	0.1	2.8	0.1	0.1	0.1	0.1	0.0
Malaysia	4.0	2.6	3.6	2.7	2.7	3.2	2.2
Myanmar	32.3	38.3	53.5	40.9	39.8	37.6	32.5
Thailand	21.8	18.8	26.5	20.4	19.9	24.0	16.1
Vietnam	26.5	20.0	27.9	21.5	21.1	25.3	16.9
Rest of Asia	122.7	129.1	174.7	136.4	133.4	158.8	110.0

Table A3. Cont.

Region/Country	1990	2015	2070				
			SSP1	SSP2	SSP3	SSP4	SSP5
CENTRAL AMERICA	39.8	44.7	57.6	47.1	46.3	53.1	40.0
Mexico	34.4	37.5	48.4	39.5	38.8	44.6	33.4
Rest of Central America	5.4	7.2	9.2	7.6	7.5	8.5	6.5
EUROPE	70.7	119.4	143.8	113.8	111.6	130.8	93.0
Austria	2.6	3.3	4.4	3.7	3.7	4.1	3.2
Belarus	0.0	2.9	4.0	3.1	3.0	3.6	2.4
Belgium	0.0	0.8	1.5	1.1	1.1	1.3	0.9
Estonia	0.0	1.9	2.0	1.6	1.5	1.8	1.2
Finland	3.0	5.0	6.4	5.1	5.0	5.8	4.3
France	36.9	27.1	35.6	28.2	27.7	32.4	23.1
Germany	4.4	16.4	9.5	7.8	7.7	8.8	6.6
Latvia	0.0	1.0	1.0	0.8	0.8	0.9	0.6
Norway	0.9	1.4	1.9	1.5	1.4	1.6	1.2
Poland	2.6	4.3	5.2	4.3	4.3	4.9	3.7
Portugal	0.5	0.6	0.6	0.5	0.5	0.6	0.4
Romania	1.9	4.8	6.8	5.4	5.3	6.2	4.4
Russian Federation	0.0	4.5	6.2	4.7	4.6	5.6	3.8
Slovakia	0.0	0.3	0.2	0.2	0.2	0.2	0.2
Spain	1.8	2.6	3.2	2.7	2.6	3.0	2.3
Sweden	3.8	5.4	6.8	5.7	5.6	6.2	4.9
Turkey	9.8	7.2	8.4	7.5	7.4	8.0	6.8
Ukraine	0.0	5.7	6.2	4.8	4.7	5.6	3.6
United Kingdom	0.2	0.4	0.5	0.4	0.4	0.3	0.3
Rest of Europe	2.2	23.8	33.4	24.9	24.2	29.7	19.0
NORTH AMERICA	122.7	93.4	122.0	97.1	98.5	109.1	82.5
Canada	6.2	4.3	5.4	4.4	4.3	5.0	3.7
Mexico	34.4	37.5	48.4	39.5	38.8	44.6	33.4
United States	82.1	51.5	68.2	53.2	55.5	59.5	45.4
Rest of North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCEANIA	15.2	16.6	14.7	11.5	11.2	13.3	9.3
Australia	3.5	4.9	6.4	5.1	5.0	5.9	4.2
New Zealand	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Oceania	11.6	11.7	8.2	6.3	6.2	7.4	5.0
SOUTH AMERICA	161.9	175.4	235.5	182.6	178.4	213.3	146.4
Argentina	3.1	4.4	6.2	4.7	4.6	5.5	3.8
Brazil	120.3	120.4	165.6	128.5	125.5	150.2	103.3
Chile	7.7	14.7	20.1	15.7	15.5	18.3	12.7
Uruguay	3.1	2.8	4.0	3.0	3.0	3.6	2.4
Rest of South America	27.7	33.1	39.7	30.5	29.8	35.8	24.3
ROW	176.5	62.9	59.9	59.1	59.1	59.6	58.6
WORLD	1833.1	1955.1	2441.6	1956.6	1992.0	2256.1	1586.4

Table A4. Wood pellet consumption (million metric tons), 1990 to 2015 historic, 2070 projections from FORUM.

	1990	2015	2070				
			SSP1	SSP2	SSP3	SSP4	SSP5
AFRICA	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Africa	0.0	0.0	0.1	0.0	0.0	0.0	0.0

Table A4. Cont.

	1990	2015	2070				
			SSP1	SSP2	SSP3	SSP4	SSP5
ASIA	0.0	2.6	11.7	7.7	1.5	8.0	10.1
China	0.0	0.5	0.0	0.0	0.0	0.0	0.0
India	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indonesia	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Japan	0.0	0.4	2.0	1.3	0.2	1.4	1.8
Malaysia	0.0	0.0	0.2	0.1	0.0	0.2	0.2
Myanmar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Vietnam	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Rest of Asia	0.0	1.6	9.0	5.9	1.2	5.9	7.7
CENTRAL AMERICA	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Central America	0.0	0.0	0.1	0.1	0.0	0.1	0.1
EUROPE	0.0	21.4	77.7	53.2	8.3	56.1	68.9
Austria	0.0	0.8	3.9	2.6	0.1	2.9	3.4
Belarus	0.0	0.0	1.0	0.6	0.0	0.7	0.7
Belgium	0.0	1.2	5.9	4.4	0.9	4.3	6.2
Estonia	0.0	0.2	1.7	1.1	0.0	1.1	1.4
Finland	0.0	0.3	2.2	1.4	0.0	1.5	1.9
France	0.0	0.9	5.6	3.7	0.1	3.9	4.9
Germany	0.0	1.8	11.3	7.2	0.7	7.6	9.8
Latvia	0.0	0.1	0.9	0.6	0.0	0.6	0.7
Norway	0.0	0.1	0.5	0.3	0.0	0.3	0.4
Poland	0.0	0.6	4.2	2.6	0.0	2.8	3.4
Portugal	0.0	0.4	2.1	1.4	0.0	1.5	1.9
Romania	0.0	0.2	1.3	0.8	0.0	0.9	1.1
Russian Federation	0.0	0.0	0.2	0.1	0.0	0.2	0.2
Slovakia	0.0	0.0	0.2	0.1	0.0	0.1	0.1
Spain	0.0	0.5	1.9	1.2	0.3	1.3	1.6
Sweden	0.0	1.8	10.6	6.8	0.1	7.3	9.1
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ukraine	0.0	0.2	0.4	0.2	0.0	0.3	0.3
United Kingdom	0.0	6.8	2.0	2.3	3.4	2.5	1.1
Rest of Europe	0.0	5.4	22.0	15.9	2.7	16.4	20.9
NORTH AMERICA	0.0	2.6	14.8	9.2	0.3	10.0	12.0
Canada	0.0	0.5	2.4	1.4	0.1	1.6	1.7
Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United States	0.0	2.1	12.3	7.7	0.2	8.4	10.3
Rest of North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCEANIA	0.0	0.2	1.1	0.7	0.0	0.8	0.8
Australia	0.0	0.1	0.7	0.5	0.0	0.5	0.6
New Zealand	0.0	0.0	0.3	0.2	0.0	0.2	0.2
Rest of Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOUTH AMERICA	0.0	0.1	0.6	0.4	0.0	0.5	0.5
Argentina	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brazil	0.0	0.1	0.4	0.2	0.0	0.3	0.3
Chile	0.0	0.0	0.2	0.1	0.0	0.2	0.2
Uruguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of South America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROW	0.0	0.1	0.9	0.8	0.4	0.8	0.8
WORLD	0.0	26.9	107.1	72.1	10.5	76.5	93.4

Table A5. Wood pellet production (million metric tons), 1990 to 2015 historic, 2070 projections from FORUM.

	1990	2015	2070				
			SSP1	SSP2	SSP3	SSP4	SSP5
AFRICA	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Africa	0.0	0.0	0.1	0.0	0.0	0.1	0.0
ASIA	0.0	3.0	9.3	6.2	1.6	6.9	6.6
China	0.0	0.5	0.0	0.0	0.0	0.0	0.0
India	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indonesia	0.0	0.1	0.3	0.1	0.0	0.2	0.1
Japan	0.0	0.1	1.5	0.9	0.0	1.0	1.1
Malaysia	0.0	0.2	0.5	0.3	0.1	0.4	0.5
Myanmar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Vietnam	0.0	1.0	3.5	2.0	0.6	2.3	0.9
Rest of Asia	0.0	0.1	0.0	0.0	0.0	0.1	0.0
CENTRAL AMERICA	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Central America	0.0	0.0	0.1	0.1	0.0	0.1	0.1
EUROPE	0.0	15.2	66.9	43.5	3.9	46.7	54.0
Austria	0.0	1.0	3.9	2.7	0.2	2.9	3.5
Belarus	0.0	0.2	1.2	0.8	0.1	0.9	1.1
Belgium	0.0	0.3	3.4	1.9	0.0	2.1	2.1
Estonia	0.0	1.1	2.8	2.3	0.7	2.2	3.4
Finland	0.0	0.3	2.2	1.4	0.0	1.5	1.9
France	0.0	1.0	5.6	3.7	0.2	3.9	4.9
Germany	0.0	2.0	10.3	6.3	0.6	6.8	7.7
Latvia	0.0	1.6	1.9	1.8	1.0	1.8	1.6
Norway	0.0	0.1	0.5	0.3	0.0	0.3	0.3
Poland	0.0	0.8	4.3	2.6	0.1	2.9	3.4
Portugal	0.0	1.0	2.6	2.2	0.6	2.1	2.9
Romania	0.0	0.6	1.6	1.0	0.2	1.1	1.2
Russian Federation	0.0	1.0	3.3	2.7	0.9	2.7	3.9
Slovakia	0.0	0.1	0.1	0.0	0.0	0.1	0.1
Spain	0.0	0.5	1.3	0.8	0.2	0.8	1.4
Sweden	0.0	1.7	10.2	6.5	0.0	6.9	9.0
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ukraine	0.0	0.4	0.7	0.5	0.1	0.6	0.7
United Kingdom	0.0	0.3	0.0	0.0	0.0	0.1	0.0
Rest of Europe	0.0	2.4	14.3	8.7	0.0	9.6	8.8
NORTH AMERICA	0.0	8.6	28.9	21.3	4.9	21.5	31.4
Canada	0.0	2.1	7.1	6.0	1.5	6.0	10.8
Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United States	0.0	6.5	21.7	15.3	3.4	15.4	20.5
Rest of North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCEANIA	0.0	0.2	1.1	0.7	0.0	0.8	0.8
Australia	0.0	0.1	0.7	0.4	0.0	0.5	0.6
New Zealand	0.0	0.0	0.3	0.2	0.0	0.2	0.2
Rest of Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOUTH AMERICA	0.0	0.1	0.5	0.3	0.0	0.5	0.4
Argentina	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brazil	0.0	0.1	0.4	0.2	0.0	0.3	0.3
Chile	0.0	0.0	0.1	0.0	0.0	0.1	0.1
Uruguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of South America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROW	0.0	0.3	0.1	0.0	0.0	0.0	0.1
WORLD	0.0	26.9	107.1	72.1	10.5	76.5	93.4

Table A6. Wood pellet net trade (million metric tons), 1990 to 2015 historic, 2070 projections from FORUM.

	1990	2015	2070				
			SSP1	SSP2	SSP3	SSP4	SSP5
AFRICA	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ASIA	0.0	0.5	−2.4	−1.5	0.1	−1.1	−3.5
China	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indonesia	0.0	0.1	0.1	0.1	0.0	0.1	0.0
Japan	0.0	−0.2	−0.4	−0.4	−0.2	−0.4	−0.7
Malaysia	0.0	0.1	0.3	0.2	0.1	0.2	0.3
Myanmar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vietnam	0.0	1.0	3.4	1.9	0.6	2.3	0.9
Rest of Asia	0.0	−1.5	−8.9	−5.9	−1.2	−5.9	−7.7
CENTRAL AMERICA	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Central America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EUROPE	0.0	−6.3	−10.8	−9.7	−4.4	−9.5	−14.9
Austria	0.0	0.2	0.1	0.1	0.1	0.1	0.0
Belarus	0.0	0.2	0.2	0.2	0.1	0.2	0.4
Belgium	0.0	−0.9	−2.5	−2.5	−0.9	−2.2	−4.0
Estonia	0.0	0.9	1.0	1.2	0.7	1.1	2.0
Finland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
France	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Germany	0.0	0.2	−1.0	−0.9	−0.1	−0.9	−2.1
Latvia	0.0	1.5	1.0	1.2	1.0	1.2	0.9
Norway	0.0	0.0	0.0	0.0	0.0	0.0	−0.1
Poland	0.0	0.1	0.0	0.0	0.1	0.1	0.0
Portugal	0.0	0.6	0.5	0.8	0.5	0.6	1.0
Romania	0.0	0.3	0.3	0.2	0.2	0.2	0.1
Russian Federation	0.0	0.9	3.0	2.6	0.9	2.5	3.7
Slovakia	0.0	0.1	−0.1	−0.1	0.0	0.0	−0.1
Spain	0.0	0.0	−0.6	−0.4	−0.1	−0.5	−0.2
Sweden	0.0	−0.1	−0.3	−0.3	−0.1	−0.3	0.0
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ukraine	0.0	0.2	0.4	0.3	0.1	0.3	0.4
United Kingdom	0.0	−6.5	−2.0	−2.3	−3.4	−2.4	−1.1
Rest of Europe	0.0	−3.0	−7.7	−7.2	−2.7	−6.8	−12.0
NORTH AMERICA	0.0	6.1	14.1	12.1	4.6	11.4	19.4
Canada	0.0	1.6	4.7	4.5	1.4	4.4	9.1
Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
United States	0.0	4.5	9.4	7.6	3.2	7.0	10.2
Rest of North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCEANIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Australia	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Zealand	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOUTH AMERICA	0.0	0.0	−0.1	−0.1	0.0	−0.1	−0.1
Argentina	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brazil	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chile	0.0	0.0	−0.1	−0.1	0.0	−0.1	−0.1
Uruguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rest of South America	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROW	0.0	0.2	−0.8	−0.8	−0.4	−0.8	−0.8
WORLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Net trade = exports minus imports.

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