UNECE/FAO Timber Section Forest Sector Outlook Studies III background paper:

Selected Scenarios and Preliminary Results

1. Introduction

This report serves as a background document supporting the final publication of the next Forest Sector Outlook Studies (FSOS III) of the UNECE subregions. The report provides detailed information on i) the selected sets of reference and the alternative scenarios, including their development and selection process, ii) the global forest sector model utilized to analyze those scenarios, and iii) the projected forest and forest products sector outcomes in the three UNECE subregions under each scenario. The objectives of the report are twofold: first, to provide transparent information on the scenario selection and modelling process, and second, to obtain feedback from the stakeholders, including the UNECE/FAO team of specialists (ToS) on Forest Sector Outlook Studies (FSOS), the Joint UNECE/FAO Working Party on Forest Statistics, Economics and Management (FSEM), and other stakeholders on the presented scenarios and results to ensure that they sufficiently represent the most relevant forest sector policy challenges and debates in the UNECE.

2. Scenarios development and selection process

After a series of meetings and workshops, the UNECE/FAO ToS on FSOS as well as the Joint UNECE/FAO Working Party on FSEM developed a range of possible policy questions to be considered for the next FSOS, which are expected to cover the majority of the current policy debates relevant for the UNECE subregions[1]. The identified important policy questions were broadly related to general aspects of i) climate change mitigation and adaptation, ii) structural changes in forest products demand and supply, and iii) green economy and sustainable development goals. A range of possible alternative scenarios were then suggested to address more specific policy questions, which were further prioritized based on the priority ranking by the participants in a scale from 1 to 3, with 3 indicating the highest priority and 1 indicating the lowest priority. The scenarios receiving average priority ranking of more than 2 were climate change mitigation, growth of specific products (construction, fibres, biorefineries, climate change adaptation, upcoming market scenarios (China and Africa), economic disturbances, forest-based natural disturbances, nature conservation, and trade barriers (Appendix A, Table A3). Seventeen specific alternative scenarios were recommended to incorporate these high priority scenarios (Appendix A, Table A1), including 1) the potential of carbon sequestration in wood products resulting from the assumed increase in wood construction in the UNECE region or globally, 2) the potential of carbon sequestration in traditional wood products due to policy-driven significant increases in demand for wood products in UNECE regions or globally, 3) the potential of carbon sequestration in new products consuming wood fibres due to assumed technological advances allowing a significant increase of wood fibre use, 4) the potential of carbon sequestration through (re-) forestation due to assumed policy driven significant increase of forest area in the UNECE regions, 5) the maximization of carbon sequestration by changing silvicultural methods (update to the EFSOS II scenario “maximizing biomass carbon”), 6) the potential of climate change mitigation through substitution in the energy sector through an increased use of energy, 7) a combination of above scenarios to determine the maximum carbon sequestration that could be achieved given competing demands for wood products (possibly looking at climate smart forestry), 8) differences in supply of forest resources under the four representative concentration pathways (RCPs) from the IPCC’s 5th Assessment Report (possibly looking at resilience as well), 9) a massive increase in demand

[1] See Appendix A for the list of recommended and prioritized policy scenarios.

for wood used in construction within UNECE region or outside (especially China), 10) a significant increase in demand for wood-fibres for textiles and other products (linked to no. 3 above), 11) a significant economic collapse globally and/or in specific countries/regions, 12) the successful development of an alternative energy source and thus a drastic decrease in the demand for wood energy, 13) a significant decrease in demand for printing and paper with a simultaneous increase in the demand for packaging paper, 14) a significant increase in biorefinery capacity, 15) a significant increase in the area of forest plantations outside of the UNECE region (e.g., in Africa and/or Asia), 16) a significant increase in the rate, severity, or extent of forest-based natural disturbances, and 17) the adoption of new and more highly restrictive trade barriers between countries and/or regions.

The modelling team[2] worked on the feasibility of modelling all the recommended high priority scenarios to the extent possible and finally selected a set of reference and alternative scenarios (Table B1 in Appendix B). The scenario selection process was guided by several criteria, including: 1) the availability of a global forest sector model with the capability to model the majority of recommended scenarios in an integrated way (i.e., avoiding a need to separately model UNECE subregions as done in the past FSOS, 2) the availability of most recent literature that could provide answers to the recommended policy questions, and 3) the available resource and expertise needed to model the recommended scenarios.

While there were several demand and supply models with varying geographic coverages that could be utilized to model the recommended policy scenarios, the core ToS decided to utilize the Global Forest Products Model (GFPM) (Buongiorno et al. 2003, Buongiorno 2015), based on its technical capabilities to accommodate the majority of the recommended scenarios and its global coverage, with the capability to provide both demand and supply projections, including forest stock development, consumption, production, trade, and prices of 14 different forest products (defined by FAO[3]) in 180 individual countries including all UNECE subregions. A more detailed description of the GFPM is provided in the sub-section 3.1 "Projection of Global Forest Products Market".

Based on the above mentioned criteria, the modelling team finally came up with 13 different scenarios (including 3 reference scenarios) that they believed would provide answers to the most of the recommended high priority policy questions relevant in the UNECE subregions (see Table A1-A3 in Appendix A). A detailed description of the selected sets of scenarios follows next, focusing on the assumptions about future socio-economic and forest sector variables and how the selected scenario assumptions are linked to those recommended important policy questions relevant in the UNECE subregions.

Following the conventional approach to forest sector outlook studies, the modelling team selected reference and alternative scenarios so that the differences in model outcomes between the given reference and the alternative scenario pair could represent the forest sector impacts of a given policy shock. However, in contrast to the conventional approach in developing reference scenario, where it usually would represent only one future where current trends would continue and policies would remain unchanged, the modelling team selected three distinct reference scenarios representing three contrasting socioeconomic futures, each of which were paired with alternative scenarios. Such an approach to utilizing differing reference scenarios will allow an understanding of policy impacts not only from the business-as-usual bench mark but also from other reference benchmarks. While one of the selected reference scenarios for the next FSOS represents conventional "business-as-usual" or the "continuation of

[2] Drs. Prakash Nepal and Jeffrey Prestemon
[3] See http://www.fao.org/forestry/34572-0902b3c041384fd87f2451da2bb9237.pdf.

the current trends" scenario, the other two reference scenarios additionally represent relatively poor and relatively rich world visions.

The three distinct reference scenarios chosen for the next FSOS were directly adopted from five different socioeconomic pathways (SSPs) developed by various scientific communities in conjunction with the fifth climate change assessment studies led by the Intergovernmental Panel on Climate Change (IPCC). These SSPs represent alternative futures that narratively and quantitatively describes future global changes in income, population, technology, energy use, and land-use changes, consistent with alternative global greenhouse gas (GHG) and aerosol concentration pathways called the representative concentration pathways, or RCPs (IPCC 2018a, 2018b). The narratives of five SSP scenarios describe different socioeconomic, technological, environmental, and policy futures of the world with varying degree of challenges for climate change mitigation and adaptation (O'Neill et al. 2017), which provide a basis for quantifying various elements envisioned under each SSP scenario (e.g., GDP projections (Dellink et al. 2017), and energy and land use projections (Riahi et al. 2017)). The detailed descriptions of the narratives are provided in O'Neill et al. (2017). Here, we briefly summarize the important elements shaping alternative world futures envisioned under each SSPs.

SSP1 is described as a "sustainable development" world view with economic rapid development in low-income countries, an open and globalized economy, and decreased global inequalities. Assumptions such as increased investments in health and education, leading to relatively increased environmental awareness, low population growth, rapid technological change toward environmentally friendly economies, and increasing international cooperation, are expected to give rise to low challenges to climate change mitigation and adaptation in SSP1.

SSP2 represents the "business-as-usual" or the "middle-of-the-road" world vision, where future development pathways are assumed to be in consistent with historical social, economic and technological trends.

SSP3 is described as "regional rivalry–a rocky road" and represents a vision of a fragmented and poor world. It projects the lowest overall per capita income and contains the most disparate income per capita across countries compared to all other SSPs. High challenges to both mitigation and adaptation are expected, due to assumed slow economic and technological development, worsening global inequalities, material-intensive consumption, a large dependence on fossil fuel, low international cooperation, and higher population growth in developing countries compared to wealthy countries.

SSP4, described as "inequality–a road divided," represents a divided world, with wide gaps in economic and technological development across countries. Economic growth is high in middle income countries but much lower in low income countries. Environmental policies are assumed to focus local issue in high- and middle-income countries. Challenges to mitigation are low because of assumed effective international cooperation across a globally connected economy. However, this pathway assumes that the future carries with it a stubbornly large proportion of the world's population that is economically, socially, and environmentally vulnerable, with low levels of development and limited access to effective institutions, combined with a lack of effective environmental policies directed at resolving critical global environmental issues, including climate change adaptation.

Finally, SSP5, described as the "fossil-fueled development–taking the highway" represents a wealthier and a more equal world vision than the other SSPs. This pathway emphasizes the development of an enhanced social and human capital base through strong investments in health, education, and institutions. However, there remains a strong dependence on fossil-fuel for development into the foreseeable future, without a concern for global environmental problem, which are expected to create increased challenges to climate change mitigation efforts, while robust economic growth coupled with attainment of human development goals are expected to reduce challenges to climate change adaptation.

While these narratives qualitatively describe how various elements would look in the future, the quantitative projections are available for only limited elements (dimensions) of each SSP. Key among those quantitative elements are projections of gross domestic product (GDP) and population by country (GDP per capita, IIASA 2018) and the shares of urban and rural populations by country (Jiang and O'Neill 2017). The quantification of future land use change is also available at the regional and global level (e.g., Riahi et al. 2017), though not by country. In addition, the modelling team developed quantitative projections of future total forests area (Nepal et al. in review-a) and planted forest area (Korhonen et al. in preparation) in individual countries across each SSP, which were incorporated as inputs to the global forest products model used in the current scenario modelling work.

While it would be ideal to consider all different quantitative elements of future world characteristics described by each SSP narrative (e.g., GDP, population, technology, energy use, land use change, and climate policy), we used only GDP, population, and forest area (total forest and planted forest) projected under each SSP, to derive three reference SSP scenarios for use in next FSOS. Initially, all five SSPs were considered as FSOS reference scenarios and therefore the GFPM model runs were obtained for each SSP, where the forest products demand and supply was driven by GDP, population, forest area, and planted forest area in 180 countries, exogenously projected in each SSP. However, because the projected results and trends were very similar between SSP1 and SSP5, and between SSP2 and SSP4, the modelling team utilized only SSP2, SSP3, and SSP5 as the FSOS reference scenarios.

Four sets of alternative or policy scenarios were developed at this time, to address two broad policy aspects, including climate change mitigation and structural changes in forest product markets, which the modelling team believes would go the furthest towards answering most of the identified policy questions relevant to the forest sector globally as well as in UNECE subregions. These four alternative scenarios included i) *High Forest Area (HFA)*; ii) *High Wood Consumption in all countries (HWC All);* iii) *High Wood Consumption in selected countries (HWC Select)* including China, India, Pakistan, Indonesia, Brazil, and Mexico, countries selected because of their high populations; and iv) a combined scenario developed from combining the *HFA* and the *HWC All*, called the *HFA_HWC_All*. Paired separately with the three SSP scenarios (SSP2, SSP3, and SSP5), these four alternative scenarios can address at least eight of the 17 recommended policy questions (discussed in the beginning of this section, and in Appendix A), with three additional policy questions expected to be answered based on the most recent past studies, two additional questions expected to be answered pending completion of additional work by the modelling team, and the remaining four questions to be answered qualitatively, based on qualitative future assessments and the results of past modelling efforts.

The *HFA* scenario represents assumed global future efforts to mitigate climate change, such as policy driven significant increases in total forest area, including both planted and natural forest area. While increasing forest area to sequester more carbon in forests is considered an important climate change mitigation strategy, no information is available regarding the magnitude of such changes in the future. Therefore, to serve as a sensitivity analysis, the modelling team assumed a 10% increase in total forest area and a 10% increase in planted forest area by 2040, compared to the projected forest areas realized in the reference scenarios by 2040. The difference in projected forest sector carbon between the given reference and its paired *HFA* scenario will answer the policy question, "what is the potential of UNECE forest sector for climate change mitigation through increased total forest area?"

The *HWC All* scenario represents assumed future worldwide structural changes in wood products demand for traditional and new wood products as well as increased use of wood fibre in biorefineries. Traditional products experiencing expanded demand include sawnwood and both structural and non-structural wood panels (plywood, oriented strandboard, other particleboard, and fibreboard). New products would include any type or dimension of engineered lumber products, such as cross-laminated timber (CLT), and all kinds of textiles utilizing wood fibres. Because of the limited degree of disaggregation of product categories (for example, CLT is a subcategory of lumber), none of the currently available global forest sector models is capable of simulating the effects of particular emerging new products. Therefore, the potential effects of increased demand for any such product are summarized, within GFPM, at more aggregated product levels: forest area, timber stocks, timber and aggregate product prices, and timber and aggregate category product consumption and production. In this scenario, we modeled the effects of expanded demand for wood fibres by simulating a doubling of global sawnwood and panel products consumption by 2040 compared to the consumption quantities projected in the reference scenario by 2040. The differences in projected consumption, production and trade quantities, and product prices, when compared with the respective quantities and prices projected in the given reference scenario, may be considered as the forest sector impacts of future structural changes in wood products demand worldwide. Similarly, the difference in projected forests and harvested wood products (hwp) carbon in the *HWC All* and its paired reference scenario can quantify the contribution of forests and hwp carbon to climate change mitigation in the UNECE.

The *HWC Select* scenario represents a future where the specific, selected countries (only) outside of the UNECE region experience large increases in demand for structural and non-structural wood products, in the same manner as described in the *HWC All* scenario. These countries include the six most populous non-UNECE countries: Brazil, China, India, Indonesia, Mexico, and Pakistan.

Finally, one additional alternative scenario was constructed by combining the *HFA* and *HWC All* scenarios and referred to as *HFA_HWC_All*. While the HFA scenario suggests the largest carbon sequestration potential in forests, the *HWC All* would suggest the largest carbon storage potential in hwp. The combined *HFA_HWC_All* scenario will reveal whether increasing forest area and wood production consumption at the same time would achieve maximum carbon sequestration among the selected scenarios. This *HFA_HWC_All* scenario was run to pair only with the SSP2 reference scenario at this time, because of expected similar differences in outcomes when paired with the SSP3 and SSP5 reference scenarios.

Table B1 in Appendix B summarizes three sets of reference scenarios, paired with four alternative scenarios, totaling to 13 individual scenarios, selected for modelling for the next FSOS, which were believed to address most of the policy debates in the UNECE subregions.

No additional scenarios were developed at this time either because 1) some recent studies have already addressed some of the identified policy questions, which can be utilized to describe the potential effect on the UNECE forest sector of such policy changes, 2) the modelling team is still working on the possibility to enhance the GFPM capability in modelling the impact of additional policy and climate change questions, 3) it is not possible to quantitatively model some policy questions and therefore only the qualitative description of the potential impacts of those policy questions will be described in the final FSOS publication, or 4) some of the identified policy questions can be addressed based on the modelling outcomes projected for the reference scenarios.

The modelling team expects to utilize past studies to answer at least three recommended policy questions. These include: a) the forest sector impacts of restricted trade between countries, b) a significant increase in forest plantations outside of the UNECE (e.g., Africa and/or Asia), and c) the potential of climate change mitigation through wood products substitution for non-wood products. In terms of trade restrictions, Buongiorno and Johnston's (2018) simulation provides important insights into U.S. and global forest sector economic effects of potential implementation of higher barriers against imports into the U.S. and of reactive countervailing measures implemented against imports by other countries. With regards to potentially rising rates of planted forests, a study by Nepal et al. (in review-a) could be useful towards gauging the potential impacts of such expansions—including in Asia and Africa—on forest stocks and on forest products production, consumption, trade, and prices. Finally, comprehensive reviews by Leskinen et al. (2018) and Sathre and O'Connor (2010), suggesting that substitution of wood for greenhouse gas intensive-materials can have important climate benefits, could serve as an excellent references for discussing, in the final FSOS report, the likely carbon mitigation benefits of using additional wood in construction.

The modelling team is currently evaluating at least two alternative approaches to modeling the effects of climate change on the UNECE region and globally. One approach would be to develop econometric models of forest growth as a function of drivers of forest growth, including climate (temperature, precipitation) and greenhouse gas concentrations (particularly CO_2). Another alternative would be to impute the effects of climate change on forest growth, based on existing studies of climate change impacts on forest growth. If completed within FSOS timeframe, either approach could enable quantification of the timber sector effects of projected future greenhouse gas concentrations consistent with alternative representative concentrative pathways (RCPs). Such a quantitative assessment of the effects of climate change is one of the policy scenarios recommended for the next FSOS by the ToS and the UNECE/FAO Working Party on FSEM. In the event that this study cannot be completed on time, modelling the effects of greenhouse gas emissions on timber growth and stock, and consequently on timber supply, could be best deferred to future iterations of the FSOS.

The policy scenario assuming future growth of wood fibres due to expanded demand by biorefineries will be discussed qualitatively. The modelling team has identified several experts who will carry out a qualitative assessment of such prospects. These include Dr. Ronalds González of North Carolina University (Raleigh, USA) and collaborators from the United States, Canada, Finland, Brazil, and Chile. Part of this special assessment will include the construction of a database of current and announced biorefinery projects and facilities for North America, Chile and Nordic countries. The information from such database, coupled with a discussion of available government programs fostering biorefinery development, would provide a basis for estimating the potential growth in the demand of wood fibres for biorefineries over the next 5 to 10 years.

While the conclusions reached by the special study of biorefineries and the quantitative assessments enabled by comparing reference and alternative scenarios can address many of the questions identified by the UNECE Joint Working Party, some of the proposed policy questions can be addressed by comparing the outcomes of the three reference scenarios themselves. Specifically, the suggested scenario envisioning the forest sector effects of a significant economic collapse (globally or in specific countries or regions) can be appreciated by comparing the SSP3 reference scenario, which represents a poor and unequal world future, with SSP2, which could be considered the business-as-usual future.

Still, given the already substantial modelling efforts planned under this outlook study, we suggest not addressing several other scenarios at this time. First, the proposed scenario characterizing a significant drop in demand for graphic papers (newsprint, printing and writing papers) simultaneous with an increase in the demand for packaging papers will not be modelled. Such a scenario would be possible, but we defer that to future study. Second, a suggested policy scenario that would evaluate the potential of climate change mitigation through substitution of wood for fossil fuels in the energy sector is not considered. The forest sector impacts of increased use of wood for energy was discussed in the past FSOS (UNECE and FAO 2011, 2012). Climate change mitigation through the substitution in the energy sector is difficult to model with the currently available modeling framework, financial resources, and expertise. It would instead be best described qualitatively in the upcoming FSOS. Third, a proposed policy scenario evaluating the consequences of maximizing carbon sequestration by changing silvicultural methods is also not modeled at this time, due to difficulty in modelling such a scenario in GFPM. We suggest that such finer-scale modeling would be enabled by coupling the GFPM with a forest dynamics model that is capable of modelling the effects of fine scale management activities. However, a similar scenario (maximizing biomass) was evaluated in the last EFSOS II (UNECE and FAO 2011), through the coupling of the EFI-GTM, a set of econometric equations modeling products, and a forest dynamics model (EFISCEN). We suggest that EFSOS II serves as an excellent reference to discuss the potential of increasing carbon sequestration through changes in silvicultural methods in the FSOS III. Fourth, a proposed scenario that would investigate the forest sector impacts of future significant increases in forest-based disturbances are not modelled at this time. Modelling the effects on forest sector of forest-based disturbances such as wildfires, droughts, storms, and insect and disease outbreaks demand a forest dynamics model that can capture finer scale timber mortality, salvage, and local market dynamics. While possible in practice, this level of modeling would require additional financial resources and expertise. Furthermore, although constraints on financial and modeling resources are the main limitations on carrying out such a scenario, the modelling team also asserts that the effects of forest-based disturbances on forest product markets are typically highly localized and short-term in nature. Forest-based disturbances tend to create short-run, mainly sub-national or national (and less often international) effects on markets; such effects include short-run salvage gluts, which drive down prices, and longer-run inventory reduction effects, which drive up prices and reduce production possibilities in the locations impacted (Prestemon and Holmes 2008). Although the effects of such disturbances on forest resources at national and subnational scales might be profound and important to explore using forest dynamics models at those same scales, global forest products markets would tend to dampen international product market dynamics. It is becoming clearer as the science of climate change has advanced that climate change can bring about altered rates of disturbances (e.g., Dale et al. 2001, Sommerfeld et al. 2018). A discussion of the long-run implications of altered rates of such disturbances, particularly in terms of how forest growth may change and how national markets might be increasingly buffeted by such shocks, might prove a useful addition to this current FSOS, however.

3. Projection methods

3.1 Projection of Global Forest Products Market

The selected sets of scenarios were modeled using the Global Forest Products Model (GFPM). The model projection covered 2015-2040, with 2014 being the base year. GFPM is a partial equilibrium model of the global forest sector, where the projections of market clearing prices, production, consumption, and transport quantities of 14 different forest products are provided by maximizing economic welfare of consumers and producers in forest sector in 180 individual countries, based on the optimization approach described by Samuelson (1952) in regional market modelling (Buongiorno et al. 2003, Buongiorno 2015). The GFPM has been widely utilized in investigating the impacts of numerous forest sector related policy questions at global, multinational, and national forest sector levels, including its application in the UNECE/FAO European and North American Forest Sector Outlook Studies (UNECE and FAO 2011, 2012), the USDA Forest Service RPA assessment studies (USDA Forest Service 2012), and numerous journal publications.

A detailed description of the model structure and parameters are available in several past studies (e.g., Buongiorno et al. 2003, Buongiorno 2015). Here only a brief description is provided on how the GFPM models demand, supply, production, consumption, and trade of various products as well as forest growth, forest stocks and forest area in individual country. The GFPM models the supply of four primary products including industrial roundwood, fuelwood, waste paper (recovered paper), and other fibre pulp. The supply of industrial roundwood is modeled as a function of its own price and forest stock, both of which are projected endogenously. The supply of waste paper is modeled as a function of its own price and GDP, along with a specified recycled paper recovery rate. The current version of the GFPM specifies a maximum recovery rate of recovered paper to be 80%. The actual recovery rate, within this range, is determined by the input-output coefficient (units of recovered paper used to produce per each unit of paper product, which differs by country) and the specified supply curve of recovered paper, which responds to its own price and GDP. The supply of other fibre pulp is modeled as a function of its own price and GDP.

On the demand side, the GFPM models demand for nine manufactured (secondary) wood products, which are functions of their endogenously projected own prices and exogenously projected GDP. These manufactured products include fuelwood, other industrial roundwood, sawnwood, plywood, particleboard, fibreboard, newsprint, printing and writing paper, and other paper and paperboard, which mainly include tissue and packaging papers. GFPM additionally models two intermediate products including mechanical pulp and chemical pulp, which are used as input to paper production. Projected production quantities of intermediate and final manufactured products are determined by the specified manufacturing costs and their respective input-output coefficients (units of industrial roundwood required to produce a unit of manufactured product) in each country, which reflects the comparative advantage of a country in producing that product.

Trade (import and export) is modeled between a country and the rest of the world. Quantities of products imported or exported are driven by the competitive advantage of a country or a region in producing and shipping each product. Competitive advantage is a function of transport costs, manufacturing costs, input-output coefficients, and the endogenously solved domestic and world prices of a product. The domestic consumption quantity of a product is calculated as import quantity minus export quantity plus domestic production quantity.

Forest stock, which drives industrial roundwood and fuelwood supply quantities in each country, evolves over time as previous year stock plus projected current year growth minus roundwood harvest quantity. Forest stock growth (net of mortality) before harvest, is modeled as a nonlinear function of forest stock density (forest stock divided by forest area) based on work by Turner et al. (2006). The specified nonlinear negative relationship between forest growth and forest stock density implies that forest growth increases with declining stock density and decreases with increasing stock density. Changes in forest stock density are determined by the endogenously projected changes in forest stock and the exogenously projected changes in forest area.

Total forest area in each country is exogenously projected in the standard, publicly available version of GFPM as a quadratic function of GDP and its squared term, based on the Environmental Kuznets Curve (EKC) model estimated by Turner et al. (2006). For this outlook, however, we updated the EKC component of the GFPM (Nepal et al., in review-b) (Appendix C). To capture the effect of projected changes in demographic variables (e.g., rural population density) in determining total forest area, the modelling team utilized separately projected total forest area in each country, which was driven not only by GDP per capita, but also by projected rural population density and labor growth under each SSP (Figures C1-C3 and Table C1, Appendix C). According to the estimated total forest area projection model (Table C1 in Appendix C) the increasing GDP per capita squared and labor growth have positive effects on total forest area and the increasing rural density has a negative effect. The amount of projected forest area in each region is therefore the net effect of each of the projected explanatory variables.

The scenario modelling for the current FSOS was also augmented by allowing for the GFPM projected forest stock in each country to be adjusted by the exogenously projected planted forest area in each country across each of the SSPs, based on the recent work by Nepal et al. (in review-a) and Korhonen et al. (in preparation). Planted forests contribute to higher forest growth (and stock). Because the GFPM does not distinguish forest growth by planted and natural forests, the modelling team adjusted the endogenously calculated forest growth in GFPM to account for the effect on forest stock of projected changes in planted forest area. Planted forest area was also projected to be driven by its separately estimated EKC model coefficients (Table C2, Appendix C) and projected GDP per capita, rural population density and labor growth in each SSP (Figures C1-C3, Appendix C). According to the estimated planted forest area projection model (Table C2, Appendix C), the GDP per capita and labor growth have positive effects while rural population density has a negative effect on planted forest area.

3.2 Projection of carbon sequestration in forest and harvested wood product (hwp)

Projected estimates of forest sector carbon in each country include carbon stored in above- and below-ground live biomass and in harvested wood products (hwp). While the projected changes in carbon stored in forest biomass are based on the projected changes in forest stocks, the carbon stored in hwp is estimated based on the projected wood products consumption, production and trade quantities endogenously projected by GFPM. The approach to estimating carbon in above- and below-ground forest biomass is based on Johnston et al. (forthcoming), which relies on estimated regional emission factors, obtained using the observed forest stocks in 2015 and the estimated carbon in above- and below-ground carbon pool reported in the Global Forest Resource Assessment report (FAO 2015). Changes in carbon stored in wood products were also estimated, following Johnston et al. (forthcoming), which was based on 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The reported estimates of hwp carbon in this paper are based on the production approach, which includes carbon stored in domestically produced and exported wood products but excludes carbon stored in imported forest products.

4. Preliminary Results

First, the projected outcomes related to the forests and forest product markets during 2015-2040 are provided for three reference SSP scenarios. These projected outcomes provide insights into how global and UNECE forest and forest products sectors will develop during next two and half decades under the assumed socio-economic futures in each reference SSPs. Next, the projected outcomes in each reference SSP are compared with the corresponding outcomes in the alternative scenarios, providing the assessments of degrees of magnitude of likely impacts of each of the alternative scenarios.

4.1 Reference Scenarios

The results for the reference SSP scenarios are summarized in terms of projected developments in i) total forest area, ii) planted forest area, iii) forest stock, iv) wood products prices, v) wood products production, consumption and trade, and vi) carbon sequestered in above- and below-ground forest biomass and in hwp.

4.1.1 Projected forest area

Each of the three reference SSPs demonstrated distinct rates of change in projected global forest area, but projected changes within each of the three UNECE subregions were comparatively similar across SSPs. Globally, SSP2 (continuation of historical trends in economy and demographics) showed an increase of 1.3%, SSP3 (poor world) a decrease of 1.2%, and SSP5 (wealthier world) an increase of 4.1% by 2040, relative to 2015 levels (Figure 1a). The trends in total forest area development for UNECE subregions were different from the projected global trends. Europe (Figure 1b) showed little variation among three

SSPs (all SSPs resulted in increases of 4.2 to 5.1% by 2040, relative to 2015). A similar pattern was observed for the Russian Federation (Figure 1d) between SSP2 and SSP3 (5% and 4.8% increases by 2040, relative to 2015), with SSP5 demonstrating a much larger increase (6.4%). The projected forest area trends for North America (Figure 1c) across SSPs were different from the projected global and European trends, with SSP5 showing lower forest area (a decline of 1.5% by 2040, relative to 2015), compared to more or less constant forest area projected for SSP2 and SSP3. Projected forest area changes were consistent with the estimated effect of the explanatory variables (Table C1, Appendix C) and projected varying GDP per capita, rural population density, and labor growth in each UNECE subregions across each SSP (Figures C1-C3, Appendix C).

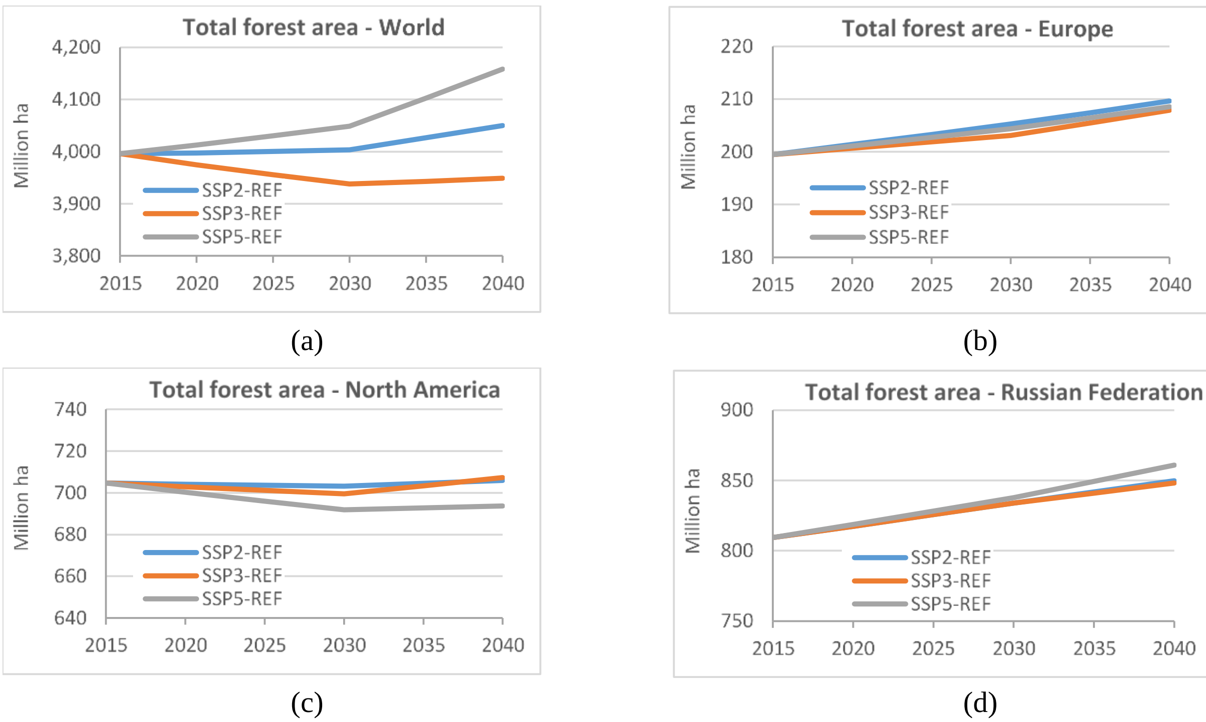
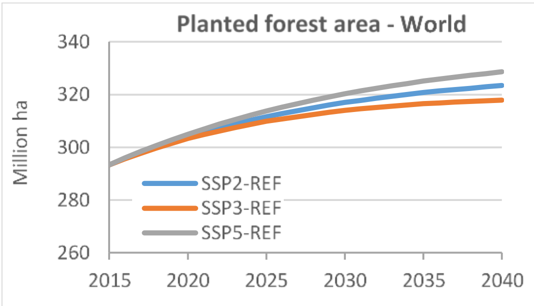


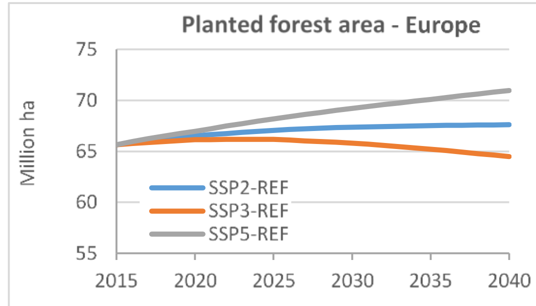
Figure 1: Projected total forest stock in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

4.1.2 Projected planted forest area

The three reference SSPs also showed three distinct projected planted forest area trends (Figures 2a-d), with SSP5 showing the largest, SSP3 showing the smallest, and SSP2 showing the moderate planted forest area growth globally and in UNECE subregions. The 293 million ha of current global planted forest area is projected to increase by 8.4%, 10.3%, and 12.1% in SSP3, SSP2, and SSP5 reference scenarios by 2040, respectively (Figure 2a). Europe showed a much smaller percentage change in planted forest area compared to other regions, with SSP2, SSP3, and SSP5 showing an increase of 3.0%, a decline of 1.8%, and an increase of 8.0% by 2040, respectively, compared to the 2015 planted forest area of about 66 million ha (Figure 2b). Similarly, the 43 million ha of planted forests in 2015 in North America were shown to increase by 11.7%, 3.6%, and 19.6% in SSP2, SSP3, and SSP5 by 2040, respectively (Figure 2c). In contrast, the Russian Federation showed slowly declining planted forest area in SSP2 and SSP3 and more or less constant forest area in SSP5; SSP2 and SSP3 showed declines of 0.9% and 2.1% by 2040, respectively, relative to about its 20 million ha of planted forests in 2015 (Figure 2d).



(a)



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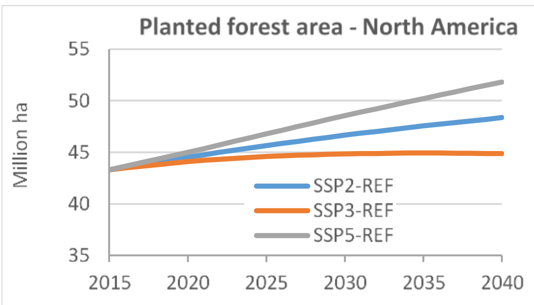

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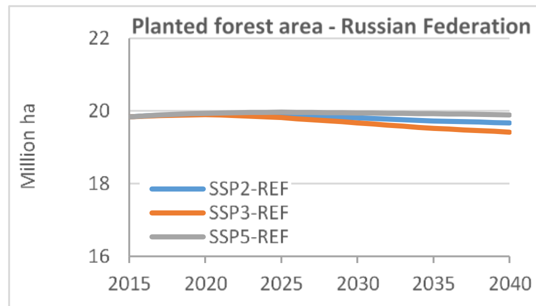
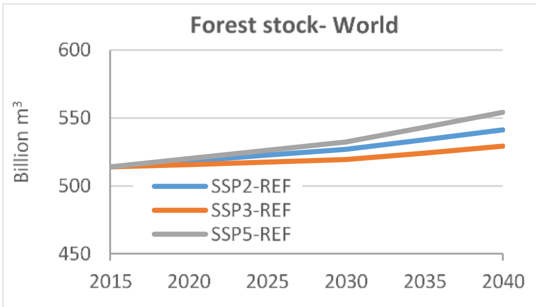


(d)

Figure 2: Projected planted forest area in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

4.1.3 Projected forest stock

Projected changes in total forest area and planted forest area largely drove projected forest growth and stock in individual countries across SSPs, which, as described in subsequent sections of this report, in turn affected primary and secondary product prices, production, consumption, and trade quantities. Globally, SSP3 and SSP5 bracketed forest stock trends: forests stocks were projected to increase by 3% in SSP3 and 8% in SSP5 by 2040, from about 514 billion m^3 of forest stocks in 2015 (Figure 3a). While forest stock was projected to grow substantially in Europe (up to 30% by 2040 from the 2015 level of 32 billion m^3), they were shown to be similar across SSPs, mainly because projected total forest areas likewise varied little across SSPs (Figure 3b). North America was shown to increase its forest stock by 8% in SSP5 and 10% in SSP3 by 2040 relative to 2015 (Figure 3c), consistent with projected total forest areas (Figure 2c). Forest stock in the Russian Federation is projected to increase by 4.7% in SSP3 and 6% in SSP5 by 2040, relative to the 82 billion m^3 of forest stock in 2015 (Figure 3d).



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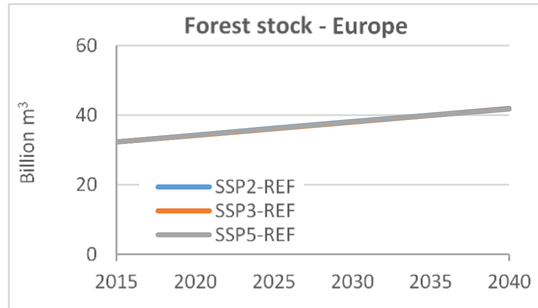

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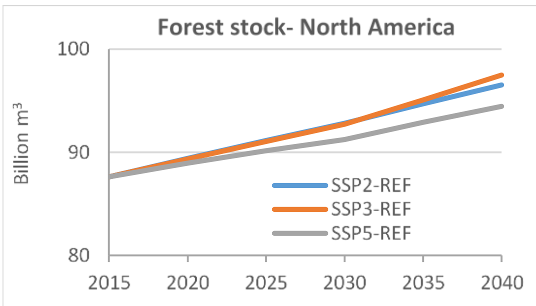

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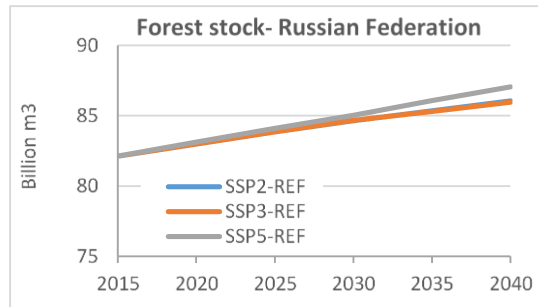
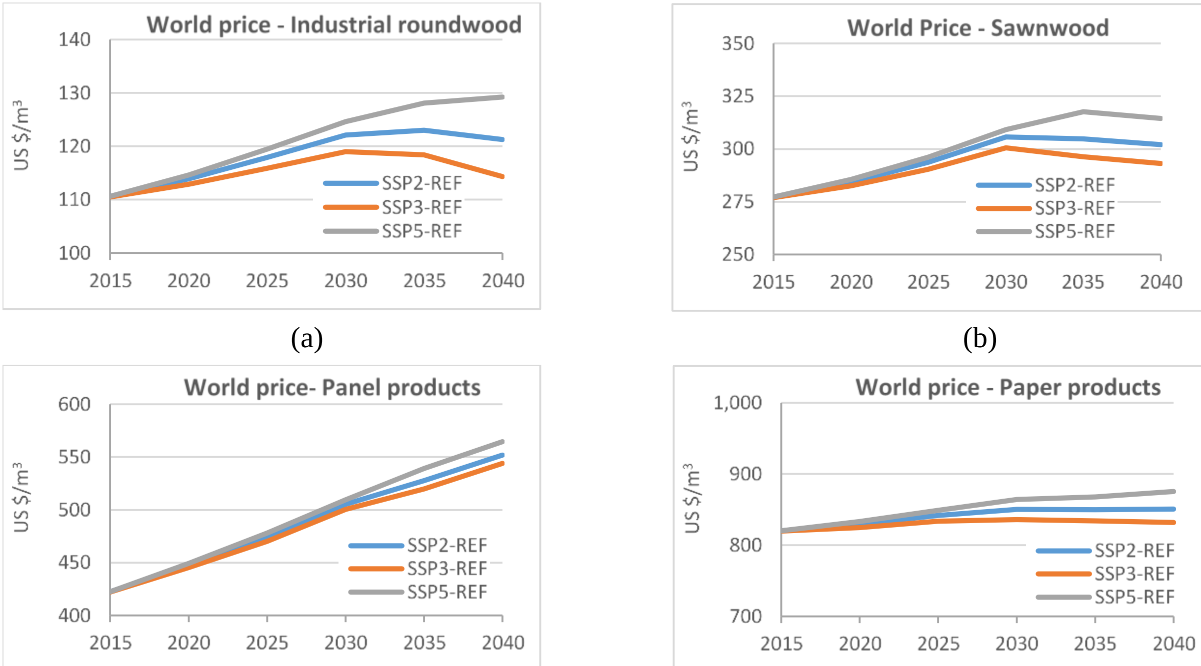


(d)

Figure 3: Projected forest stock in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

4.1.4 Projected prices

In spite of increasing forest stocks globally (Figures 3a-d), when combined with generally increasing GDP and GDP per capita, primary and secondary product prices were projected to mostly increase in real terms across the three reference scenarios (Figures 4a-d). Just as was the case for forest stocks, projected world price changes for industrial roundwood were bracketed by SSP3 and SSP5. Industrial roundwood prices were projected to increase by 3.4% in SSP3 to 16.8% in SSP5, with SSP2 showing a 10% increase by 2040, relative to the 2015 price level (Figure 4a). While similar price trends were projected for sawnwood (Figure 4b), panels (Figure 4c), and paper (Figure 4d) products across SSPs, the magnitude of price increases were highest for panel products, for which the average price of plywood, particleboard and fibreboard increased by 29% in SSP3 and 34% in SSP5 by 2040, relative to 2015 level, followed by sawnwood (5.8% in SSP3, 13.5% in SSP5), and paper products (1.5% in SSP3, 6.7% in SSP5).

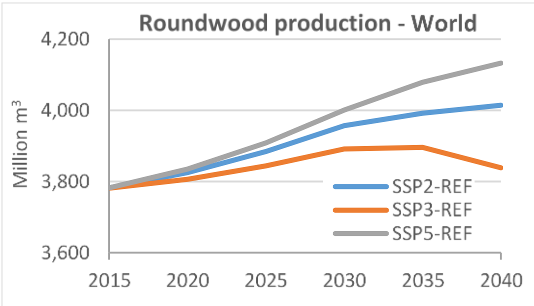


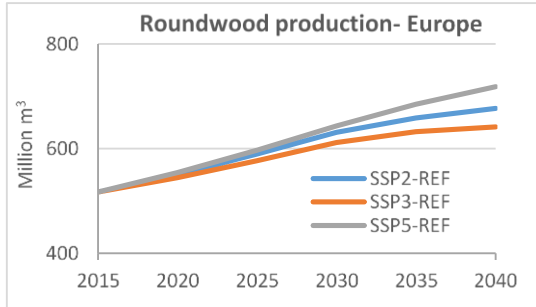
(a) (b) (c) (d)

Figure 4: Projected world prices of a) industrial roundwood, b) sawnwood, c) panel products (the average of prices for plywood, particleboard, and fibreboard), and d) paper products (the average of prices for newsprint, printing and writing paper, and other paper and paper board) under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

4.1.5 Projected production and trade

Following its projected price trends, roundwood production also increased in all three SSPs, and as in the cases of stocks and prices, bracketed in their projections by SSP5 and SSP3, with SSP2 intermediate (Figures 5a-d). For instance, global roundwood production increases were 1.5% in SSP3 and 9.3% in SSP5 by 2040, relative to the 2015 production level of about 3,800 million m^3 (Figure 5a). Europe showed the largest percentage increase in roundwood production, with increases of 24.1% in SSP3 and 38.8% in SSP5, by 2040, relative to about 517 million m^3 in 2015 (Figure 5b). Projected roundwood production increases in North America (Figure 5c) and the Russian Federation (Figure 5d) were similar (15% in SSP3, 26% in SSP5).





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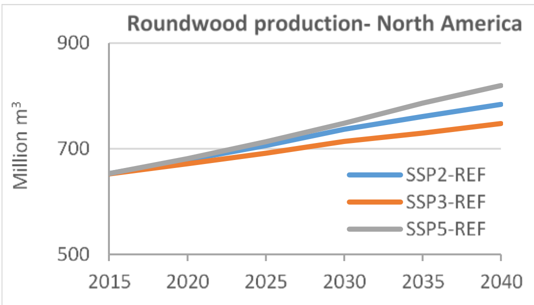
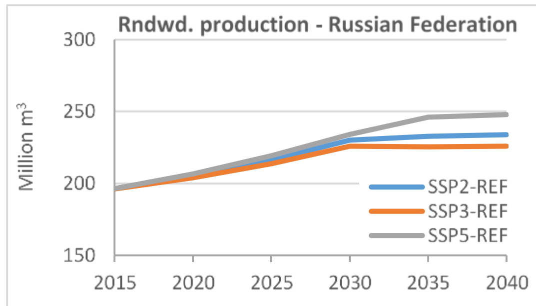




(c) (d)

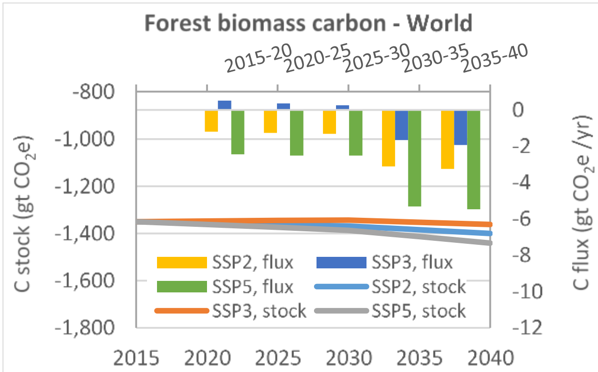
Figure 5: Projected roundwood production in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

Projections showed little variations in industrial roundwood trade across SSPs, with almost all gains in production absorbed by projected increases in consumptions (Figure D1, Appendix D).

Production of sawnwood, panels, and paper products were all projected to increase in ways mirroring projections for industrial roundwood. However, unlike trends in the projected trade of industrial roundwood, the differences across SSPs in projected net exports of these products were relatively larger (see Figures D2-D7 in Appendix D).

4.1.6 Projected carbon stock and flux

Carbon stored in above- and below-ground forest biomass followed projected forest stocks trends in each SSP, indicating that the world's forests, including the UNECE subregion's forests, will remain a net carbon sink in all three SSP reference scenarios (Figures 6a-d). Estimated carbon flux (annual change) indicated global above- and below-ground biomass carbon sequestration potentials of about 2.0 gigatons (gt) of CO_2e per year in SSP3 and 5.5 gt of CO_2e per year in SSP5, with SSP2 projected to sequester 3.3 gt of CO_2e per year by 2035-2040 (Figure 6a). Europe was projected to show little change in its forest biomass carbon sequestration, with a projected 0.6 gt of CO_2e per year throughout the projection period (Figure 6b). North American forests were projected to sequester 0.9 to 1.4 gt of CO_2e per year during 2035-2040 in its above- and below-ground biomass (Figure 6c), with SSP3 showing the largest sequestration potential, due mainly to projected higher forest area (Figure 1c) and forest stock (Figure 3c) in SSP3 in North America. Biomass carbon sequestration in the Russian Federation (Figure 6d) was projected to increase in SSP5, reaching up to 0.3 gt CO_2e per year during 2035-2040 in SSP5. However, it was projected to decline slightly in SSP2 and SSP3 during 2035-2040 (0.2 gt of CO_2e per year), compared to the projected annual sequestration rates during 2015-2020 (0.22 gt of CO_2e per year) in these SSPs.



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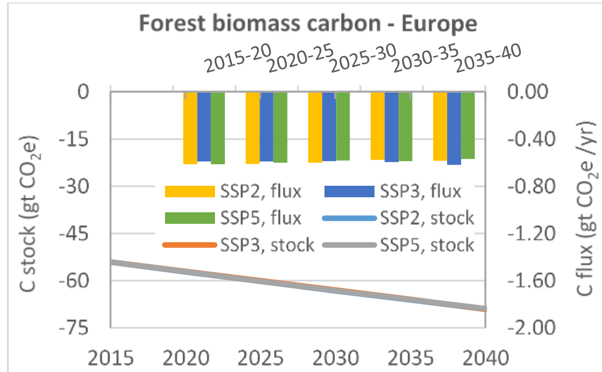

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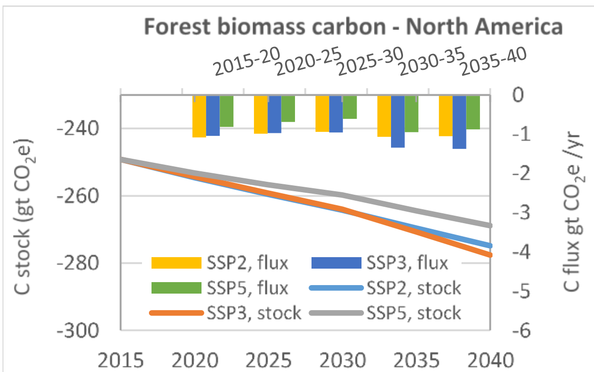

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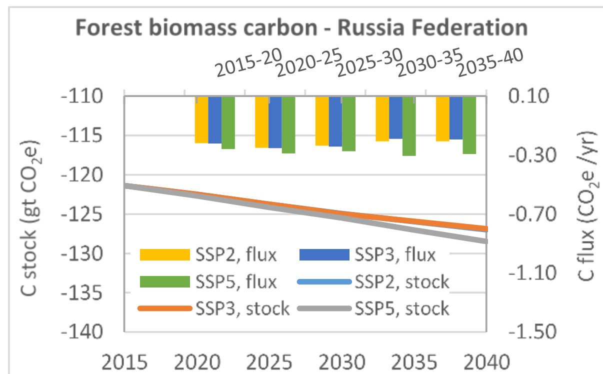


(d)

Figure 6: Projected C stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in above- and below-ground forest biomass in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

Projected carbon stored in hwp followed projected wood production trends across countries and scenarios, with SSP5 sequestering the largest and the SSP3 sequestering the smallest amounts of hwp carbon worldwide as well as in all UNECE subregions (Figures 7a-d). Globally, projected rates of hwp carbon sequestration by 2035-2040 varied from a decline of 1% in SSP3 to an increase of 19% in SSP5, compared to the corresponding sequestration rates during 2015-2020 (Figure 7a). Although the projections show a substantial potential to increase the rate of annual carbon sequestration in hwp (by up to 19% by 2040 in SSP5), these rates are relatively small compared to the rates of carbon sequestration carried out by above- and below-ground biomass carbon, with hwp sequestration rates that are only about 7% to 15% of the above- and below-ground rates. Europe showed the largest projected increase in the rate of annual hwp carbon sequestration, with increases of up to 90 thousand metric tons (mt) of CO_2e per year during 2035-2040, compared to about 34 mt CO_2e per year during 2015-2020 in SSP5 (Figure 7b). North America also showed a higher annual hwp sequestration rate in SSP5, up by 20% over the 2015-2020 sequestration rate of 29.3 thousand mt CO_2e per year, but smaller declines in hwp carbon sequestration rates after 2030 in SSP2 and SSP3 (Figure 7c). The Russian Federation followed European trends and showed increasing carbon sequestration across SSPs: a 90% increase in annual hwp carbon sequestration for SSP5 during 2035-2040 (13.5 thousand mt CO_2e per year) compared to the sequestration rate of 7.2 thousand mt CO_2e per year during 2015-2020 (Figure 7d).

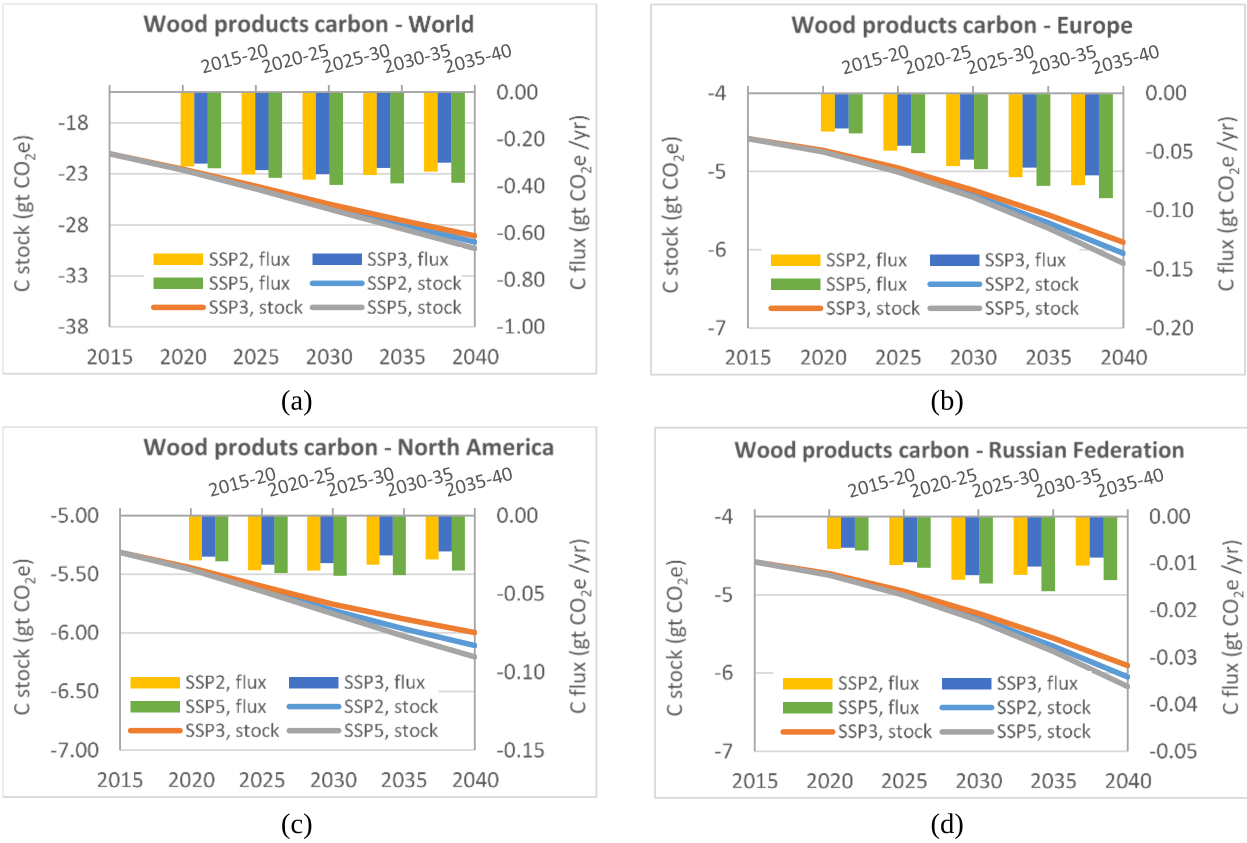


Figure 7: Projected C stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in wood products harvested in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

4.2 Alternative scenarios

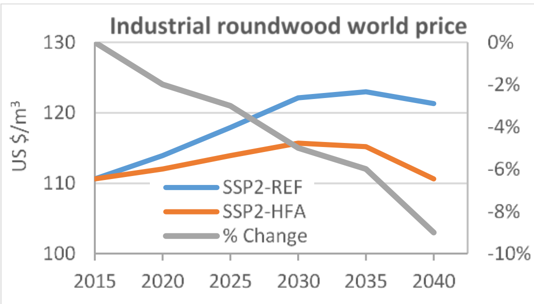
Projected differences in outcomes between the given SSP reference scenario and its paired alternative scenario can provide the estimates of degrees and magnitudes of likely impacts of assumed policy driven changes in forests and the forest products sector. Here, only the projected outcomes related to the SSP2 reference and its paired alternative scenarios are reported. The results for the alternative scenarios paired with SSP3 and SSP5 reference showed similar differences in outcomes as observed in SSP2-alternative pair. The results for those two pairs are not presented here but are available upon request.

4.2.1 High Forest Area (HFA) scenario

As expected, the *HFA* scenario, representing assumed policy driven increases in total forest area (planted plus natural forests), resulted in increased forest stock, relative to the reference scenario, which led to a substantial increase in the amount of carbon stored in above- and below-ground forest biomass in all countries and regions. Projected increases in forest stocks in the *HFA* scenario also led to increased global roundwood production and consumption and reduced timber and forest product prices. The reduced prices were shown to alter the individual countries' comparative advantages in producing and trading forest products, resulting in reduced production of various forest products in countries with low comparative advantages and increased production of these products in countries with higher comparative advantages. Price decreases, however resulted in unambiguous increases in manufactured products consumption in all countries.

4.2.1.1 Projected prices

Projected increases in worldwide forest stocks in the *HFA* scenario resulted in reductions in prices of up to 9% for industrial roundwood by 2040, relative to its price projected in the SSP2 reference case in 2040 (Figure 8a). The price impacts of assumed increases in forest area were smaller in the case of manufactured wood products, ranging from 5% for sawnwood to less than 1% for paper products by 2040, compared to corresponding prices projected in the SSP2 reference scenario (Figures 8b-d).



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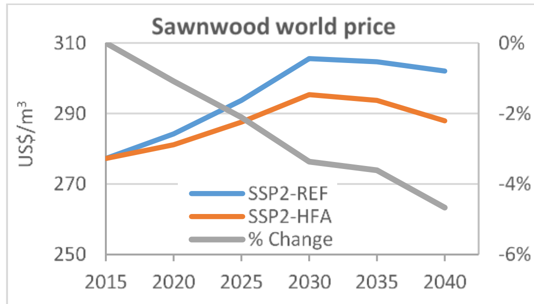

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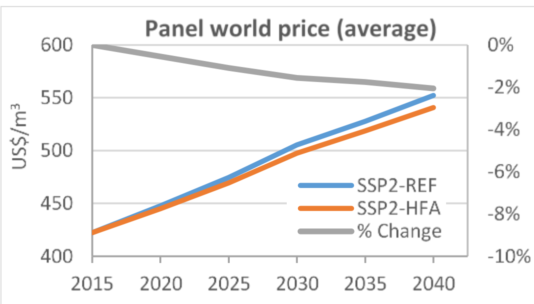

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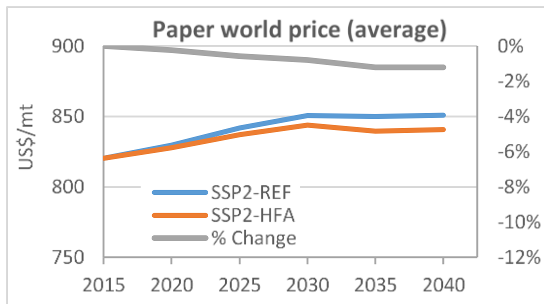


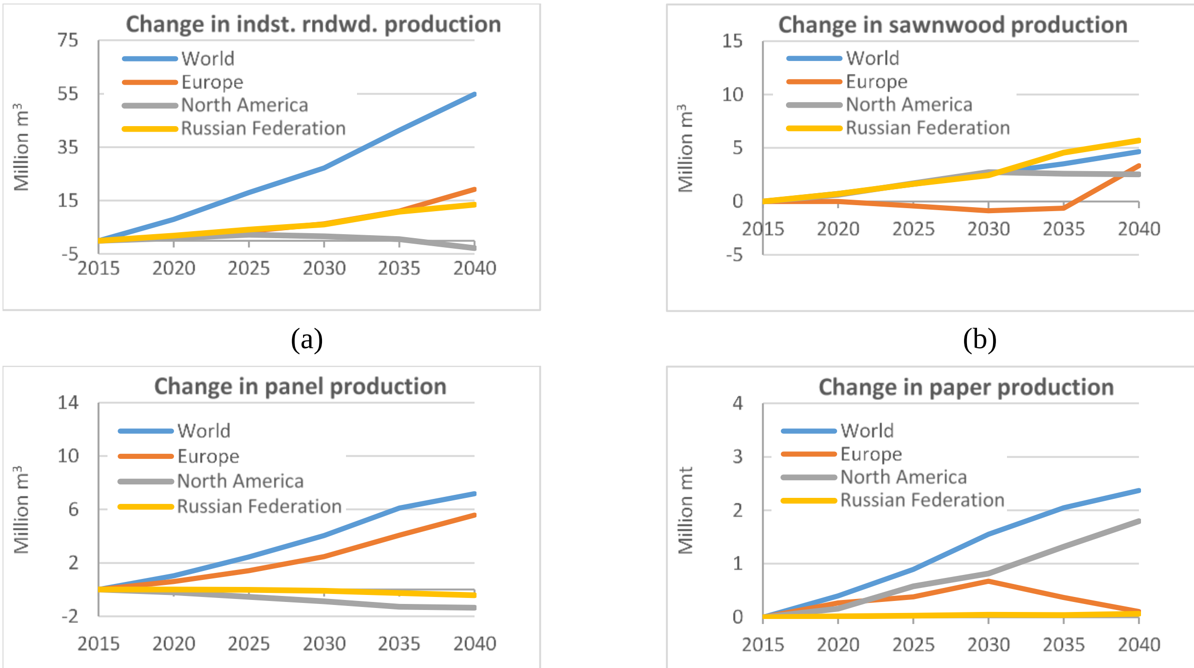
(d)

Figure 8. Projected changes in the world price of industrial roundwood, sawnwood, panel products (the average of prices for plywood, particleboard, and fibreboard), and paper products (the average of prices for newsprint, printing and writing paper, and other paper and paperboard) under the SSP2 reference and its High Forest Area (*HFA*) scenarios, 2015-2040.

4.2.1.2 Projected production, consumption and trade

Assumed increases in world forest area resulted in global increases in industrial roundwood production (and consumption) of about 55 million m^3 by 2040, representing a 2.5% increase relative to its projected production in the SSP2 reference scenario in 2040 (Figure 8a). Europe and the Russian Federation were projected to increase their industrial roundwood production by 19 and 13 million m^3, respectively, representing 4% and 7% increases, relative to the SSP2 reference production in 2040, respectively (Figure 8a). North America, in contrast, reduced its industrial roundwood production by about 3 million m^3 by 2040, representing a 0.5% decline, relative to the SSP2 reference production in 2040 (Figure 8a). Production of manufactured wood products (sawnwood, panels and paper products) followed the projected trends in industrial roundwood production, but they were relatively lower in magnitude (Figures 8b-d).

Most of the projected gains in production were absorbed by gains in consumption, resulting in small or negligible changes in projected net export quantities (not shown in figures).



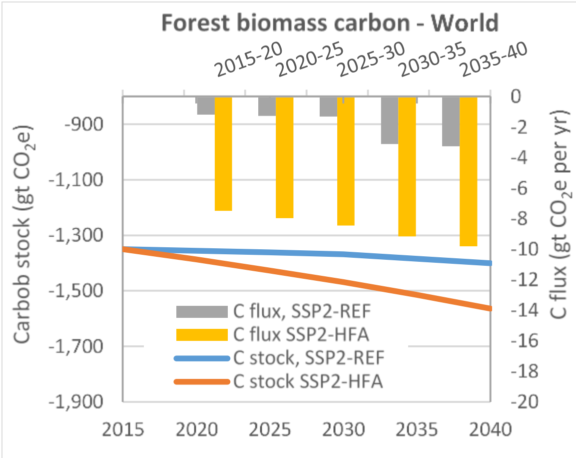
(a) (b) (c) (d)

Figure 8: Projected changes in production of a) industrial roundwood, b) sawnwood, c) panel products (the sum of plywood, particleboard, and fibreboard), and d) paper products (the sum of newsprint, printing and writing paper, and other paper and paperboard) under the SSP2 reference and its High Forest Area (*HFA*) scenarios, 2015-2040.

4.2.1.3 Projected carbon stock and flux

The *HFA* scenario showed the largest potential to increase above- and below-ground carbon sequestration (Figure 9), due to substantial increases in projected forest stocks. This scenario showed a global potential to increase carbon sequestration by 6.5 gt CO_2e per year during 2035-2040, relative to the annual carbon sequestration rate of about 3.3 gt CO_2e per year in SSP2 during the same period. Forests in Europe, North America and the Russian Federation showed potential to increase their above- and below-ground carbon sequestration rates by 0.5, 1.3, and 0.7 gt CO_2e per year, respectively, during 2035-2040, compared to their respective projected sequestration rates in SSP2 during 2035-2040.

Projected increases in hwp carbon in the *HFA* scenario were negligible, due to relatively small increases in wood products production and consumption in this scenario compared to the reference SSP2. For instance, the global annual wood products carbon sequestration rate increased only by 0.01 gt CO_2e per year during 2035-2040 compared to the projected sequestration rate in SSP2 during the same period (Figure E1, Appendix E).



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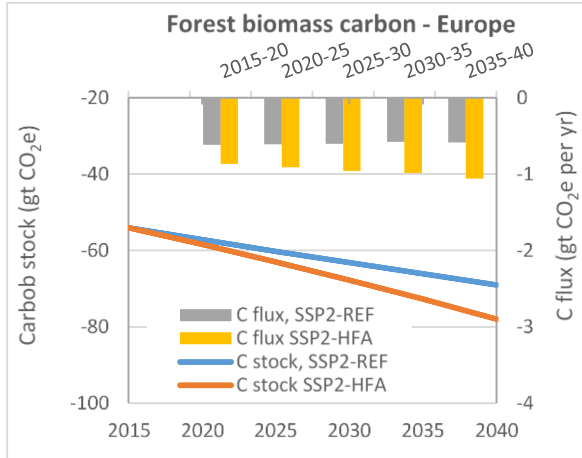

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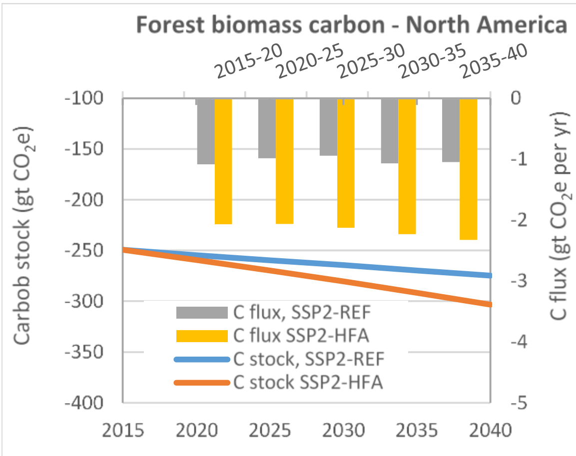

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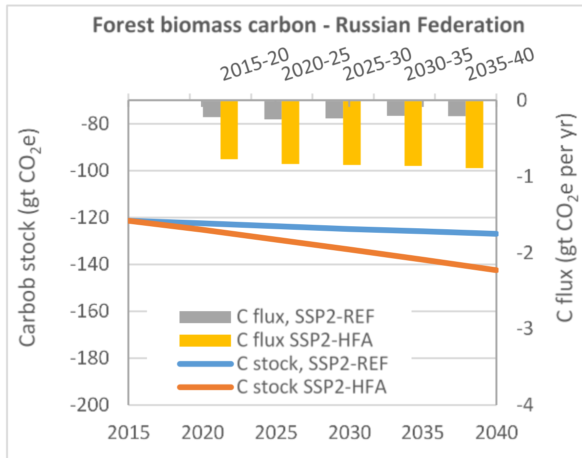

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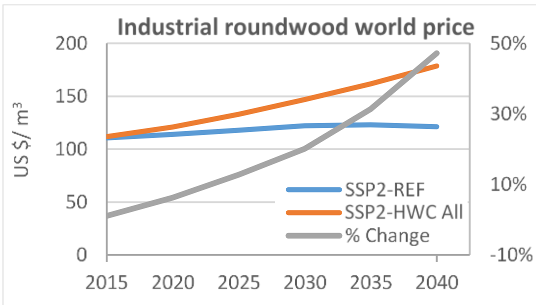
Figure 9: Projected carbon stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in above- and below-ground forest biomass in a) World, b) Europe, c) North America, and d) the Russian Federation under SSP2 reference and its High Forest Area (*HFA*) scenarios, 2015-2040.

4.2.2 High Wood Consumption in all countries (HWC All) scenario

The *HWC All* scenario, representing the assumed doubling of sawnwood and panel products (plywood, particleboard and fibreboard) consumption in all countries (due to assumed structural changes in wood product markets) by 2040 above levels projected by 2040 under the SSP2 reference scenario, demonstrated a substantial increase in timber and wood products prices. Higher wood products consumption also led to substantial increases in carbon stored in hwp. However, higher wood removals needed to meet increasing wood products consumption led to reduced carbon sequestered in forest biomass in this scenario, compared to the projected biomass carbon sequestration in the SSP2 reference. The increased wood products prices resulting from an assumed increase in consumption improved production and trade competitiveness of individual countries, mostly resulting in increased production and net exports. Production of paper products, however, declined in this alternative scenario relative to the reference scenario, due to more profitable roundwood use in meeting increasing sawnwood and panel consumption.

4.2.2.1 Projected product prices

The assumed doubling of worldwide consumption of sawnwood and panel products in the *HWC All* scenario resulted in substantial increases in world prices of wood products, ranging from as large as 47% for industrial roundwood (Figure 10a) to as small as 8% for paper products (Figure 10d), by 2040, relative to their respective prices projected in the SSP2 reference case in 2040. While price impacts of similar magnitudes were observed for sawnwood (up to a 44% increase), panels and paper products showed relatively smaller increases (up to 19%, and 8% increases, respectively) (Figures 10b-d).



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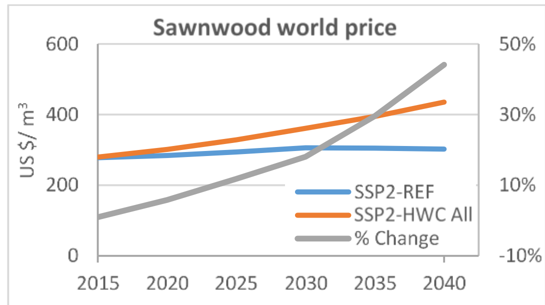

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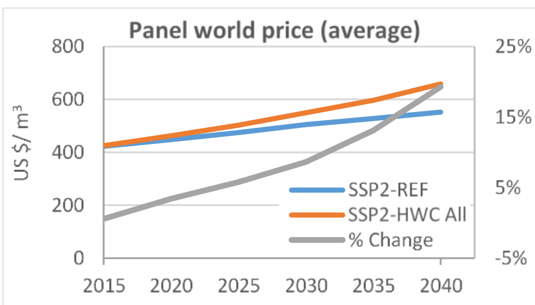

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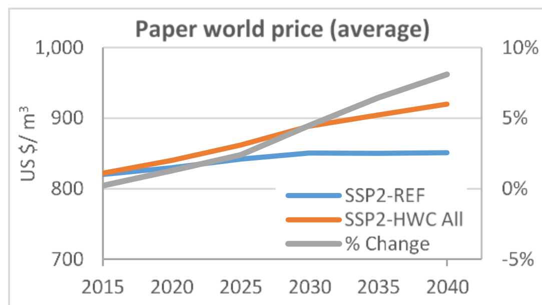

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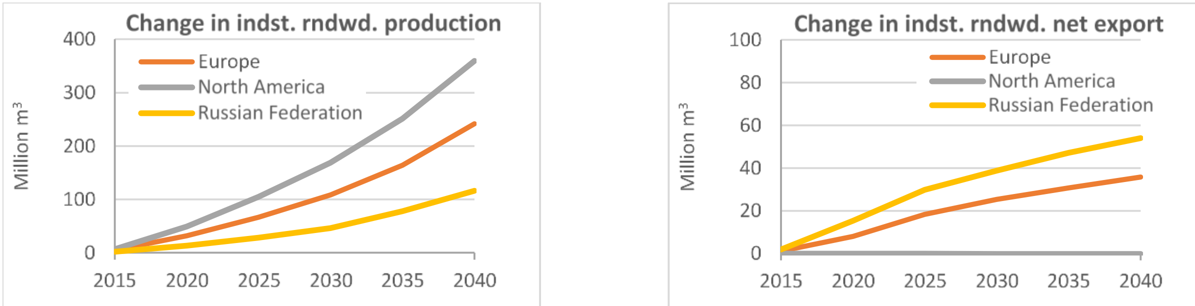
Figure 10. Projected changes in world prices of industrial roundwood, sawnwood, panel products (the average of prices for plywood, particleboard, and fibreboard), and paper products (the average of prices for newsprint, printing and writing paper, and other paper and paperboard) under the SSP2 reference and its High Wood Consumption in All countries (*HWC All*) scenarios, 2015-2040.

4.2.2.2 Projected production and trade

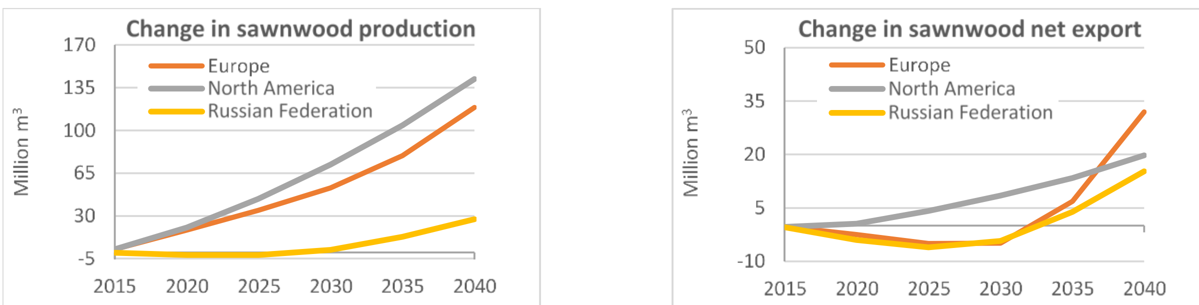
A doubling of sawnwood and panel products consumption in all countries by 2040, above the SSP2 reference consumption in 2040, resulted in a global increase in industrial roundwood production of about 14.4 billion m^3, representing a 65% increase. Similarly, industrial roundwood productions in Europe, North America and the Russian Federation increased by 242, 359, and 116 million m^3, respectively, representing increases of 46%, 56%, and 57%, respectively, relative to the projected production quantities in the SSP2 reference in these UNECE subregions in 2040 (Figure 11a). Most of these increases in industrial roundwood production were consumed domestically within each UNECE subregion, with the small surplus in production exported to the rest of the world (Figure 11b). While Europe and the Russian Federation were projected to increase their industrial roundwood net exports by 36 and 54 million m^3 by 2040, respectively, North America did not show any change in its trade (Figure 11b).



(a) (b)

Figure 11: Projected changes in a) production and b) net export (export minus import) of industrial roundwood in UNECE subregions under the SSP2 reference and its High Wood Consumption in all countries (*HWC All*) scenarios, 2015-2040.

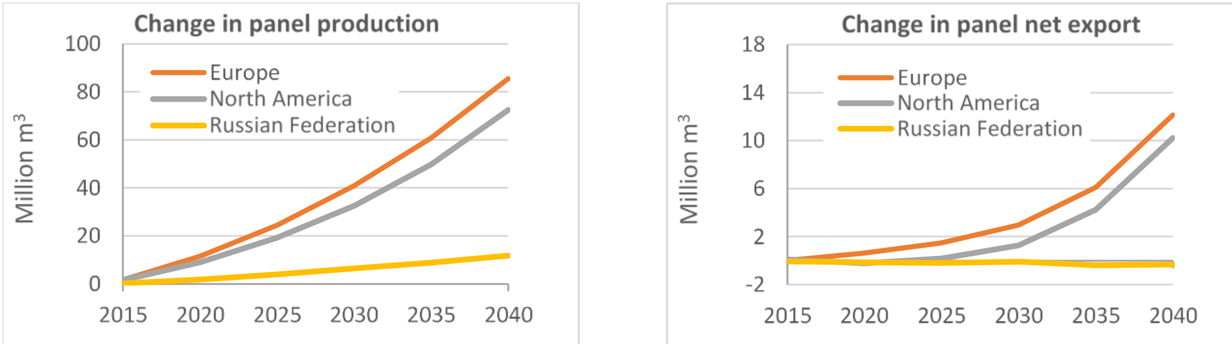
Sawnwood production followed similar trends as roundwood productions in Europe, North America and the Russian Federation, with projected increases of 119, 142, and 27 million m^3 by 2040, respectively, representing respective increases of 67%, 119%, and 63%, relative to the projected production quantities in SSP2 reference scenario in these UNECE subregions in 2040 (Figure 12a). Most of these projected increases in sawnwood production were also consumed domestically in each , with the surplus production exported to the rest of the world, with Europe, North America, and the Russian Federation increasing their sawnwood net exports by 32, 20, and 15 million m^3 by 2040, respectively (Figure 12b).



(a) (b)

Figure 12: Projected changes in a) production and b) net export (export minus import) of sawnwood in UNECE subregions under the SSP2 reference and its High Wood Consumption in all countries (*HWC All*) scenarios, 2015-2040.

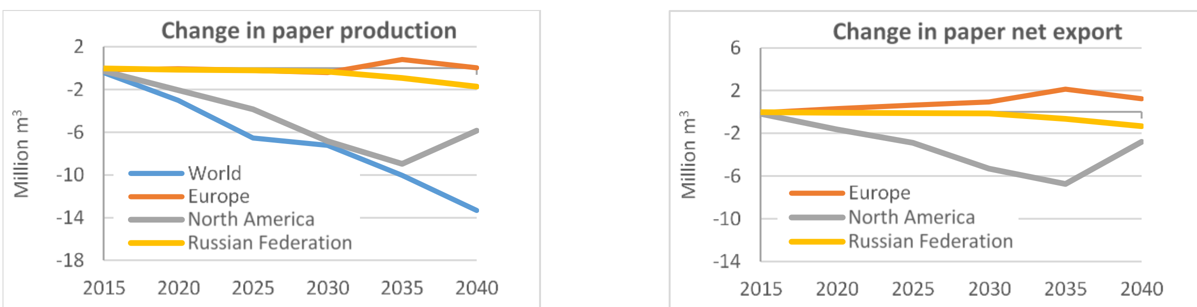
Unlike projected trends in industrial roundwood and sawnwood production, Europe showed the largest increase in panel production quantity in the *HWC All* scenario, followed by North America and the Russian Federation , showing increases of 85, 73, and 12 million m^3 by 2040, respectively, relative to the projected production quantities in SSP2 reference scenario in 2040 (Figure 13a). However, in percentage terms, these increases represented 77%, 136%, and 50% for Europe, North America, and the Russian Federation, respectively. While Europe and North America increased their panel products net exports by 10 and 12 million m^3 by 2040, respectively, the Russian Federation showed a slight decline in its net exports, compared to its net export quantities projected in the SSP2 reference scenario in 2040 (Figure 13b).



(a) (b)

Figure 13: Projected changes in a) production and b) net export (export minus import) of panel products (the sum of plywood, particleboard, and fibreboard) in UNECE subregions under the SSP2 reference and its High Wood Consumption in all countries (*HWC All*) scenarios, 2015-2040.

Unlike the projected trends in solidwood products, paper production declined worldwide and in each UNECE subregion (except in Europe where its production increased slightly), as a result of more profitable use of roundwood in meeting increasing sawnwood and panel demands. Such declines in paper production were projected to be 13 million metric tons (mt) globally, and 6 and 2 million mt for North America and the Russian Federation, by 2040, respectively (Figure 14a), compared to the respective paper production quantities projected in SSP2 reference scenario in 2040. Trade in paper products followed projected trends in its production, with North America, and the Russian Federation decreasing its net exports by about 3 and 1 million mt, and Europe increasing its net export by about 1 million mt by 2040, relative to the projected net export quantities in SSP2 reference scenario in 2040 (Figure 14b).



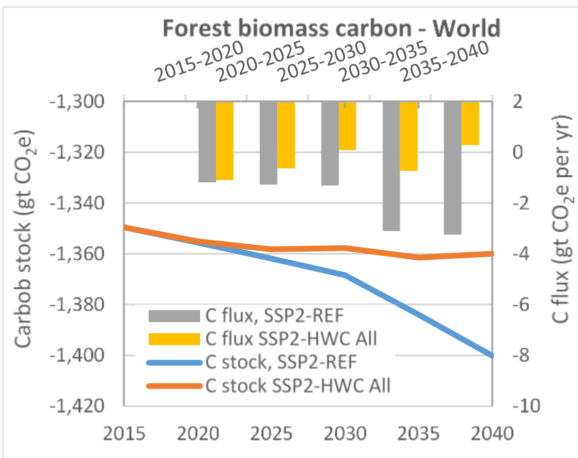
(a) (b)

Figure 14: Projected changes in a) production and b) net export (export minus import) of paper products (the sum of newsprint, printing and writing paper, and other paper and paperboard) in UNECE subregions under the SSP2 reference and its High Wood Consumption in all countries (*HWC All*) scenarios, 2015-2040.

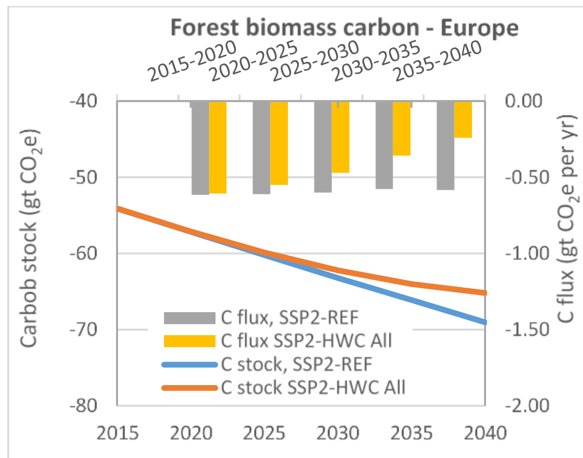
4.2.2.3 Projected carbon stock and flux

While increased wood products consumption in the *HWC All* scenario resulted in projected substantial increases in carbon sequestration rates in hwp, these increases were accompanied by reduced above- and below-ground carbon sequestration, a consequence, relative to the SSP2 reference case, of depleting forest stocks caused by greater wood removal quantities, the net effect being reduced total forest sector carbon compared to the reference case. For instance, projected global annual increases in wood products carbon of 0.55 gt of CO_2e per year (Figure 16a) during 2035-2040 in the *HWC All* scenario was accompanied by reduced rates of above- and below-ground carbon sequestration of about 3.53 gt of CO_2e

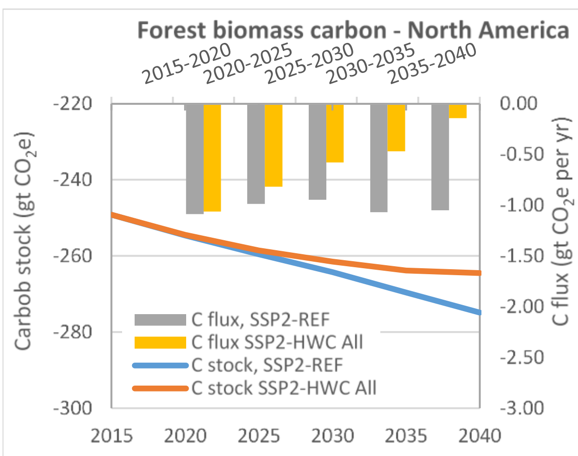
per year (Figure 15a) during the same period (net loss of 2.98 gt of CO_2e per year), relative to the projected carbon sequestration rates in the SSP2 reference case during 2035-2040. Similar trends were also observed in UNECE subregions. Wood produced in Europe resulted in an increase in the hwp carbon sequestration rate, by 0.1 gt CO_2e per year (Figure 16b) over the SSP2 reference, accompanied by a reduction of about 0.34 gt CO_2e per year in above- and below-ground biomass (Figure 15b) during 2035-2040 (net loss of 0.23 gt CO_2e per year). North America showed a similar increase in the rate of hwp carbon sequestration (0.11 gt CO_2e per year, Figure 16c) but greater reductions in above- and below-ground carbon sequestration (0.9 gt CO_2e per year, Figure 15c) than Europe during the same period. Finally, wood removals from the Russian Federation were shown to increase wood products carbon by just 0.02 gt CO_2e per year (Figure 16d), with a resulting loss in biomass carbon of 0.14 gt CO_2e per year (Figure 15d) during 2035-2040, compared to the SSP2 reference case.



(a)



(b)



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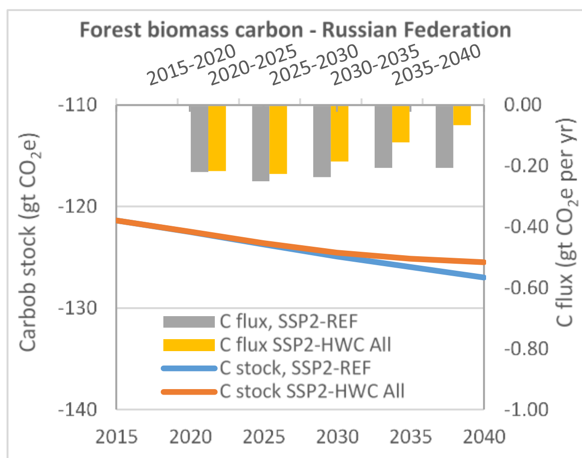
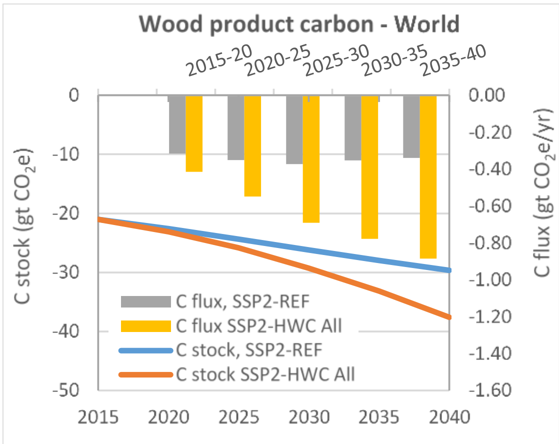
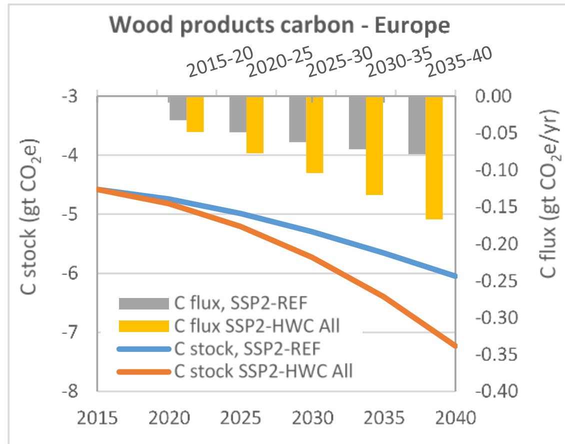


(d)

Figure 15: Projected carbon stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in above- and below-ground forest biomass in a) World, b) Europe, c) North America, and d) the Russian Federation under the SSP2 reference and its High Wood Consumption in all countries (*HWC All*) scenarios, 2015-2040.



(a)



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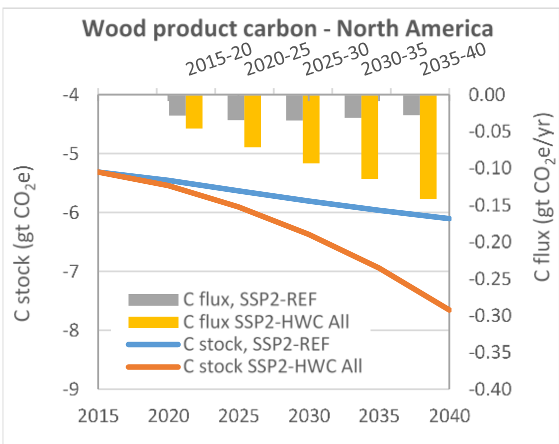
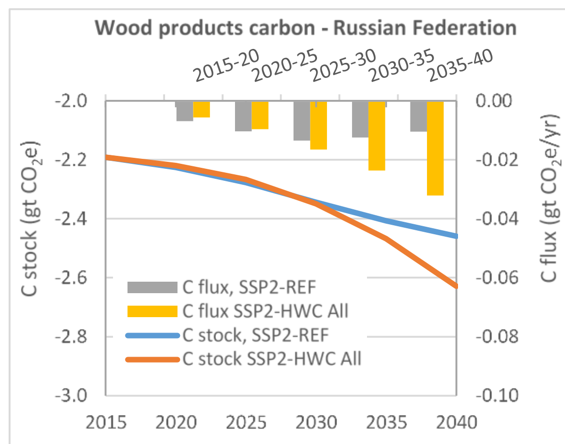


(c)



(d)

Figure 16: Projected carbon stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in wood products harvested in a) World, b) Europe, c) North America, and d) the Russian Federation under the SSP2 reference and its High Wood Consumption in all countries (*HWC All*) scenarios, 2015-2040.

4.2.3 High Wood Consumption in selected countries (HWC Select) scenario

Assumed doubling of sawnwood and panel products consumption only in the six most populous countries outside of the UNECE, a scenario designed to isolate the effects of changes in wood products consumption in those countries on global and UNECE forests and forest sectors, had notable effects on global as well as on UNCECE subregions' forests and forest products sectors (Figures F1-F7 Appendix F). The projected effects similar to the effects observed in the *HWC All* scenario, but of lesser magnitudes. Increased demands for wood products in those countries led to increased world product prices (Figure F1 Appendix F), ranging from up to 12% (sawnwood) to up to 1% (paper products), relative to the SSP2 reference case, altering comparative advantages of each country in producing and trading forest products. As a result, all UNECE subregions showed increased production: up to a 14% increase in industrial roundwood production (the Russian Federation), a 44% increase in sawnwood production (the Russian Federation), a 19% increase in panel production (North America), and a 9% increase in paper production (North America) by 2040, compared to projected respective production quantities in SSP2 reference scenario in 2040 (Figures F2a, F3a, F4a, and F5a, Appendix F). The majority of the projected gains in production in the UNECE subregions were projected to be absorbed by projected increases in their domestic consumption and relatively smaller increases in their net exports (Figures F2b, F3b, F4b, and F5b, Appendix F).

The effects of the *HWC Select* scenario on forest sector carbon was similar to the effects observed in HWC all scenario, i.e., increased carbon sequestered in harvested wood products and reduced carbon sequestered in above- and below-ground carbon. However, both the magnitude of increases in hwp and shrinkages in the rates of sequestration in biomass carbon were smaller by about 50%, compared to the *HWC All* scenario (Figures F6 and F7, Appendix F).

4.2.4 High Forest Area and High Wood Consumption in all countries (HFA_HWC_All) scenario

The *HFA_HWC_All* scenario, representing policy driven increases in forest area coupled with increased sawnwood and panel products consumption in all countries due to assumed worldwide structural changes in the wood products market, was developed mainly to assess whether this scenario would result in maximum rates of sequestration of forest sector carbon. The projections indicated that this scenario would result in both increased carbon sequestration in hwp and in above- and below-ground biomass worldwide and in all UNECE subregions. However, the combined forest sector carbon in this scenario was less than the *HFA* scenario because the projected increase in wood products carbon in this scenario was not enough to offset the loss in biomass carbon due to increase removals depleting forest stocks. Thus, *HFA* resulted in a scenario that could provide the highest forest sector carbon potential, followed by the *HFA_HWC_All* scenario (Figures G6 and G7, Appendix G) among the evaluated alternative scenarios.

In terms of effects on forest products markets, this scenario also resulted in increased product prices, but these increases were smaller in magnitude, compared to prices projected in *HWC All* scenario (about 10% lower for industrial roundwood and sawnwood prices, and about 2% lower for panel and paper products), which was the result of higher forest stock levels compared to the *HWC All* scenario. However, the projected production, consumption and trade quantities were slightly higher than in *HWC All* scenario, again due to projected higher forest stocks, leading to increased roundwood supply and resultant increased production of manufactured products (Figures G1-G5, Appendix G).

5. Discussion and conclusions

The scenarios developed and modelled so far are based on FSOS country representatives' own suggestions, gathered through outreach by the Secretariat and the FSOS leadership in 2018, on the most important policy and management questions and related issues likely to be affecting the forest sector of the UNECE. The scenario selection process and modelling outcomes reported here are an attempt to show how global forest sector modelling can provide the information needed to answer these most important questions. For example, scenarios modelling increased consumption of sawnwood and panels captures how the UNECE region would be affected by significantly increased demands for wood products in a world of higher rates of use of these products in the residential multi-family housing and non-residential construction sectors, perhaps enabled by changes in policies allowing more wood used in large buildings. Similarly, the scenarios modelling the effects of large increases in forest area and forest stocks, perhaps resulting from enactment of international efforts to combat climate change may lead to global shift in supply of industrial roundwood, manufactured wood products, and their prices.

The projected outcomes of the evaluated scenarios revealed varying insights into the likely effects of relevant future forest sector policy and market changes on forests and forest products sectors globally and in UNECE subregions. These effects are mainly related to projected changes in forest products prices, and the associated impacts on wood removals, forest stocks, and production, consumption, and trade of solidwood and paper products in individual countries. Estimates of changes in these variables can portray the likely future picture of available forest resources, trade-offs associated with the use and management of these resources for various timber and non-timber products and services, and the overall economic wellbeing of the forest products sector, including potential economic impacts to producer and consumers of forest products. Such pictures of how forests and forest products markets evolve under various economic and alternative futures are not only crucial for investors, forest landowners and forest products manufacturers to make informed decision about potential profitability of their businesses, they are equally important to government agencies and policy makers who face the critical question of how to best sustain available forest resources in the face of future climate change and increasing, and increasingly wealthy, populations, which are likely to demand more forest products and their services than ever before.

The key observations, based on the current scenario modelling, are that the wealthier and more equal worlds represented by SSP5 (and SSP2) scenarios would mostly induce larger increases in forest products consumption, leading to higher product prices, increased wood removals and increased production and trade of manufactured wood products in the majority of countries of the UNECE, relative to respective projections for the poor and divergent world represented by SSP3. The SSP5 economic futures also suggested the largest forest sector carbon sequestration potential for the majority of the countries compared to the SSP2 and SSP3, except for North America and Europe where SSP3 showed the largest carbon sequestration potential, due to higher forest area projected in SSP3 for that region.

Similarly, results projected in the alternative *HFA* scenario, representing policy driven increases in global forest area (therefore increased forest stocks), suggested the largest forest sector carbon mitigation potential in all countries. Such a policy scenario, ceteris paribus, also indicated a relatively smaller disruption in forest product markets, with relatively smaller projected decline in prices and associated changes in consumption, production, and net exports of forest products.

In contrast, the *HWC All* scenario, representing worldwide increases in sawnwood and panels consumption, showed the largest disruption in forest products markets, with the largest projected changes in prices (up to 47%), production, and net exports of forest products. Because of more profitable use of roundwood in meeting higher demands for sawnwood and panel products, this scenario indicated future declines in production and consumption of paper products. This scenario also resulted in the lowest projected forest sector carbon sequestration potential, because depletion in forest stocks would result in greater wood removals needed to meet assumed increase in sawnwood and panel products consumption, although this scenario showed substantial potential to increase carbon sequestered in wood products, but not enough to counter losses in forest carbon. The other two scenarios (*HWC Select* and *HFA_HWC_All*) showed impacts that were intermediate between the projected impacts for the *HFA* and *HWC All* scenarios.

Needless to say, the projections reported here suffer from the inherent uncertainties like any other forest sector projection would suffer, which can arise from a wide range of sources including but not limited to uncertainties in assumptions about future demography, economies, and wood consumption tastes and preferences, over and above those driven by income and price changes. The GFPM, as well, models forest area as a relatively simple expression of what drives changes in forest area, ignoring direct modeling of all sectors affecting land use (e.g., agriculture and urban uses), although we contend that the modified EKC and planted forest projection models go a long way to alleviating some of that uncertainty. However, because our interest is in understanding the projected trends and the projected differences in outcomes between the reference and the alternative scenarios, conclusions made based on these projected trends and outcomes will still be valid and can stimulate important discussions on how current scenarios and results addressed the identified policy questions. Moreover, this presentation may assist in identifying which revisions and/or further work might be needed to better evaluate the important forest sector policy questions relevant to the UNECE region, for inclusion in the final FSOS publication.

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APPENDIX A

Policy scenarios recommended for the UNECE/FAO Forest Sector Outlook Studies (FSOS) III by the UNECE team of specialists (ToS) on FSOS and the UNECE/FAO Working Party on Forest, Statistics, Environment and Management (FSEM) and their development and selection process.

Table A1: First draft of the possible scenarios discussed by the ToS members in their meeting on 21 March 2018

General aspect	Policy questions	Reference Scenario / Variables to compare	Possible alternative scenarios
Climate Change	What is the potential of UNECE forest sector for climate change mitigation? What can the UNECE forests contribute?	Carbon sequestration and avoided emissions in forests and wood products under a normal economic growth scenario = reference scenario (no change in forest land)	CC1: Potential of carbon sequestration in wood construction; assumption: significant increase in wood construction (UNECE and/or worldwide) CC2: Potential of carbon sequestration in traditional wood products; assumption: (policy-driven) significant increase in demand for wood products (UNECE and/or worldwide) CC3: Potential of carbon sequestration in new products based on wood fibres; assumption: technological advances that allow a significant increase of use of wood fibres CC4: Potential of carbon sequestration through (re-)forestation; assumption: policy- driven, significant increase of forests area in the UNECE region (e.g. Bonn challenge) CC5: Maximising carbon sequestration by changing silvicultural methods (update to the EFSOS II scenario “Maximising biomass carbon”) CC6: Potential of climate change mitigation through substitution in the energy sector through an increased use of wood energy CC7: Combination of the above – what is the maximum that could be achieved given competing demands for wood products (possibly looking at Climate Smart Forestry)
	How will UNECE forests be affected by climate change? How will adaptation look like?	Supply of forest resources under current forest growth scenario (no further climate change)	CC7-CC10: Differences in supply of forest resources under the four representative concentration pathways (RCPs) from the IPCC 5th Assessment Report (possibly looking at resilience as well)
Structural Changes	How would different demand changes affect the UNECE forest product market?	Demand and prices for wood products under reference scenario	SC1: Massive increase of demand for wood constructions – within UNECE – and outside (especially China); closely linked to calculations for CC1 SC2: Significant increase of demand for wood-fibres for textiles and other products; closely linked to calculations for CC3 SC3: Significant economic collapse (whole world and/or specific countries/regions) SC4: Successful development of an alternative energy source and thus drastic decrease in demand for wood energy

			SC5: Significant decrease of demand for print and paper with simultaneous increase of demand for packaging SC6: Significant increase of biorefineries.
	How would different supply changes affect the UNECE forest product market?	Supply and prices for wood products under reference scenario	SC7: Significant increase of forest plantations outside of UNECE (e.g. Africa and/or Asia) SC8: Significant increase of natural disasters
	What would be the effect of massive restrictions to trade on the UNECE forest product market?	Supply, demand and prices under reference scenario	SC9: Trade between countries and/or regions is significantly restricted
Green Economy & SDGs	What are opportunities and challenges regarding green jobs?	Employment under the reference scenario	GS1: Effect of a significant increase of technology in forest employment (qualitative analysis) GS2: Effect of a significant decrease of qualified labour supply (qualitative analysis)
	What is the potential of the Payment of Ecosystem Services	What are current examples of PES	GS3: Effects of a wide-spread use of PES (qualitative & quantitative analysis)
	What is the potential contribution of UNECE forests and forest products to the achievement of the SDGs	SDG achievement under the reference scenario	GS4: Effects of a specific focus on the achievement of certain SDG targets (qualitative analysis)

Table A2: Second draft of the possible scenarios discussed by the ToS based on technical feasibilities.

Possible scenario	**Technical feasibility**
Climate change mitigation (different aspect: potential carbon sequestration in wood construction and other wood products, different silvicultural methods, reforestation, substitution in energy (wood energy) and combination of the previous)	Feasible with a set of models
Climate change adaptation	Country-based review (no or little modelling involved)
Upcoming market scenarios (China, Africa)	Feasible, based on SSPs
Growth of specific products (construction, fibres, biorefineries)	Feasible
Economic disturbances	Feasible
Significant increase of forest plantations outside of UNECE	Feasible
Impact on forest product market by significant increase of natural disasters	Feasible
Impact of trade barriers (increase or decrease)	Feasible
Potential of Payment for Ecosystem Services	Not feasible as a full outlook scenario; parts could be covered (carbon payment), and current case studies be added
Employment	Not feasible as a outlook scenario, could potentially be a “post-analysis” on all scenarios
SDGs	Not feasible as a outlook scenario, could potentially be a “post-analysis” on all scenarios; labor-intensive
Circular Economy/Cascading-use of wood	Difficult to define well as a scenario, could be a “post-analysis” on all scenarios

Table A3: Third draft of the possible scenarios prioritized by the participants at the 40th session of the Joint UNECE/FAO Working Party on FSEM.

Possible scenario	**Average priority**
Climate change mitigation	2.8
Growth of specific products (construction, fibres, biorefineries)	2.8
Climate change adaptation	2.6
Upcoming market scenarios (China, Africa)	2.6
Economic disturbances	2.6
Impact on forest product market by significant increase of natural disasters	2.4
Nature conservation	2.4
Impact of trade barriers (increase or decrease)	2.2
Potential of Payment for Ecosystem Services	1.8
SDGs	1.8
Circular Economy/Cascading-use of wood	1.8
Employment	1.6

APPENDIX B

Summary of the selected reference and alternative scenarios and their descriptions

Table B1: Modeled scenario for the next FSOS meeting

Modeled scenarios	**Policy questions addressed**	**Projected variables**

1. 1 Shared Socioeconomic Pathways 2 (*SSP2*)
• One of the three reference scenarios
• Middle-of-the-road world vision
• Continuation of current trend in income and population
	• Impacts on forest area, planted forest area, forest stock, and forest products market evolve during 2020-2040 under the "middle-of-the-road" world vision?
	• How the projected forest sector development in the middle-of-the-road world vision would contribute to climate change mitigation?
		• Planted area
		• Total forest area
		• Forest stock
		• Wood harvest
		• Products prices
		• Consumption
		• Production
		• Trade
		• Forest sector C sequestration
		  ○ C in forest biomass
		  ○ C in wood products

1.2 SSP2-High Forest Area (*SSP2-HFA*) • Paired with the SSP2 reference scenarios • Total forest and planted forest area respectively increase by 10% by 2040, relative to the respective areas projected in SSP2 reference scenario in 2040.	• How future climate change mitigation policies, contributing to increased planted and total forest area during 2020-2040 would affect forests and forest product sector in UNECE regions? • What would be UNECE regions forest sector contribution to climate change mitigation under the middle-of-the world vision combined with an aggressive climate change mitigation policy leading to overall increase in total forest area?	Same as above
1.3 SSP2-High Wood Consumption in All countries (*SSP2-HWC All*) • Paired with the SSP2 reference scenario • Sawnwood and panel products consumption double by 2040, relative to the projected consumption of those products in SSP2 reference scenario in 2040.	• How perceived structural changes in forest product markets such as increased wood use in construction sector (e.g., high-rise construction using mass timber), increased wood fiber use in new products, and increased overall per capita wood consumption would affect forest and forest products sector development in UNECE regions? • How such structural changes in forest product markets affect forests and wood products carbon sequestration in the UNECE regions?	Same as above
1.4 SSP2-High Wood Consumption in selected countries (SSP2-HWC Select)	• How potential structural changes in forest product markets such as increased wood use in construction sector and overall wood consumption in the six most populous countries in the world including China, India,	Same as above

<table>
<tr><td>Paired with the SSP2 reference scenario
Sawnwood and panel products consumption double by 2040 in six most populous countries, relative to the projected consumption of those products those countries in SSP2 reference scenario in 2040.</td><td>Indonesia, Pakistan, Brazil, and Mexico would affect forest and forest products sector development in the UNECE regions.
How such structural changes in forest product markets only in selected countries affect forests and wood products C sequestration in the UNECE regions?</td><td></td></tr>
<tr><td>1.5 SSP2-High Forest Area and High Wood Consumption in all countries (SSP2-HFA_HWC_All)
Paired with the SSP2-reference scenario
Total forest and planted forest area respectively increase by 10% by 2040, relative to the respective areas projected in SSP2 reference scenario in 2040.
Sawnwood and panel products consumption double by 2040 in all countries, relative to the projected consumption of those products in SSP2 reference scenario in 2040.</td><td>How future climate change mitigation policies, contributing to increased planted and total forest area during 2020-2040, combined with future increases in wood consumption in all countries would affect forests and forest product sector in the UNECE regions?
How UNECE regions forest sector carbon sequestration would be affected when climate change mitigation policies increasing total forest area during 2020-2040 were accompanied by increased wood consumption during the same period?</td><td>Same as above</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>2.1 Shared Socioeconomic Pathways 3 (SSP3)
One of the three reference scenarios
Poorest world vision
increasing inequality
high population growth</td><td>How would forest area, planted forest area, forest stock, and forest products market evolve during 2020-2040 under the “poorest” world vision?
How the projected forest sector development in the poorest and unequal world vision would contribute to climate change mitigation?
What are the forest sector impacts of future collapse in global economies?</td><td>Same as above</td></tr>
<tr><td>2.2 SSP3-HFA
Paired with the SSP3 reference scenario
Total forest and planted forest area respectively increase by 10% by 2040, relative to the total forest area projected in the SSP3 reference scenario in 2040.</td><td>Same as in SSP2-HFA</td><td></td></tr>
<tr><td>2.3 SSP3-HWC All
Paired with the SSP3-reference scenarios
Sawnwood and panel products consumption double by 2040, relative to the projected consumption of those products in the SSP3 reference scenario in 2040.</td><td>Same as in SSP2-HWC All</td><td>Same as above</td></tr>
<tr><td>2.4 SSP3-HWC Select
Paired with the SSP3 reference scenario</td><td>Same as in SSP2-HWC Select</td><td>Same as above</td></tr>
</table>

• Sawnwood and panel products consumption double by 2040 in six most populous countries, relative to the projected consumption of those products those countries in the SSP3 reference scenario in 2040.		
3.1 Shared Socioeconomic Pathways 5 (*SSP5*) • One of the three reference scenarios • Wealthiest world vision • Global equality • Low population growth	• How would forest area, planted forest area, forest stock, and forest products market evolve during 2020-2040 under the "wealthiest" world vision? • How the projected forest sector development in the wealthiest and equal world vision would contribute to climate change mitigation?	Same as above
3.2 *SSP5-HFA* • Paired with the SSP5 reference scenario • Total forest and planted forest area respectively increase by 10% by 2040, relative to the total forest area projected in the SSP5 reference scenario in 2040.	Same as in SSP2-HFA	Same as above
3.3 *SSP5-HWC All* • Paired with the SSP2-reference scenarios • Sawnwood and panel products consumption double by 2040, relative to the projected consumption of those products in the SSP5 reference scenario in 2040.	Same as in SSP2-HWC All	Same as above
3.4 *SSP5-HWC Select* • Paired with the SSP3 reference scenario • Sawnwood and panel products consumption double by 2040 in six most populous countries, relative to the projected consumption of those products those countries in the SSP5 reference scenario in 2040.	Same as in SSP2-HWC Select	Same as above

APPENDIX C

Estimated coefficients of total forest and planted forest area Environmental Kuznets Curve model and projected drivers of total and planted forest area

Table C1: Estimated coefficients, standard errors, and significance levels of the Environment Kuznets Curve (EKC) model of global total forest area, which were further used to project development total forest area in all countries.

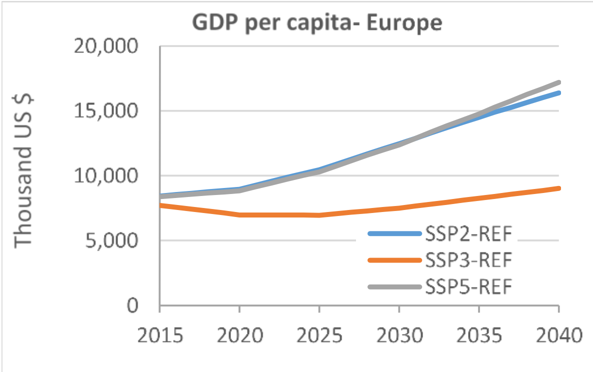
Variables	Fixed Effect Model[1]		
$(Y/N)_{it}$, GDP per capita	-0.16	(0.10)	*
$(Y/N)^2_{it}$	0.015	(0.010)	**
U_{it} rural population density	-0.70	(0.0001)	***
$(L/A)_{it}$, labor per forest area	0.42	(0.01)	***
$(K/A)_{it}$, capital per forest area	-0.010	(0.010)	
$(L/A)_{it}$*$(K/A)_{it}$	0.0003	(0.0001	***
I_{it}	0.020	(0.050)	
I_{it}*$(Y/N)_{it}$	0.024	(0.010)	**
I_{it}*$(L/A)_{it}$	0.030	(0.020)	
I_{it}*$(K/A)_{it}$	-0.020	(0.010)	**
I_{it}*$(L/A)_{it} * (K/A)_{it}$	0.0025	(0.0010)	
Intercept	25.69	(1.07)	***
R^2 (adjusted)	0.38		
Pooling test	117.24	***	
Hausman test	24.2	**	

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

Table C2: Estimated coefficients, standard errors, and significance levels of the Environment Kuznets Curve (EKC) model of planted forest area, which were further used to project development in planted forest area in all countries.

Variables	Fixed Effect Model[1]		
$(Y/N)_{it}$, GDP per capita	1.07	(0.58)	*
$(Y/N)_{it}^2$	-0.052	(0.034)	
U_{it} rural population density	–1.31	(0.36)	***
$(L/A)_{it}$, labor per forest area	1.98	(0.01)	***
$(K/A)_{it}$, capital per forest area	0.030	(0.091)	
$(L/A)_{it}$*$(K/A)_{it}$	-0.047	(0.010)	***
I_{it}	0.21	(0.30)	
I_{it}*$(Y/N)_{it}$	-0.054	(0.076)	
I_{it}*$(L/A)_{it}$	0.16	(0.12)	
I_{it}*$(K/A)_{it}$	0.032	(0.060)	
I_{it}*$(L/A)_{it} * (K/A)_{it}$	-0.021	(0.010)	
Dummy- South America	-0.41	(1.48)	
Dummy- Asia	-0.48	(1.43)	
Dummy- Africa	-1.64	(1.38)	
Dummy- Europe	0.23	(1.41)	*
Dummy- North America	-2.48	(1.47)	***
Intercept	26.83	(5.92)	**
R^2 (adjusted)	0.26		
Pooling test	40.79 ***		

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



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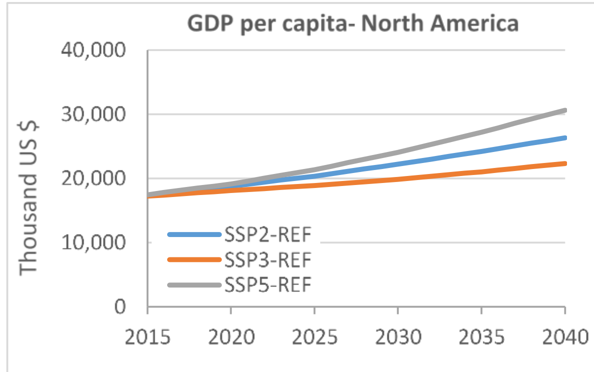

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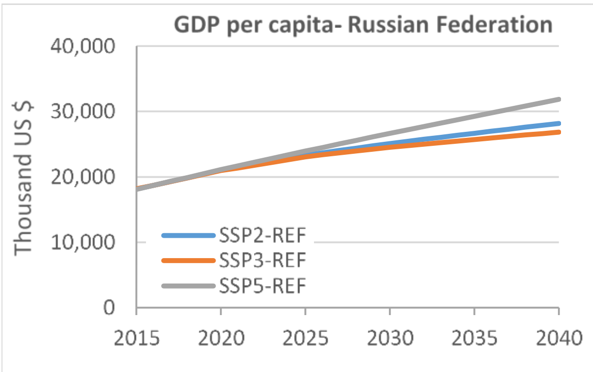
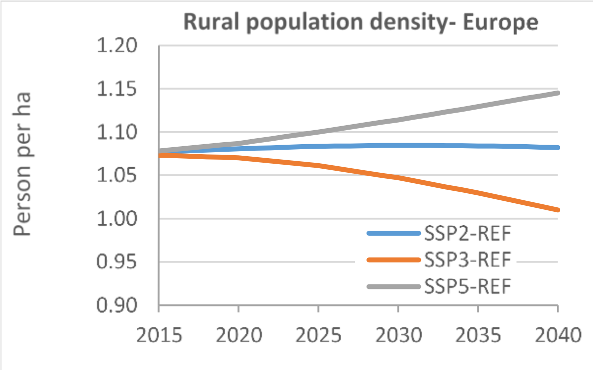


(c)

Figure C1: Projected average per capita gross domestic products (2010 constant US$) for a) Europe, b) North America, and c) the Russian Federation under different socioeconomic pathways, 2015-2100. The source of data is IIASA database (IIASA 2018).



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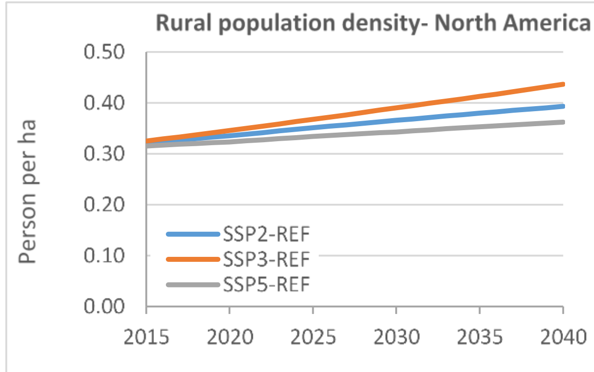

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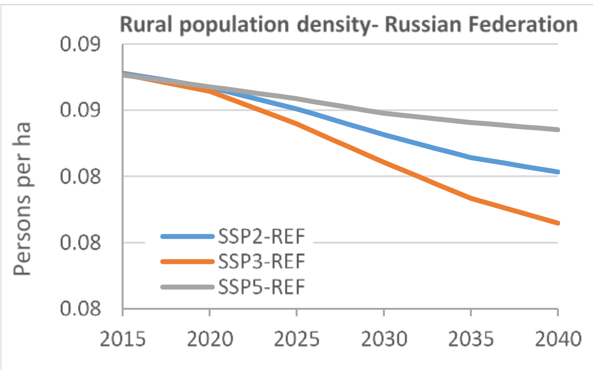
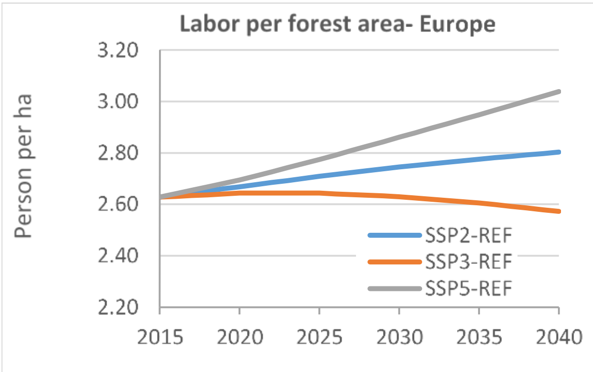


(c)

Figure C2: Projected rural density (person per ha) for a) Europe, b) North America, and c) the Russian Federation) under different socioeconomic pathways, 2015-2100. The source of data are World Bank (2018) and Jiang and O'Neill (2017). Rural land area was assumed to change in future in proportion to the projected trends in rural population.



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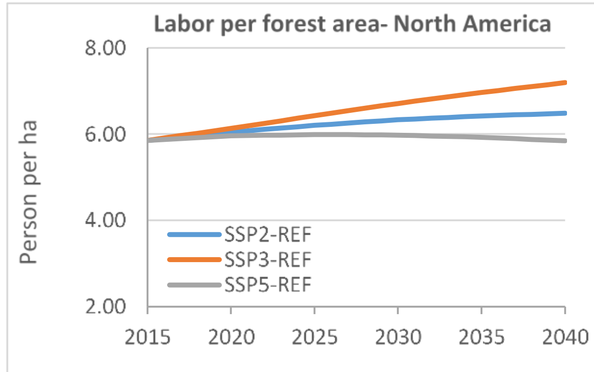

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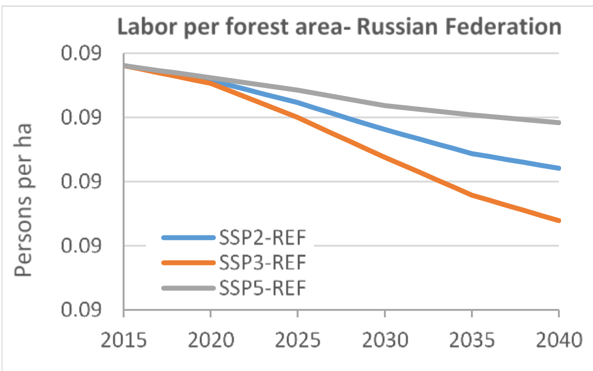
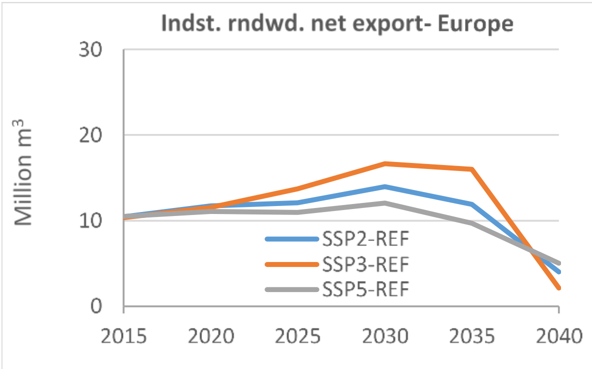


(c)

Figure C3: Projected average labor per forest area (person per ha) for a) Europe, b) North America, and c) the Russian Federation under different socioeconomic pathways, 2015-2040. The source of data are World Bank (2018) and FAO (2015). The base year labor per forest area was assumed to follow the population growth trends projected in respective SSPs.

APPENDIX D

Projected variables for three SSP reference scenarios



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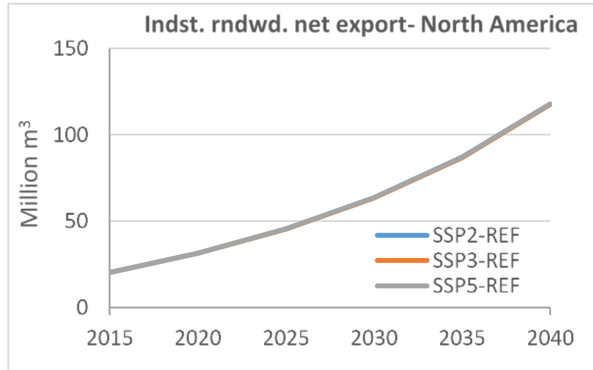

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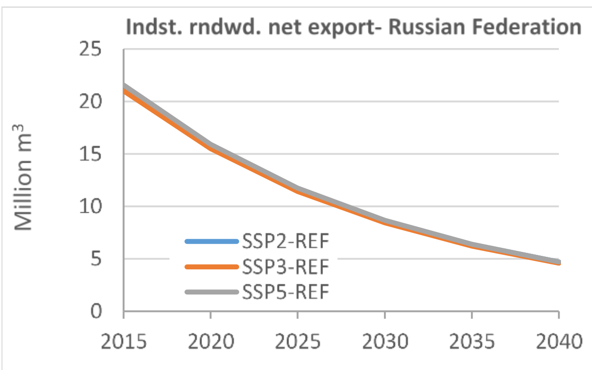
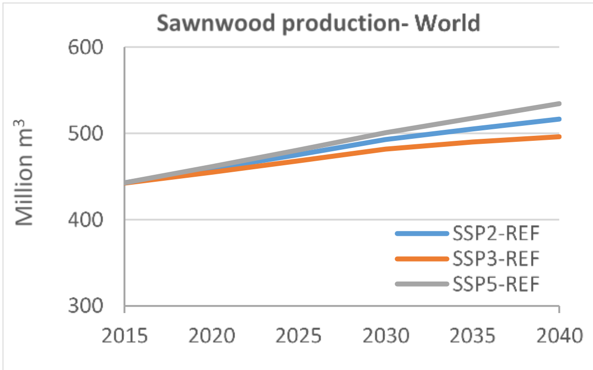


(c)

Figure D1: Projected industrial roundwood net export (export minus import) in a) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.



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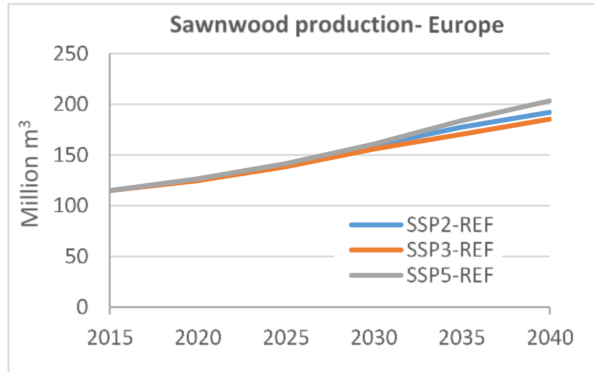

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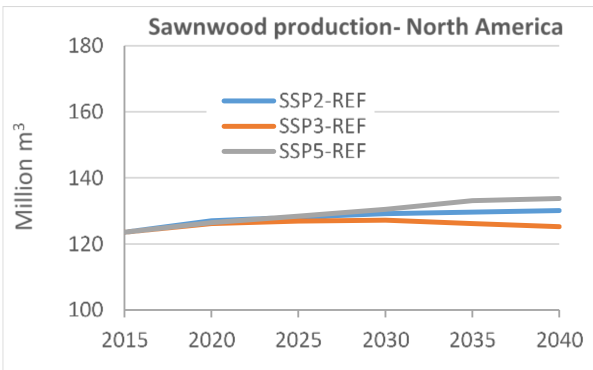

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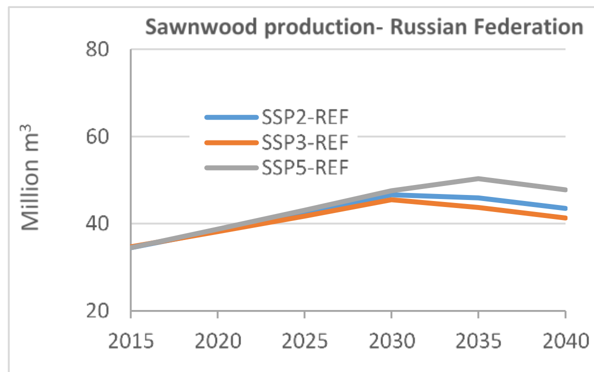
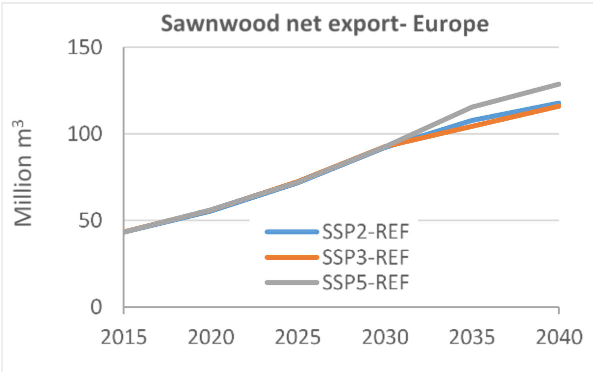


(d)

Figure D2: Projected sawnwood production in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.



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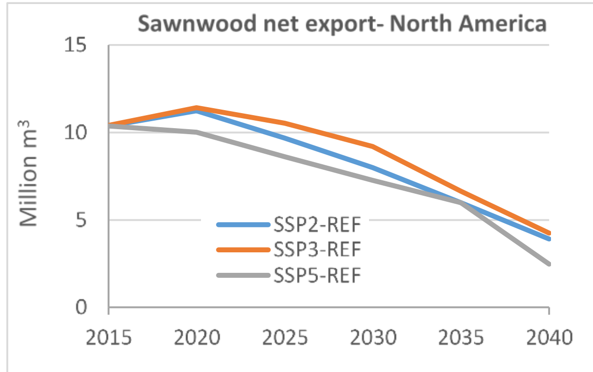

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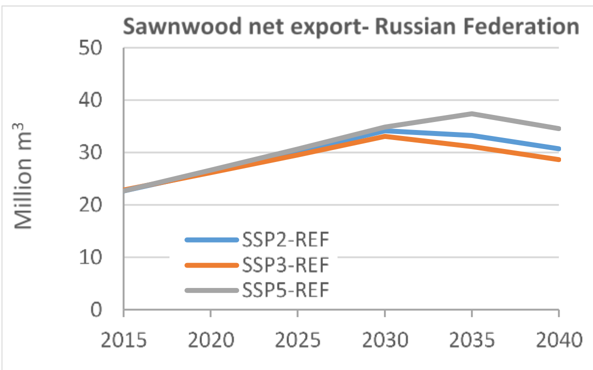


(c)

Figure D3: Projected sawnwood net export (export minus import) in a) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.

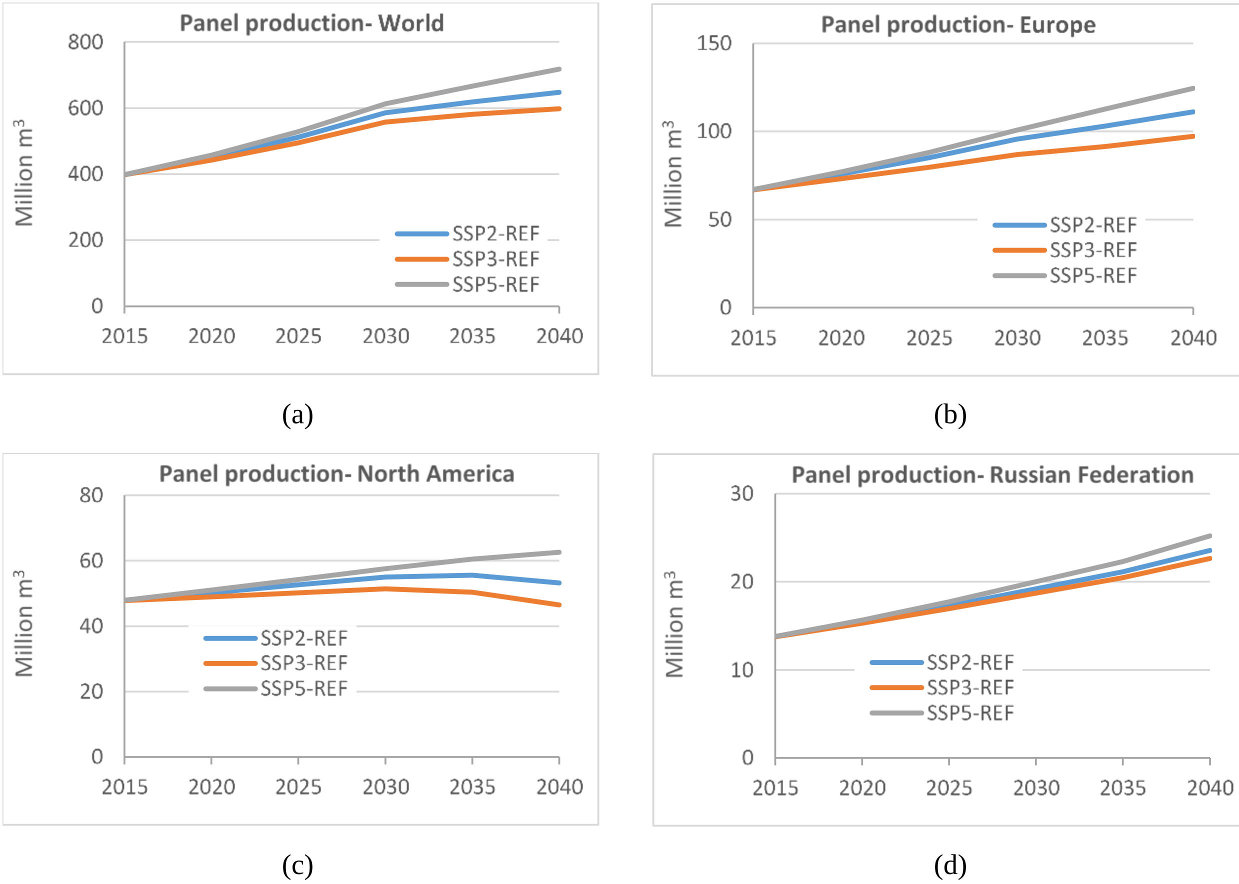


Figure D4: Projected panel (the sum of plywood, particleboard, and fiberboard) production in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSP) reference scenarios, 2015-2040.

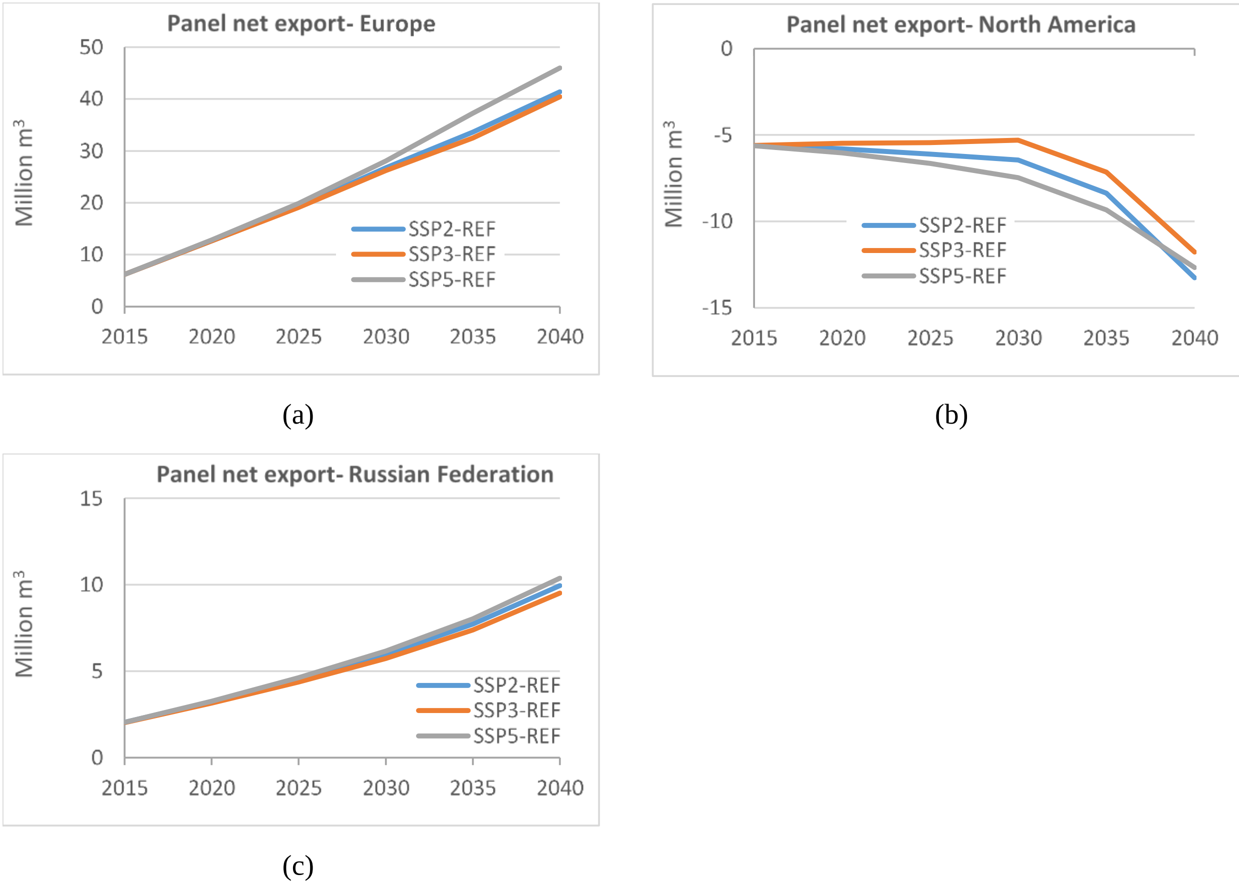
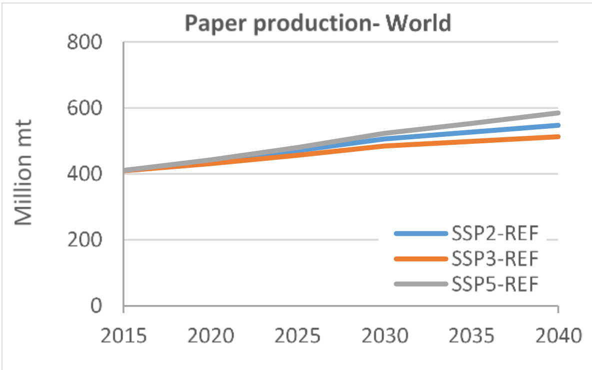


Figure D5: Projected panel (the sum of plywood, particleboard, and fiberboard) net export (export minus import) in a) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.



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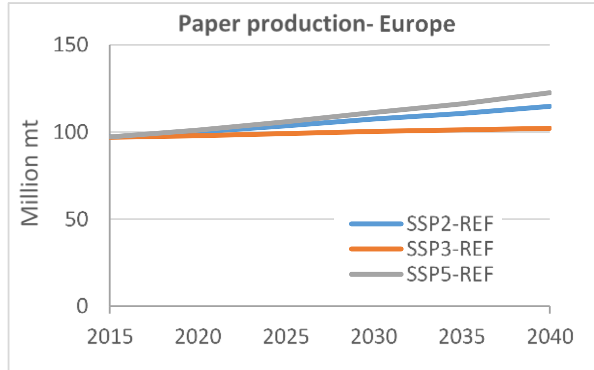

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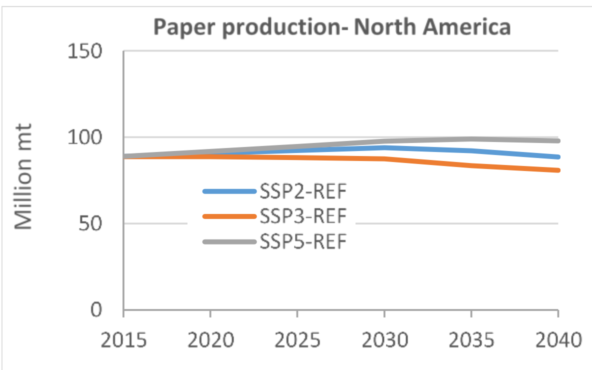

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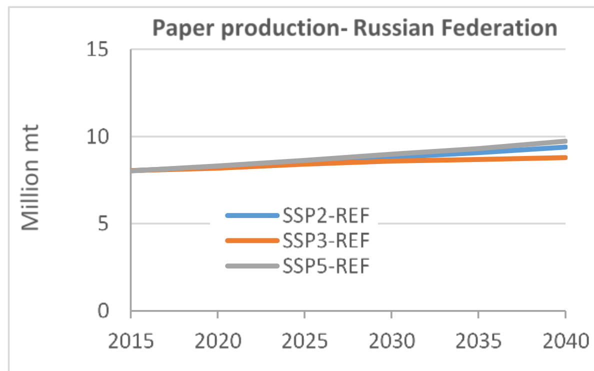
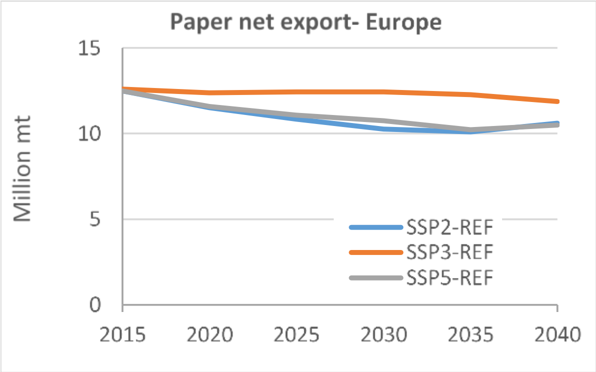
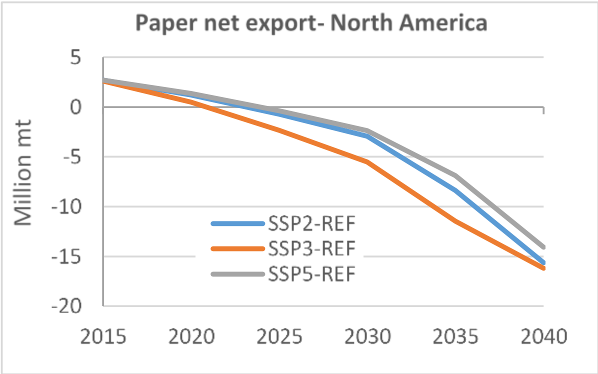


(d)

Figure D6: Projected paper (the sum of newsprint, printing and writing paper, and other paper and paperboard) production in a) World, b) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways (SSPs) reference scenarios, 2015-2040.



(a)



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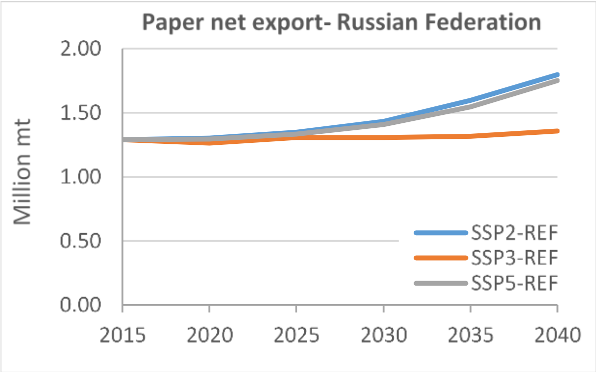
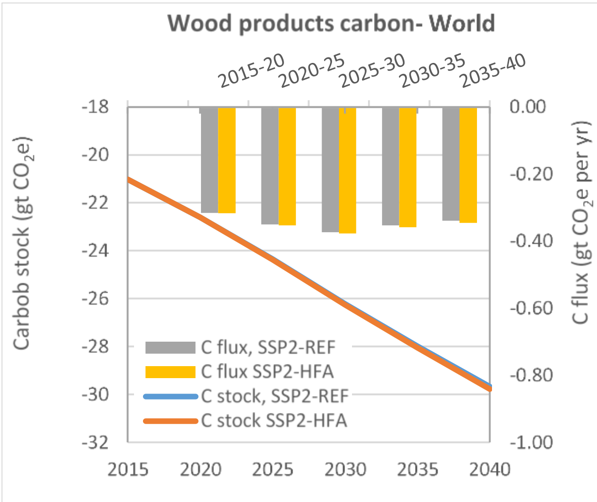


(c)

Figure D7: Projected paper products (the sum of newsprint, printing and writing paper, and other paper and paperboard) net export (export minus import) in a) Europe, c) North America, and d) the Russian Federation under three shared socio-economic pathways reference scenarios.

APPENDIX E

Projected variables for the High Forest Area (*HFA*) scenario



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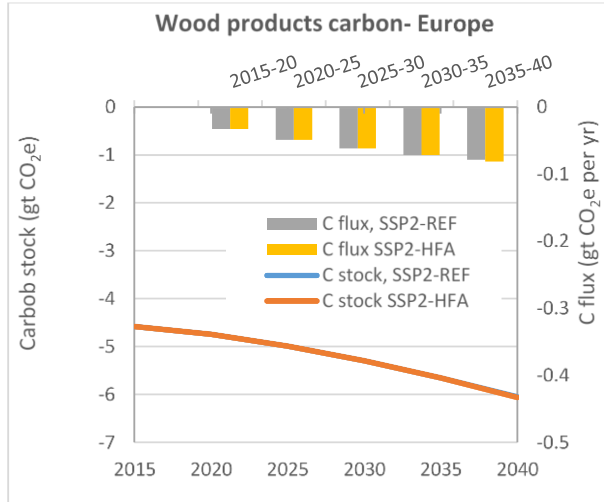

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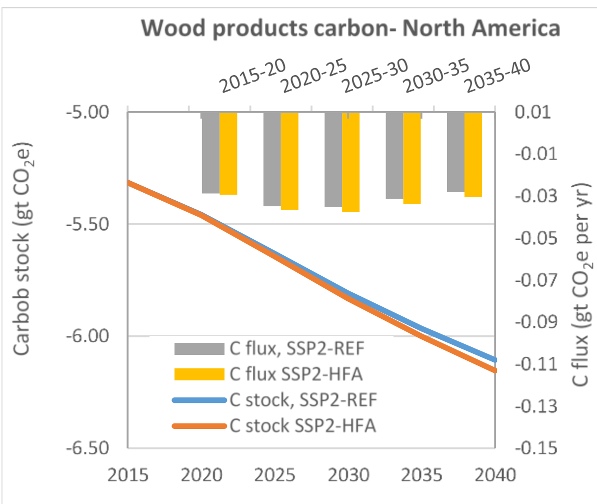

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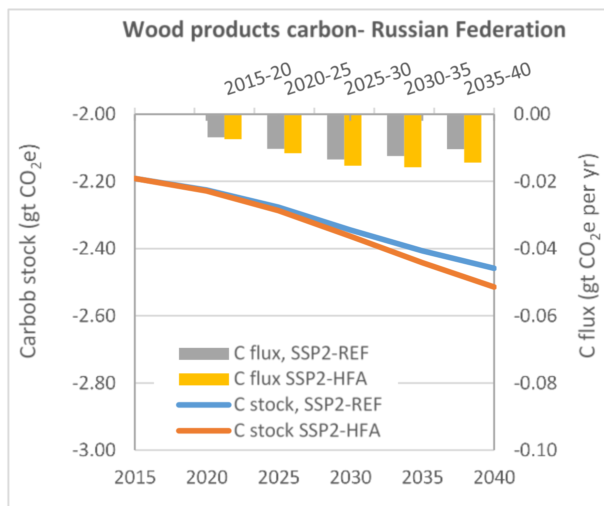
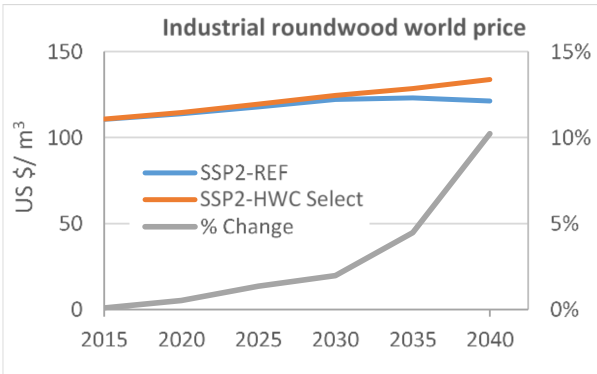


(d)

Figure D8: Projected carbon stock (gigtons CO_2e) and flux (gigatons CO_2e per year) in wood products harvested in a) World, b) Europe, c) North America, and d) the Russian Federation under SSP2 reference and its High Forest Area (*HFA*) scenarios, 2015-2040.

APPENDIX F

Projected variables for the High Wood Consumption in selected countries (*HWC Select*) scenario



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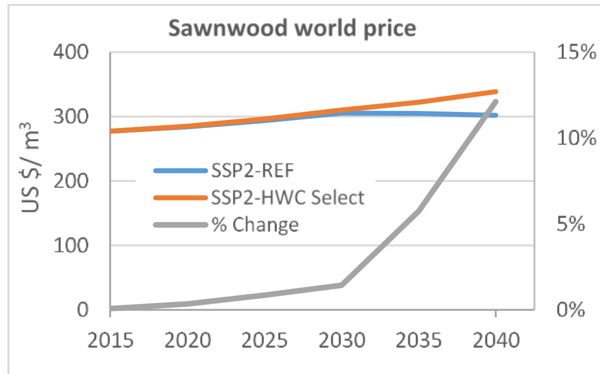

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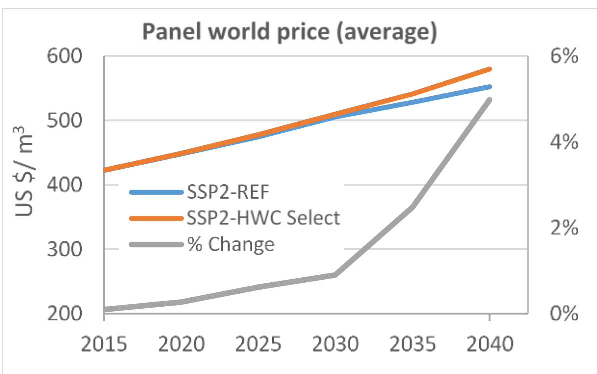

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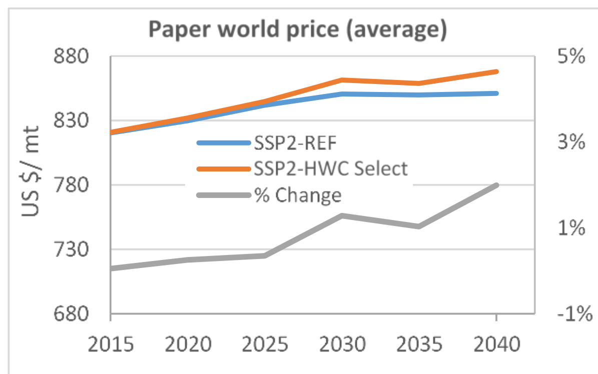
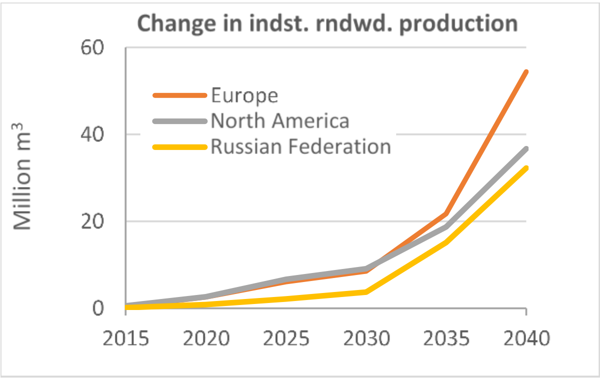
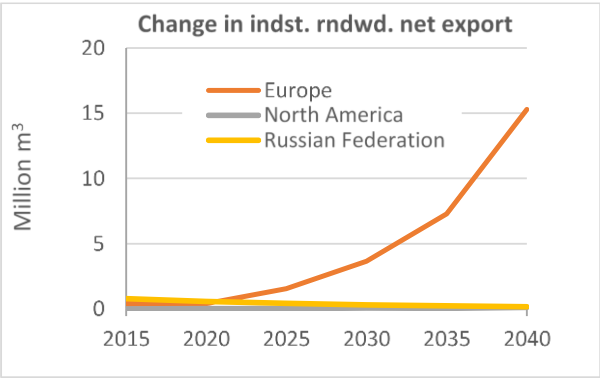


(d)

Figure F1. Projected changes in world price of industrial roundwood, sawnwood, panel products (the average of prices for plywood, particleboard, and fiberboard), and paper products (the average of prices for newsprint, printing and writing paper and other paper and paperboard) under the SSP2 reference and its High Wood Consumption in selected countries (*HWC Select*) scenarios, 2015-2040.

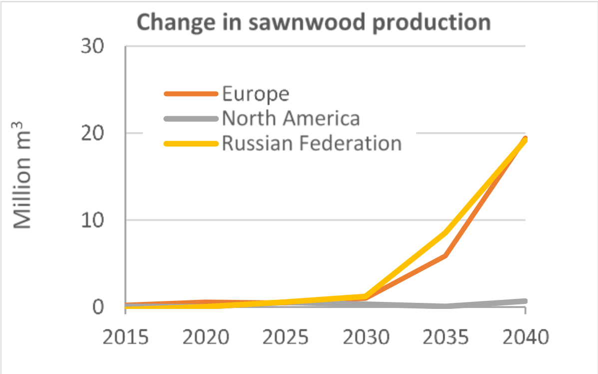


(a)

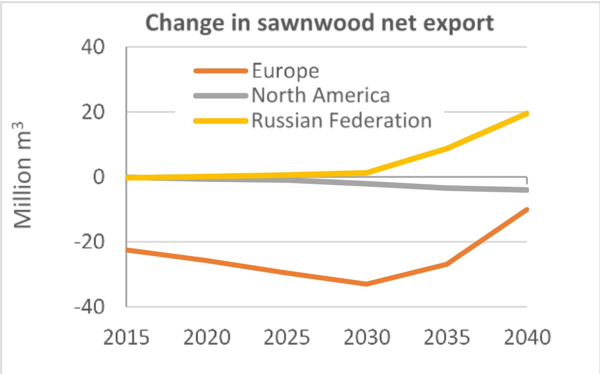


(b)

Figure F2: Projected changes in a) production, and b) trade of industrial roundwood in UNECE sub-regions under the SSP2 Reference and its High Wood Consumption in selected countries (*HWC Select*) scenarios, 2015-2040.

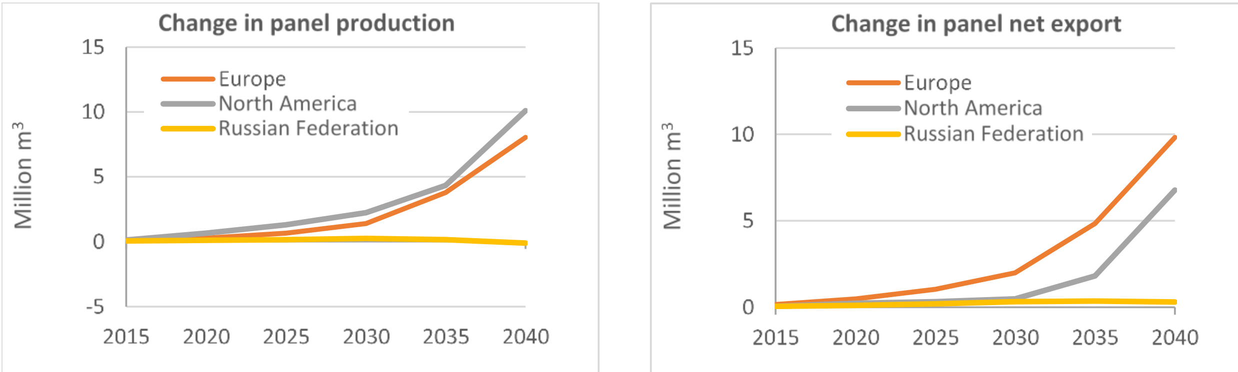


(a)



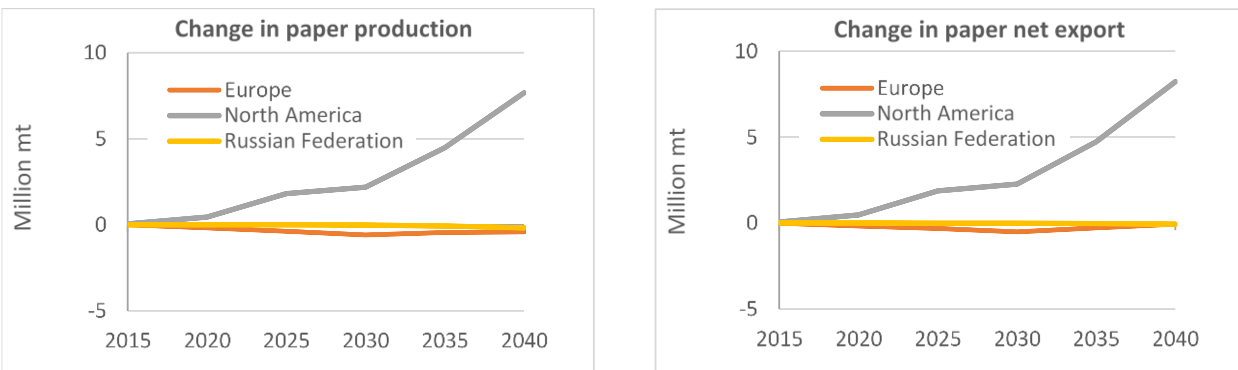
(b)

Figure F3: Projected changes in a) production and b) net export (export minus import) of sawnwood in UNECE sub-regions under the SSP2 reference and its High Wood Consumption in selected countries (*HWC Select*) scenarios, 2015-2040.



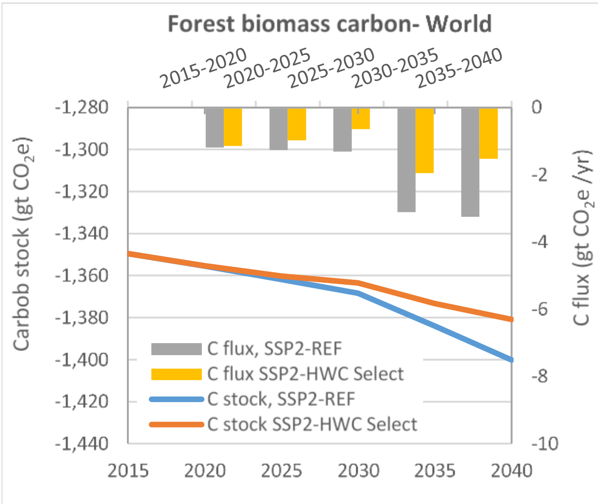
(a) (b)

Figure F4: Projected changes in a) production, and c) net export (export minus import) of panel products (the sum of plywood, particleboard, and fiberboard) in UNECE sub-regions under the SSP2 reference and its High Wood Consumption in selected countries (*HWC Select*) scenarios, 2015-2040.

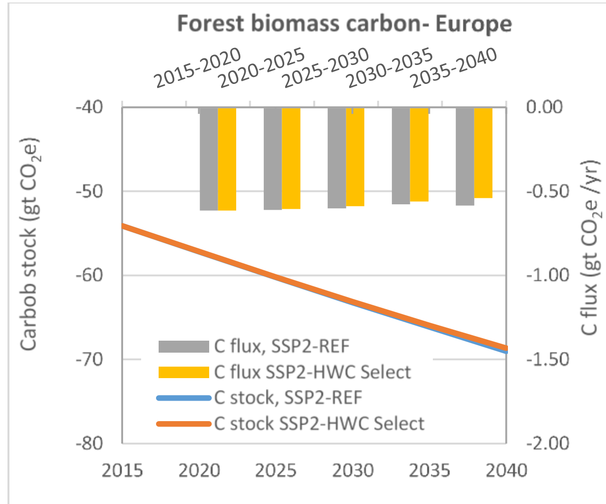


(a) (b)

Figure F5: Projected changes in a) production and c) net export (export minus import) of paper products (the sum of newsprint, printing and writing paper, and other paper and paperboard) in UNECE sub-regions under the SSP2 reference and its High Wood Consumption in selected countries (*HWC select*) scenarios, 2015-2040.



(a)



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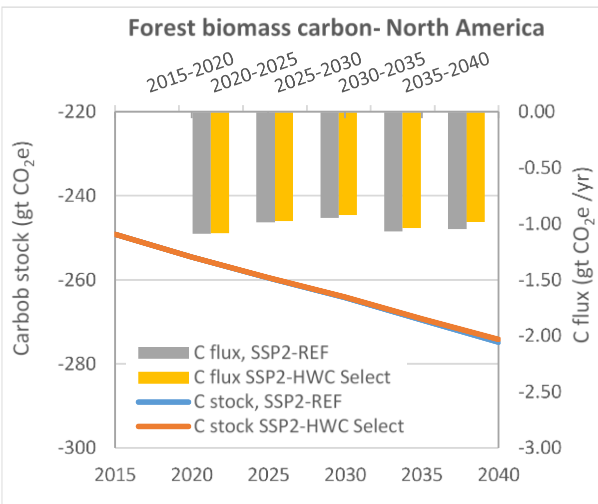

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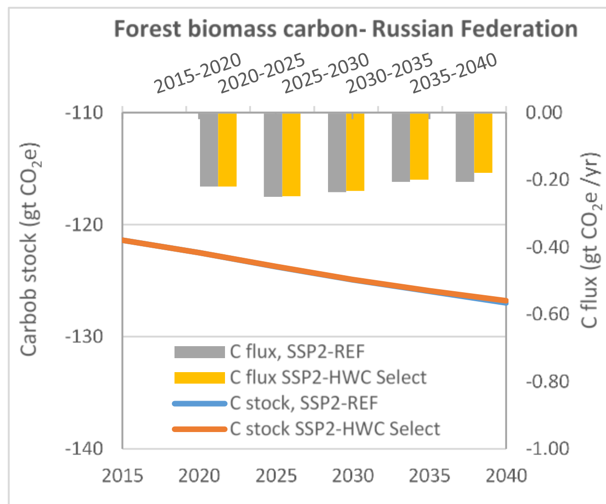
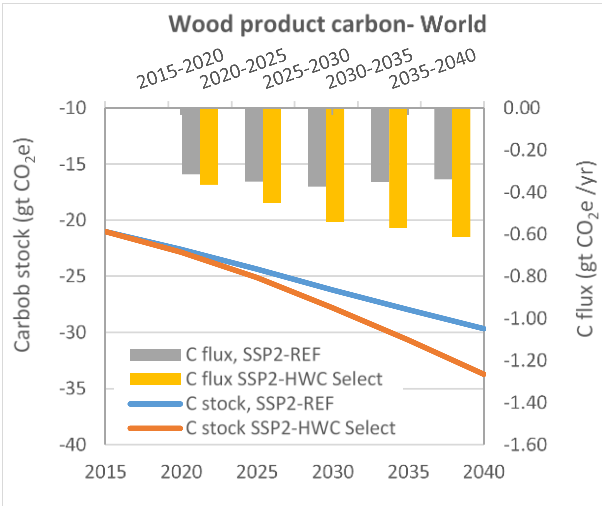


(d)

Figure F6: Projected carbon stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in above and below-ground forest biomass in a) World, b) Europe, c) North America, and d) the Russian Federation under SSP2 reference and its High Wood Consumption in selected countries (*HWC Select*) scenarios, 2015-2040.



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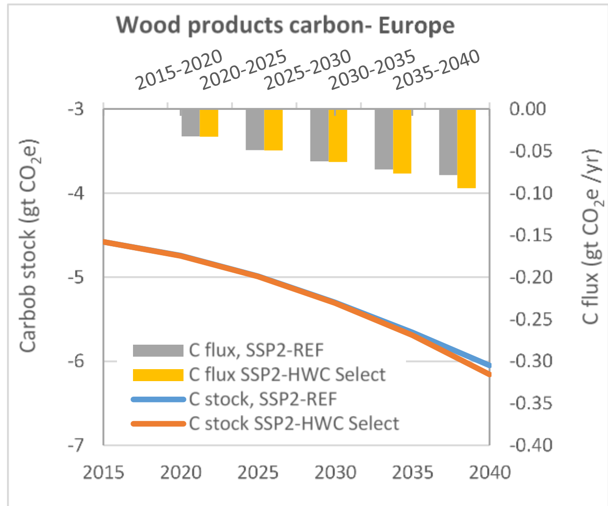
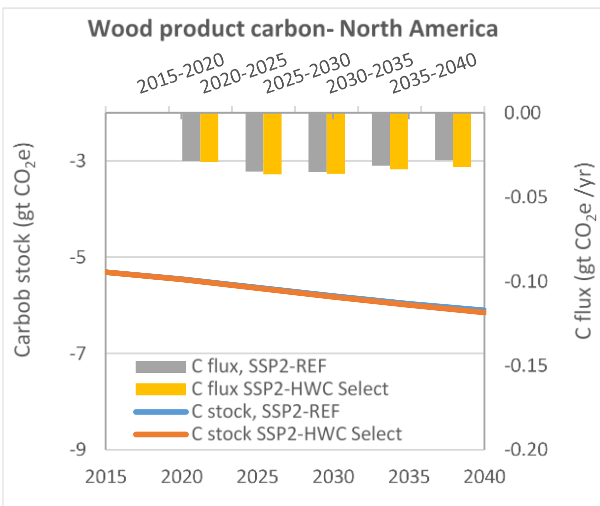
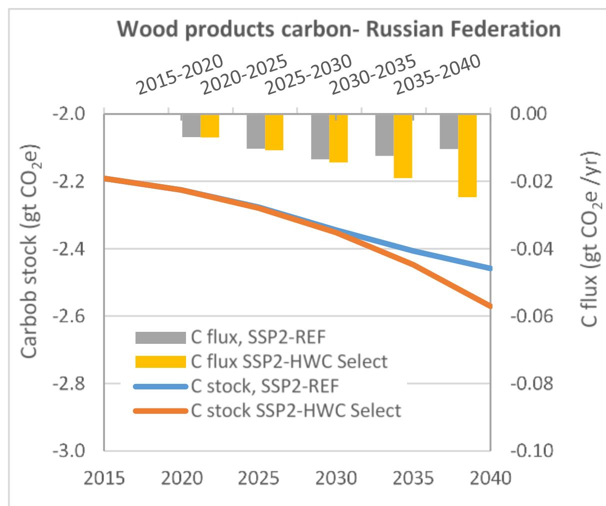


(b)



(c)

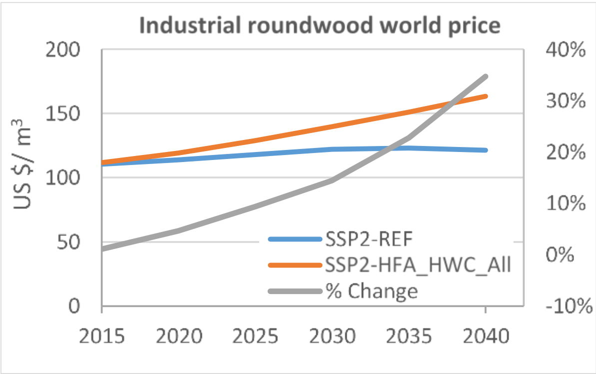


(d)

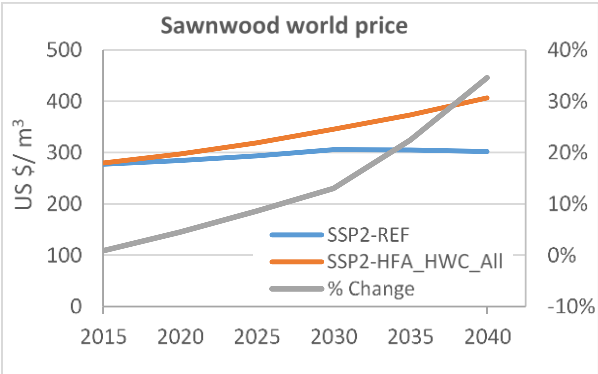
Figure F7: Projected carbon stock (gigotons CO_2e) and flux (gigtons CO_2e per year) in wood products harvested in a) World, b) Europe, c) North America, and d) the Russian Federation under SSP2 reference and its High Wood Consumption in selected countries (*HWC Select*) scenarios, 2015-2040.

APPENDIX G

Projected variables for the combined Higher Forest Area and High Wood Consumption in all countries (HFA_HWC_All) scenario



(a)



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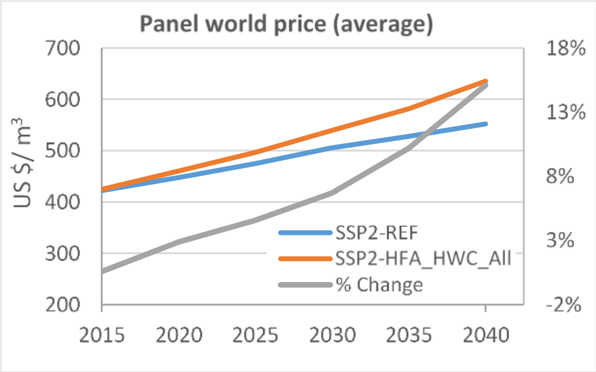
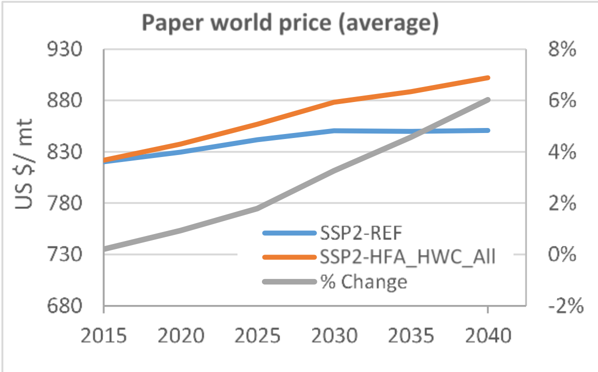
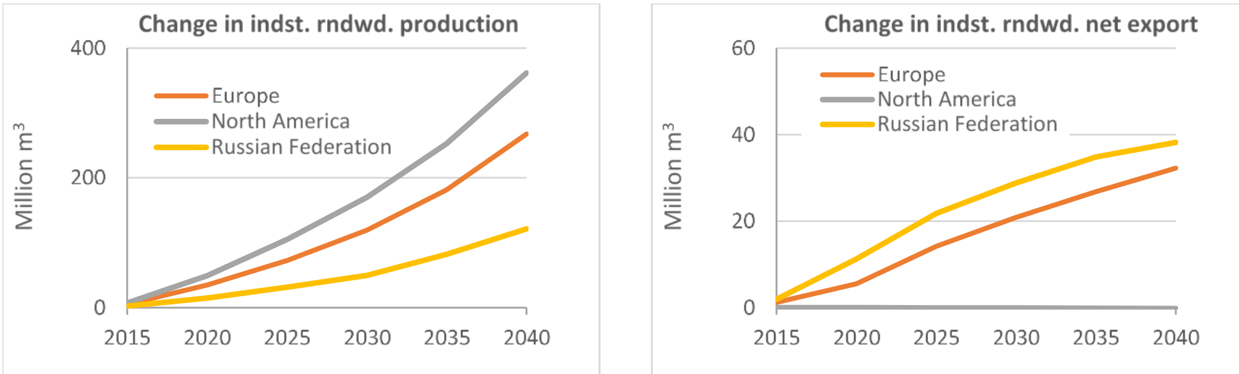


(c)



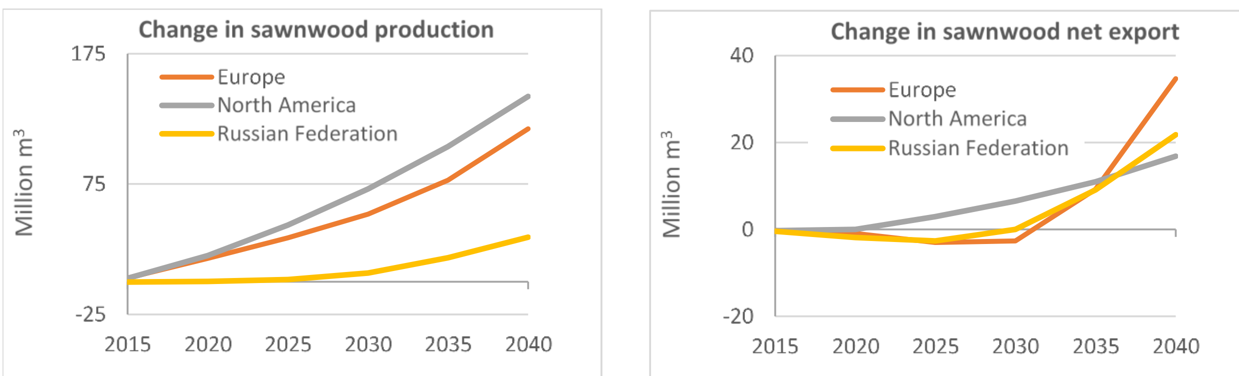
(d)

Figure G1. Projected changes in world price of industrial roundwood, sawnwood, panel products (the average prices for plywood, particleboard, and fiberboard), and paper products (the average prices for newsprint, printing and writing paper and other paper and paperboard) under the SSP2 Reference and its combined High Forest Area and High Wood Consumption in All countries (*HFA_HWC_All)* scenarios, 2015-2040.



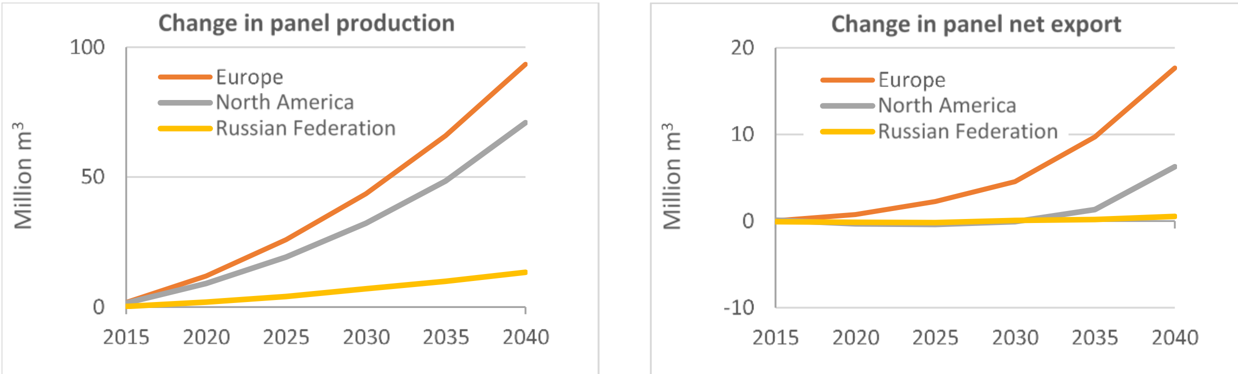
(a) (b)

Figure G2: Projected changes in a) production and b) net export (export minus import) of industrial roundwood in UNECE sub-regions under the SSP2 reference and its combined High Forest Area and High Wood Consumption in all countries (*HFA_HWC_All*) scenarios, 2015-2040.



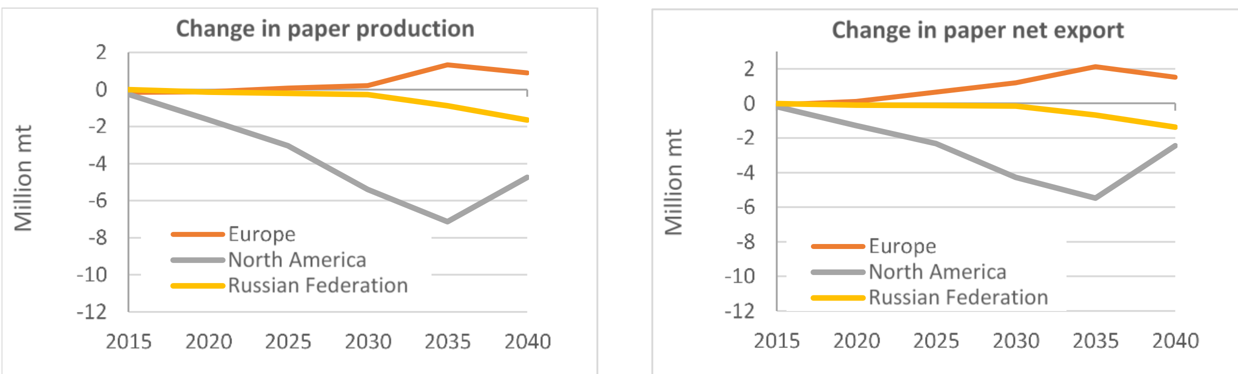
(a) (b)

Figure G3: Projected changes in a) production and b) net export (export minus import) of sawnwood in UNECE sub-regions under the SSP2 reference and its combined High Forest Area and High Wood Consumption in all countries (*HFA_HWC_All*) scenarios, 2015-2040.



(a) (b)

Figure G4: Projected changes in a) production and b) net export (export minus import) of panel products (the sum of plywood, particleboard, and fiberboard) in UNECE sub-regions under the SSP2 reference and its combined High Forest Area and High Wood Consumption in all countries (*HFA_HWC_All*) scenarios, 2015-2040.



(a) (b)

Figure G5: Projected changes in a) production and c) net export (export minus import) of paper products (the sum of newsprint, printing and writing paper, and other paper and paperboard) in UNECE sub-regions under the SSP2 reference and its combined High Forest Area and High Wood Consumption in all countries (*HFA_HWC_All*) scenarios, 2015-2040.

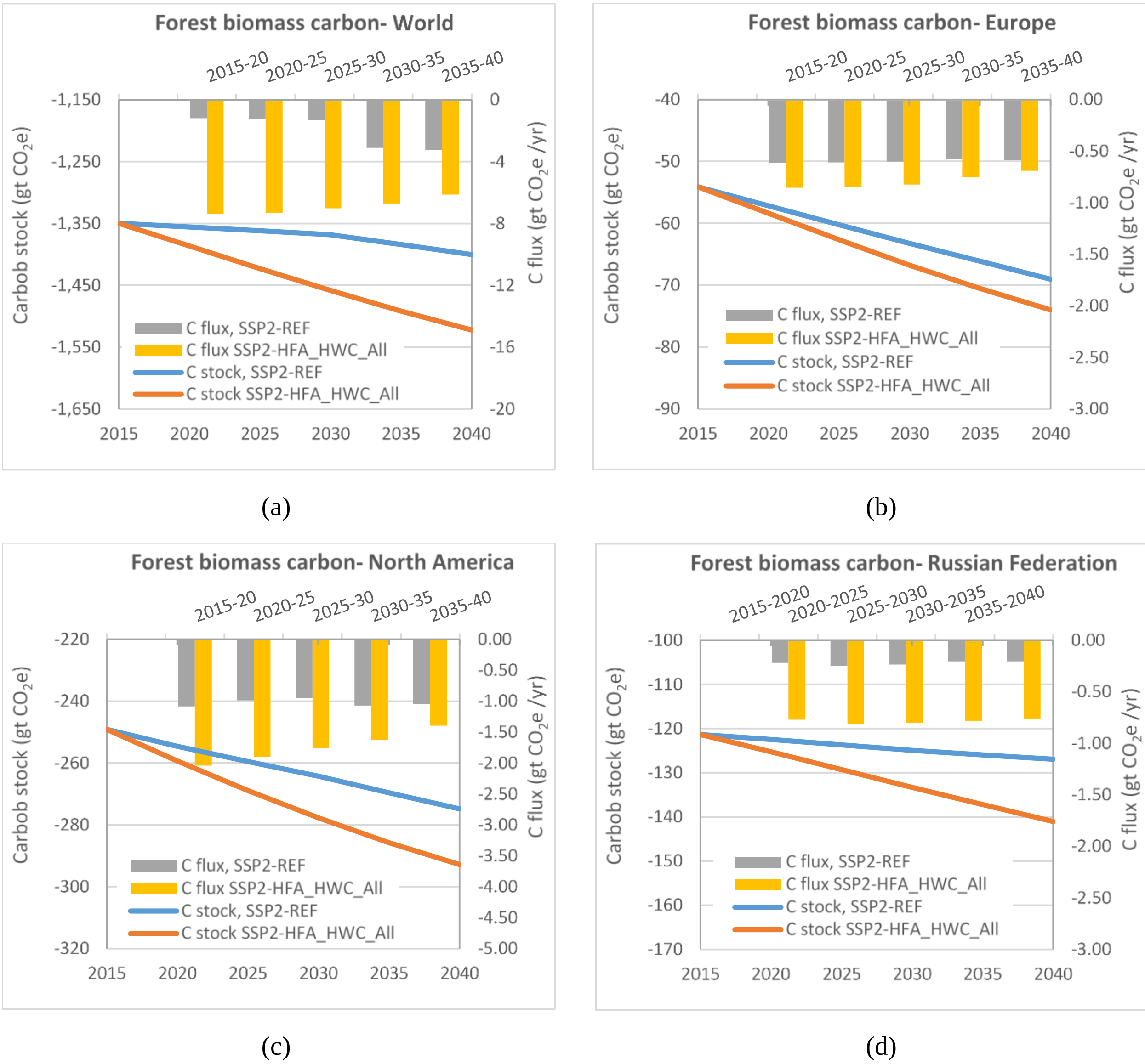
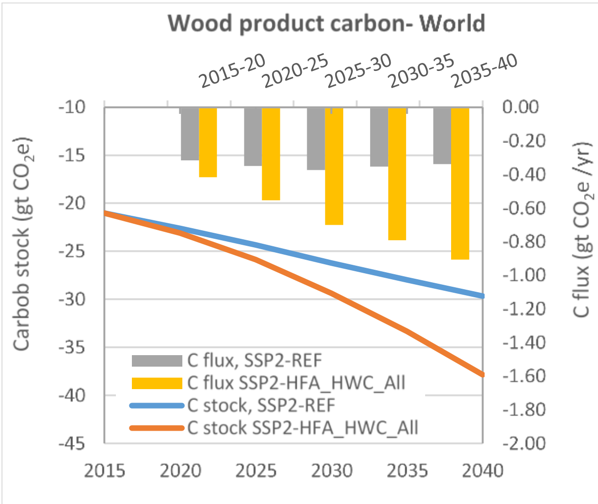
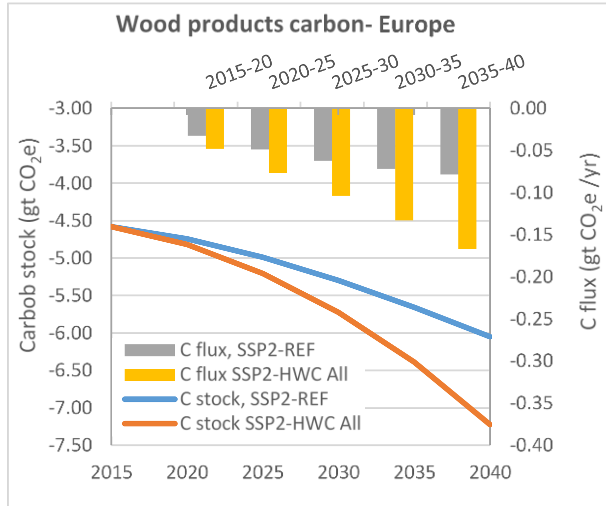


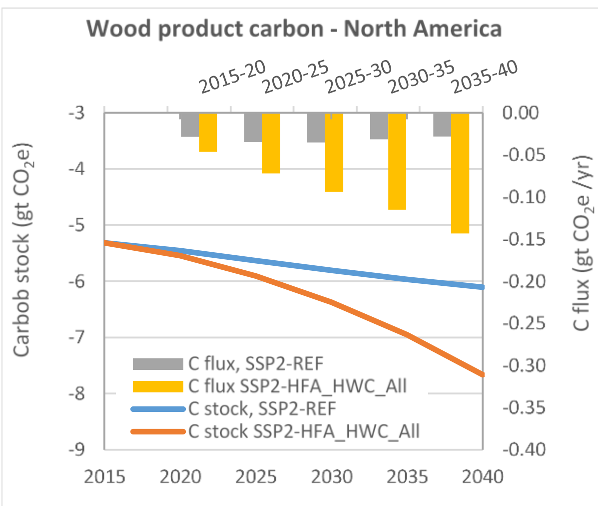
Figure G6: Projected carbon stock (gigatons CO_2e) and flux (gigatons CO_2e per year) in above and below-ground forest biomass in a) World, b) Europe, c) North America, and d) the Russian Federation under SSP2 reference and its combined High Forest Area and High Wood Consumption in all countries (*HFA_HWC_All*) scenarios, 2015-2040.



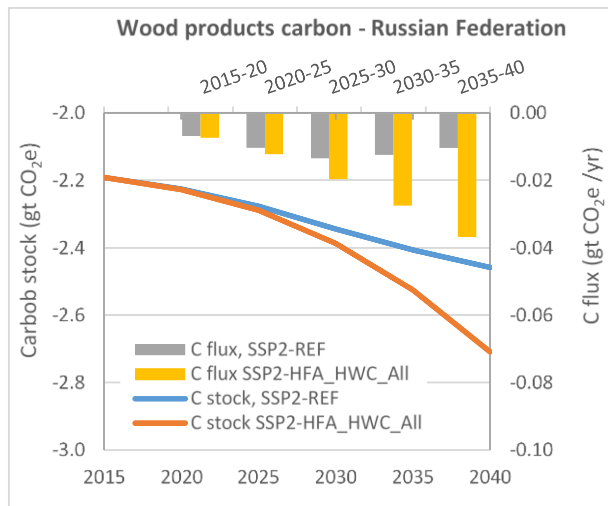
(a)



(b)



(c)



(d)

Figure G7: Projected carbon stock (gigtons CO_2e) and flux (gigatons CO_2e per year) in wood products harvested in a) World, b) Europe, c) North America, and d) the Russian Federation under SSP2 reference and its combined High Forest Area and High Wood Consumption in all countries (*HFA_HWC_All*) scenarios, 2015-2040.