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Estimating future wood outtakes in the Norwegian forestry sector under the shared socioeconomic pathways

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ABSTRACT

The forest sector plays a key role in achieving low temperature stabilization targets, as woody biomass represents a cost-efficient alternative to fossil fuels for energy and material production. Estimates of future woody biomass demands vary in the Shared Socioeconomic Pathways (SSPs), depending on societal development trends, climate model projections, socioeconomic conditions, and climate and energy policies. The SSPs are qualitatively and quantitatively defined at global and macro-regional level, and their implementation for individual sectors at a national basis is challenging. In this paper, we provide estimates for forest wood outtakes in Norway until 2100 using key drivers from the SSPs such as population and Gross Domestic Product (GDP) and specific aspects of developments in the land use sector. First, we analyze historical wood harvest trends from 1960 to 2016 for the main tree species and wood classes and construct a regression model based on population, GDP and time. The model framework is based on a statistical approach that does not explicitly include market adjustments, but it is adapted to an interpretation of the salient characteristics of the different SSP scenarios to estimate future outtake volumes for each combination of tree species and wood classes in Norway. The SSP characteristics implemented in the model framework are GDP and population, land-use change regulation, participation of the land-use sector to climate change mitigation, and starting year of international cooperation for climate change mitigation. The produced estimates span a range of possible harvest rates and resource use potentials. Results show that SSP1 achieves a maximum mean extraction rate of 17.7 million m^3 (in 2090). Forest wood outtake volumes are the lowest in SSP3, reaching a maximum of about 11.9 million m^3 in 2040 and then declining. SSP2 and SSP4 generally lie in between SSP1 and SSP3. SSP5 is the most resource intensive scenario, with harvest rates achieving 27.5 million m^3 in 2100. Driven by high population and GDP, SSP5 far exceeds the forest maximum harvest potential in Norway. Variability in the estimates is larger when land use regulation is weak and market fluctuations are high, such as in SSP2, SSP3 and SSP5. The proposed model framework is an approach to interpret and translate the global qualitative SSP narratives into quantitative projections at a finer scale, and can favor the use of a consistent background setting such as the SSPs in interdisciplinary research activities across different spatial scales of analysis.

1. Introduction

Forestry products are key for the climate-energy-material nexus (Creutzig et al., 2015; Sikkema et al., 2017; Fulton et al., 2015; Guest et al., 2013a), and management of bioresources will play a major role to achieve low temperature stabilization targets (Popp et al., 2014b; Lauri et al., 2017). Forest products can contribute to supply of renewable biomass for energy and construction materials, which are predicted to increase in a more sustainable future (Lauri et al., 2017; Van Vuuren et al., 2011), and forestry projects are valuable instruments to achieve emission reduction targets (van der Gaast et al., 2016). High resolution information and future estimates of wood outtakes and material products is key for studying the biophysical basis of socioeconomic metabolism and resource potentials (Pauliuk et al., 2015), for characterizing the role of environmental stocks in human development and emission growth (Lin et al., 2017), and, more particularly, for assessing the climate change impacts of transformation in the dwelling and wood industry subsectors (Pauliuk et al., 2013; Guest et al., 2013b).

The Shared Socioeconomic Pathways (SSPs) describe alternative societal development trends over the next decades through combinations of different scenarios for climate model projections, socio-economic conditions, and climate and energy policies (O' Neill et al., 2014; Ebi et al., 2014; Van Vuuren et al., 2014). These integrated future scenarios are designed to serve the scientific community in facilitating

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the adoption of a common and harmonized framework for interdisciplinary research in the field of climate change mitigation and adaptations and to study future changes in technological, societal, and environmental systems. Extensive quantitative and qualitative information about the SSPs are today available, with descriptions of the characteristics of the different SSP components (Riahi et al., 2017; O'neill et al., 2017; Popp et al., 2017; Fujimori et al., 2017; Kriegler et al., 2017; Calvin et al., 2017; Fricko et al., 2017). The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development (Riahi et al., 2017). The five SSPs have different land-use change regulations and land-based mitigation policies (O'Neill et al., 2014). In SSP1 ("taking the green road"), the world shifts towards a sustainable path. There is a strong land-use change regulation with international efforts to minimize environmental impacts and tradeoffs. This scenario envisions a full participation of the land-use sector, and there is no delay (i.e., starting from 2020) in the international cooperation for climate change mitigation. In SSP2 ('middle of the road'), the world follows a path that does not shift markedly from historical patterns, and the land-use change regulation is incomplete (medium regulation). There is a partial participation of the land-use sector and the international cooperation for climate change mitigation is delayed to 2030. In SSP3 ('regional rivalry—a rocky road'), countries are more concerned about domestic issues and competitiveness, with lower attention to climate and environmental aspects. There is limited or almost no regulation on land-use change, and the participation of land-use sector is also limited. International cooperation for climate change mitigation is delayed to 2040 for high-income countries and to 2050 for the rest of the world. In SSP4 ('Inequality—A road divided'), there will be increasing inequalities in the development of the different countries. There is a partial participation of the land use sector, and only developed countries introduce strong regulation to land-use change with no delay in the international cooperation for climate change mitigation (starting in 2020). In SSP5 ('fossil-fueled development—taking the highway'), the world will strengthen the role of competitive markets, and the regulation of land-use change is incomplete. Compared to SSP2, there is full participation of the land-use sector with a delay of international cooperation for climate change mitigation to 2040. We refer to (O' Neill et al., 2014) for more detailed discussion on the narratives of SSPs, and to (Popp et al., 2017) for the specific focus on the land use component.

The SSPs are defined at a global and macro level, and regional/sectorial extensions are seen as critical next steps for future applications (Riahi et al., 2017; Absar and Preston, 2015). The core principles of their different narratives can be used as drivers to estimate future developments of individual and smaller-scale sectors. This has the potential advantage to consolidate interdisciplinary research under a common framework and different spatial scales of analysis. Future forest wood outtakes can be estimated with integrated assessment models using sophisticated non-linear recursive dynamic optimization approaches or partial equilibrium models that are linked to spatially explicit biophysical constraints (Popp et al., 2014a; Humpenöder et al., 2015; Havlík et al., 2014). These models, such as the economic model GLOBIOM (Havlik et al., 2011; IIASA, 2017; Havlík et al., 2012) and the recursive dynamic optimization model MAgPIE (Lotze-Campen et al., 2008; PIK, 2017), are rather complex and global in scope, although they can be used for regional and/or grid-level applications. In this study, we use a simpler approach and develop a bottom-up model framework based on historical data (from 1960 to 2016) of forest wood outtakes in Norway using country-specific information on tree species (birch, pine and spruce) and wood classes (sawn wood, pulpwood, bioenergy, and unsorted logs). Multiple linear models with GDP per capita and time as explanatory variables are adopted to describe the historical trends in harvest rates (normalized to population) for each combination of tree species and wood class. White Gaussian noise processes are introduced to capture the randomness of market fluctuations. The model is based on a double-logarithmic formula which allows to explicitly include the effects of GDP and populations. Future projections of wood outtakes from Norwegian forests over the twenty-first century are developed to be consistent with the narratives of the different SSPs. Future harvest rates will be linked to future changes in GDP and population, and to an interpretation of the specific aspects of the land use sector in the various SSPs. These include different policies in terms of land-use change regulation, participation of the land-use sector to climate change mitigation, and starting year of international cooperation for climate change mitigation. This can produce estimates to bridge (and downscale) the major SSP global framework with the dynamics of an individual sector at a country level.

2. Methodology

2.1. Data gathering

The total forested area of Norway amounts to about 12 million hectares (about 38% of the country's total surface area), of which more than 7 million hectares are productive forest. The most important tree species are coniferous, mostly Norway spruce (*Picea abies*) (47%) and Scots pine (*Pinus sylvestris*) (33%), and deciduous species (mostly *Betula pubescens* and *Betula pendula*) (18%). Historical data for the harvested wood product sector in Norway are gathered from the Norwegian national statistics in terms of commercial roundwood removals from 1960 to 2016 (SSB, 2017a). The dataset includes information about wood harvests for three species of trees (spruce, pine, and birch) and four types of wood classes (sawlog, pulpwood, unsorted sawlog/pulpwood and fuelwood). In the period 1960–1979, official data are only available for individual tree species and not for the different wood classes. It is assumed that distribution of wood classes among species reflects the average shares for each tree species in the time interval 1980–1989.

The historical population from 1960 to 2016 is obtained from the Norwegian national statistics (SSB, 2017d). The historical GDP by expenditure in fixed price per capita (relative to 2005) is obtained from the Norwegian Central Bank (Norges-Bank, 2017) for the period 1960–1969, and from the Norwegian National statistics for the period 1970–2016 (SSB, 2017b). The future national estimates of GDP and population from 2017 to 2100 are obtained from the SSP Public Database hosted at the International Institute for Applied Systems Analysis (IIASA) (SSP-Database, 2017). Data are available at a 10 year time step interval, and are connected through linear interpolation. The historical and future trends of population and GDP are shown in Fig. 1. The strongest growth in population occurs under SSP5, where it increases from 5.21 million in 2016 to 13.9 million in 2100. On the other hand, population is expected to decline to 4.57 million in 2100 under SSP3. Similarly, GDP per capita shows the steepest increase under SSP5, and the smallest variations under SSP3.

2.2. Model framework and integration with SSP scenarios

Three steps are used for generating future wood harvest scenarios in Norway under the different SSPs. We first construct a multiple linear regression model of historical wood outtakes and estimate the parameters. We then integrate key drivers of the different SSPs in terms of GDP, population and the aspects of the land use sector into the model framework to estimate future scenarios of wood harvest rates. Finally, the predicted wood harvest rates are aggregated for each SSP, and an analysis of the maximum harvest potential as a constraint is introduced to calibrate model outcomes.

The first step is to use the historical wood harvest dataset to make a regression analysis. The model has the following form, which is adapted from the double-logarithmic formula (Houthakker, 1965),