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Forest-based bioeconomy pathways with emerging lignocellulosic products: A modeling approach

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Abstract

The forest-based sector plays an important role in a growing bioeconomy. Long-term resource availability and allocation will be a major challenge for the bioeconomy development. Therefore, this study aims to assess how forest product markets could develop in a growing bioeconomy and which interdependencies occur between traditional and emerging forest-based subsectors. Especially, the demand for wood-based textile fibres could dynamically grow over the next decades while there might be conflicting demand for wood resources from traditional subsectors. Thus, we include dissolving pulp, lignocellulose-based textile fibres and chemical derivatives in our modelling assessment. For this purpose, we extend the product structure of a partial equilibrium model, the Global Forest Products Model (GFPM). We use an econometric approach to compute demand and trade elasticities of the emerging products. We parameterize the extended model with these elasticities and analyze three different bioeconomy scenarios. In the first scenario, the demand for woody biomass remains similar to the current pattern. In the second scenario, the use of woody biomass increases primarily to satisfy growing input demand from the energy sector. In the third scenario, biomass is increasingly used as input to produce diverse industrial and everyday products. The simulation results show that, in the third scenario, where the world is changing toward a sustainable bioeconomy, wood consumption pattern shifts away from fuelwood (-30% by 2050) and paper products (-32% by 2050) towards emerging products. In this context, the dissolving pulp subsector could outpace the continuously shrinking paper pulp subsector in 2050. For this development, the dissolving pulp subsector mainly uses released resources from the decreasing paper pulp production. Simultaneously, wood-based panels are increasingly applied (+196% by 2050) while the growth of sawnwood remains limited.

Keywords: Economic Development, Value chain, Research, Sustainable forest management, Policies

Introduction

In public discussion the transformation of the current economic model to more sustainable and “green” economy is becoming more and more important. One significant contribution to this transformation may be made by moving away from the dependence on finite, fossil resources to an economy based on renewable, bio-based raw materials: the bioeconomy (Banse et al. 2020). In some economic sectors, the bio-based economy is already a relevant player (Iost et al. 2019; Kallio and Schier 2021; Szarka et al. 2021). However, a sustainable bioeconomy is not yet widely implemented across the entire economy, but the economic re-orientation is spreading and fed by numerous and forward-looking innovations in the field of bio-based product and process developments (Kallio and Schier 2021). In the light of an emerging bioeconomy, forest-based market pattern can change and diversify due to the increasing consumption of traditional wood products and the substitution of fossil-based materials with lignocellulose-based products in, e.g., chemical and textile industries. In this context, traditional "niche" products such as dissolving pulp, and lignocellulose-based fibres and chemicals are expected to gain in importance.

The transition to a more bio-based economy is associated with an increasing demand for biomass. Depending on the design of future scenarios, there will be different consequences for the production, consumption and international trade of raw materials from forestry. Crucial questions that arise in this context are: (i) What interactions and competing uses occur if demand for woody resources is surging, and how could the available biomass resources be allocated? and (ii) are there sufficient woody raw materials available for a wood-driven bioeconomy?

In this study, we investigate possible bioeconomy developments in quantitative terms using a model-based simulation approach for scenario analysis. For this task we translate qualitative scenario narratives into the quantitative model environment of a global forest products model. It is important to note that scenarios do not represent forecasts. Rather, they provide structures that offer the space to think about and discuss possible future developments. Furthermore, they can show which steps have to be designed and how to initiate a desirable development towards a bioeconomy (Kosow and Gaßner 2008). This study bases on three bioeconomy scenarios which are composed of storyline elements from the Shared Socioeconomic Pathways (SSP) scenarios (Riahi et al. 2017) and the BEPASO (Bioeconomy pathways and societal transformation strategies) research project (Banse et al. 2020): "Bioeconomy islands", "Bioeconomy on the drip", and "Bioeconomy change". The BEPASO storylines are linked to a macroeconomic framework provided by different SSP storylines. For this, the GDP and GDP per capita developments up to the year 2050 were extracted from three (SSP1, SSP2, SSP4) of the five SSP scenarios. Table 1 highlights the most important and forest-related aspects from the scenario storylines.

Table 1: Storyline elements of three bioeconomy scenarios relevant for forest product market analysis. HIR = High-income countries, MIR = Middle- and low- income countries

Bioeconomy Drip	Bioeconomy Island	Bioeconomy Change
digitalized world	**duties and subsidies are either constant or increasing due to trade disputes**	**digitalized world**
technological development primarily takes off in HIR and MIR countries		**globally efficient exchange of R&D activities and technologies**
slight increase in the material use of wood	**slight decrease in the material use of wood**	**strong increase in the material use of wood**
slight increase in the material use of wood for construction purposes	**lightweight wood panels remain an expensive niche product**	**strong increase in the material use of wood for construction purposes**
individual conversions of paper pulp mills to dissolving pulp production	**demand for dissolving pulp remains constant**	**frequent conversion of paper pulp mills for the production of dissolving pulp**
slight increase in the use of fuelwood	**slight increase in the use of fuelwood**	**decrease in the use of fuelwood**
production of films, plastics, etc. increases	**few technological innovations in production and use of biomass**	**new fields of applications for veneer, plywood and wood-based panels**
	slightly increasing efficiency in resources' use	**optimization of resources' use**

Methodological approach

We use a global forest products model (GFPM) for model-based scenario simulation and impact analysis. The basic version of the model in use is the GFPM as developed and published by Buongiorno et al. in 2003. The

GFPM is a dynamic, price-endogens, partial equilibrium model to simulate the development of the forest-based product markets in the mid- and long run and thus, is suitable for scenario simulations of alternative forest sector developments, "what- if" and policy impact analysis (Buongiorno 2014, Buongiorno et al. 2014, Van Kooten and Johnston 2014, Johnston and Buongiorno 2017). The application of a partial equilibrium model enables to reveal long term interdependencies between economic, social, and technical developments that are otherwise difficult to grasp due to their complexity. The GFPM computes production, consumption, and trade for 180 countries in competitive world markets (Buongiorno et al. 2003, Buongiorno et al. 2014). The model version used for this study is an enhanced version introduced by Schier et al. (2018), which distinguishes 16 wood-based products. In addition to the original model version, industrial roundwood and sawnwood are split into two different products, while all subsequent commodities can be produced from a mix of coniferous and non-coniferous industrial roundwood. To include emerging wood-based bioeconomy markets, and thus to improve the inferences drawn from forest products market analysis, this study adds lignocellulosic-based products into the model framework of the GFPM (Morland and Schier 2020). The model structure is described in Figure 1.

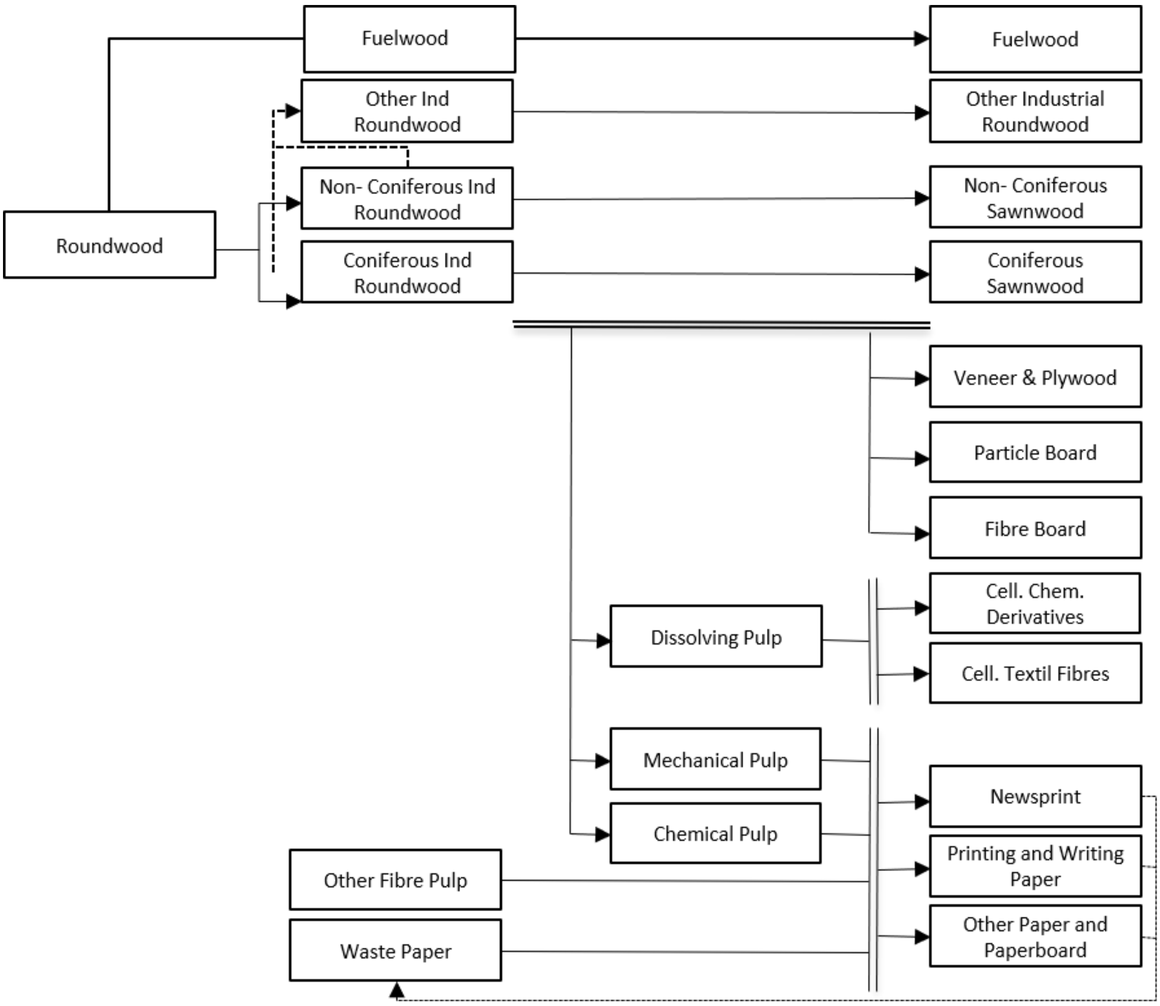

Fig. 1: The modified model structure of the GFPM for bioeconomy scenario simulations (adopted from Morland and Schier 2020)

Partial equilibrium models like the GFPM use market elasticities as behavioral parameters for scenario simulations. Thus, the inclusion of new products into the model structure strictly requires the determination of the respective income and price elasticities. Based on econometric panel data models, Schier et al. (2021) estimated global price and income elasticities of import demand. They show, that these elasticities are suitable for use as demand elasticities in the GFPM.

The main sources for data needed to calibrate and run the GFPM for the present study came from the United Nations FAO Statistical Database (FAOStat, 2020), the UN International Trade Statistical Database (UN Comtrade, 2019), and the World Bank Database (WorldBank, 2019).

Results

For the scenario modelling of the emerging bioeconomy sector, the following elasticities coefficients were chosen from Schier et al. 2020: The income elasticity of demand for lignocellulose-based chemical derivatives is 1.12 and the price elasticity of demand is -1.08. The income elasticity of demand is (unit-) elastic and positively correlated to changes while the price elasticity of demand is (unit-) elastic and negatively correlated to changes. The income and price elasticities of lignocellulose-based textile fibres are 1.13 and -1.48, respectively. Again, the income elasticity of demand is (unit-) elastic and is positively correlated to income changes. The price elasticity of demand responds highly elastic and is negatively correlated to price changes. The explanatory power of income (GDP) and price coefficients are significant for all periods and fit theoretical expectations (Schier et al. 2021).

From global to national level, the modelling results indicate larger increases of total roundwood consumption in the case that a bio-based development of economies is fostered (“Bioeconomy Island” and “Bioeconomy Change”) compared to a scenario where this not envisaged (“Bioeconomy Drip”) (Figure 2).

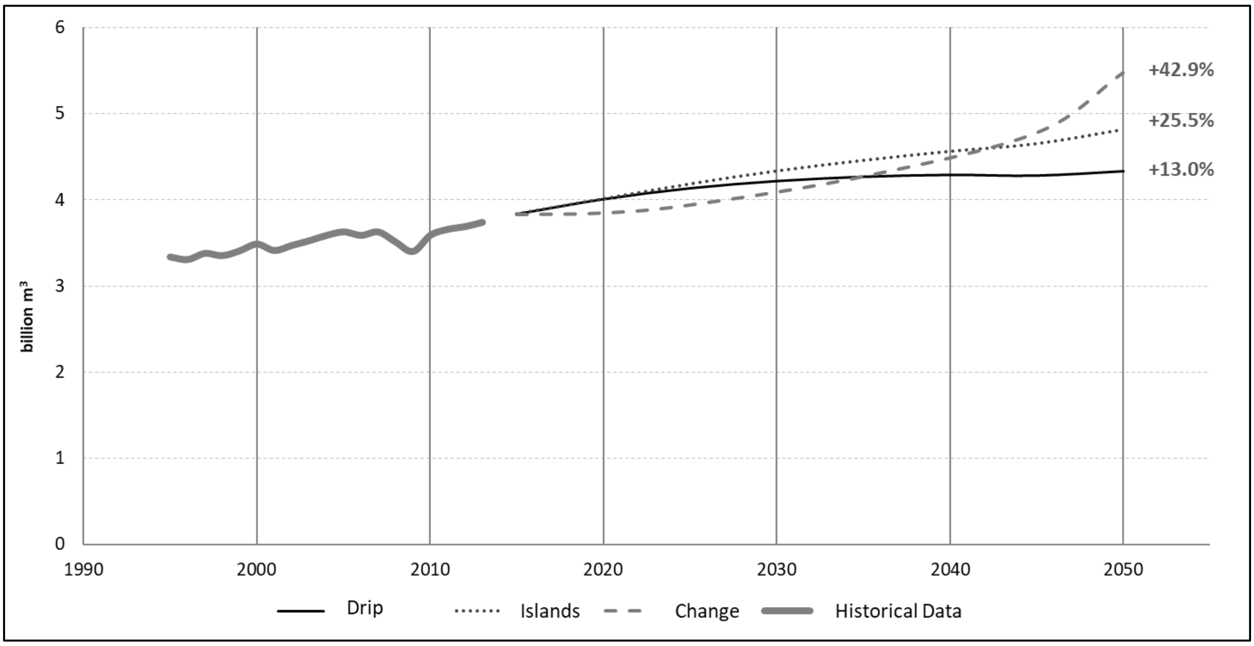

Fig. 2: Development of global roundwood production in different bioeconomy scenarios

In addition, the development of roundwood consumption pattern shows different pathways in the three scenarios. While the global fuelwood consumption in the “Bioeconomy Change” scenario decreases from 1.85 billion m³ (2015) to 1.27 billion m³ (2050), it increases until the year 2050 in the “Bioeconomy Island” (2.39 billion m³) and “Bioeconomy Drip” (2.40 billion m³) scenarios. The global consumption of industrial roundwood slightly decreases in the “Bioeconomy Drip” scenario between 2015 and 2050 from 1.83 billion m³ to 1.73 billion m³ but increases in the “Bioeconmy Island” and “Bioeconomy Change” scenarios to 2.22 billion m³ and 4.02 billion m³, respectively. The consumption of sawnwood and wood-based panels remains roughly constant at the 2015 level in the “Bioeconomy Drip” scenario. While the global sawnwood consumption shows a moderate increase in the “Bioeconmy Island” and “Bioeconomy Change” scenario from 0.64 billion m³ to 2015 to 0.53 billion m³ and 0.55 billion m³ in 2050, respectively, global the consumption of wood-based panels strongly growth from 0.42 billion m³ in 2015 to 0.68 billion m³ and 1.24 billion m³ in 2050. The consumption of paper pulp slightly increases in the “Bioeconomy Drip” scenario from 0.17 billion t in 2015 to 0.19 billion t in 2050 while it falls to 0.15 billion t and 0.13 billion t in the “Bioeconomy Island” and “Bioeconmy Change” scenario, respectively. The overall consumption of paper and paperboard remains nearly constant in the “Bioeconomy Island” scenario but increases in the “Bioeconomy Drip” scenario from 4.13 billion t to 4.66 billion t and decreases in the “Bioconomy Change” scenario to 2.88 billion t from 2015 to 2050. The global consumption of dissolving pulp shows the most dynamic growth potential in relative terms. While its material use fails to evolve in the “Bioeconomy Drip” scenario, the global consumption substantially grows in the “Bioeconomy Islands” and “Bioeconomy Change” scenario from 0.07 billion t in 2015 to 0.81 billion t and 2.17 billion t in 2050. As a result, the production of lignocellulose-based chemicals and fibers is also expected to increase by 2050. Thus, in the two scenarios fostering a bio-based economic transformation, these products are growing out of the niche market in which they find themselves today.

Discussion

This work was guided by two questions. The first one asks what interactions and competing uses occur if demand for woody resources is surging and the second one asks how the available biomass resources could be allocated. Our analysis shows, that although the demand for wood-based products is increasing, especially in the “Bioeconomy change” scenario, the demand for roundwood is only growing at a disproportionally low rate. This is due to the assumptions made in this scenario about technological progress which lead to a, in some cases drastically, decrease in the input of raw materials. This progress is mainly based on further optimized manufacturing processes, improved raw material yields, but also on the increase in the proportion of waste wood in wood-based panels. Due to the latter case, wood-based panels are increasingly produced and consumed while the growth of sawnwood sector remains limited. A further assumption for a sustainable bioeconomy scenario is that the consumption of fuelwood continuously declines due to more efficient heating systems and shifting consumer preferences. Such a shift can reduce the competition for scarce wood resources. In addition, and as a result of digitization, paper consumption continues to decline in the “Bioeconomy Island” and “Bioeconomy Change” scenario, and thus consumption of paper pulp also decreases significantly. This frees up capacities in pulp production which can partly be used for the production of dissolving pulp. Dissolving pulp is a raw material for the production of lignocellulose-based chemical derivatives and cellulose-based fibers. The latter are of particular importance, as they can replace cotton as a raw material for textile production by 2050. Thus, one scenario is that the dissolving pulp sector outpace the shrinking paper pulp sector until 2050. For this development, the dissolving pulp subsector could use released resources from the shrinking paper pulp sector.

The second question asks if there are sufficient woody raw materials available for a wood-driven bioeconomy. Based on the outcome of the scenario simulations this question can be positively answered given that technological changes reduce the total amount of raw material input in the wood-processing sector and thus, generate a potential for increasing raw material input in new products. This development needs to be accompanied by a shift in consumption pattern, e.g. away from fuelwood and classical paper products.

Conclusions

Based on the results it can be concluded that the change towards a sustainable and increasingly wood-based bioeconomy could be a possible scenario. In such a scenario the raw material allocation could change in the sense that consumption patterns shift from fuelwood or paper products towards more the production of wood-based panels or lignocellulose-based materials. To free additional resources for new wood-based products, the scenario analysis further reveals that such a development should evolve hand-in-hand with technological improvements in production processes to reduce the total input of wood input in the final products. In light of an emerging bioeconomy, the analysis shows that the lignocellulose-based sector, including dissolving pulp subsector, has the potential to outpace today's paper pulp subsector. In the here presented scenario simulations, growing dissolving pulp production would not negatively affect production volumes of the sawnwood and wood-based panels sector compared to the production levels observed in the year 2015. This is mainly due to two aspects: First, proceeding digitization and technological progress set free fibre resources that were formerly used for, e.g., the production of paper products. Second, non-coniferous wood is an entirely suitable raw material for the production of dissolving pulp the subsequent lignocellulose-based products. At this point the competition for scarce coniferous resources needed for material wood processing is defused.

Future research in the field of the wood-based bioeconomy could be dedicated to the basic estimation of domestic market parameters for emerging or innovative products made from wood components. This would help to refine scenario simulations for the development of these sectors in the context of global forest products market modelling. Another point is, that compared to other demand elasticities used in wood-products market modelling (e.g. see Morland et al. 2018), the import demand for lignocellulose-based products tend to respond more price elastic. This could be a hint that these products have a close substitute that consumers can use while achieving the same benefit (Schier et al. 2021). Future research should be carried out to deeper investigate this topic.

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