Simulating the transformation to a low-carbon bioeconomy with an integrated model of the energy system and the forest sector

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Abstract: The European Union has committed itself to establish a low-carbon bioeconomy until 2050. The challenges related to such a transformation are considerable, and it is necessary to gain a clear view of how it can be accomplished. In this paper, a modelling approach for identifying efficient strategies for carbon mitigation through wood utilization is presented. It is based on the optimization environment TIMES and comprises the entire forest sector, and according representations of (wood- and fossil-based) energy consumption and supply. The model is suitable for quantitatively simulating developments in wood-supply, international trade, the utilization of wood-based products and fuel wood, and analysing possible developments with consideration of interrelations and dependencies of the different branches of the forest sector. Carbon stock changes and carbon flows are tracked from primary production to final uses.

Four exemplary “alternative” scenarios are compared against a “business-as-usual” (BAU) scenario with regard to greenhouse gas (GHG) emissions and sequestration. Carbon stock changes in forests, wood products and raw wood as well as emissions from fossil and wood-based fuels, natural decay of wood, energy consumption of the wood industries and embedded energy of reference products (functional equivalents to wood products) are taken into account. The preliminary results show that substituting carbon-intensive materials with long-lived wood products (sometimes referred to as “material substitution”) is a highly efficient way of GHG mitigation. In contrast, if wood removals from forests are strongly increased for energy purposes, this results in an initial loss of carbon stocks in forests. In the presented “wood energy+” scenario (which is in fact far too extreme to be considered a realistic option in Austria but serves as an illustrative example), it takes more than 20 years to repay this “carbon debt” by substituting fossil fuels with wood fuels (i.e. only after 2030 the wood energy scenario shows a better GHG balance than the BAU scenario). The net GHG mitigation until 2050 in this scenario is almost negligible compared to that of the aforementioned scenario with increased material substitution. The remaining two alternative scenarios illustrate the benefits of enhanced recycling of wood and paper products.

Keywords: bioeconomy, low-carbon economy, energy system, forest sector, biomass, bioenergy, harvested wood products, simulation, 2050, optimization model, carbon debt, carbon cycle

1 Introduction

1.1 Motivation

With its “Low Carbon Roadmap” [1] and the “Bioeconomy Strategy” [2], the European Union has committed itself to establish a low-carbon bioeconomy until 2050. The economic and societal challenges related to such a transformation are considerable, and it is necessary to gain a clear view of how it can be accomplished. While the Low Carbon Roadmap and accompanying studies provide some insight into pathways for the EU, there is currently little knowledge on the feasibility and implications of transformation on a smaller scale (i.e. on national level). Apart from the energy sector, which will have to undergo major structural changes to significantly reduce greenhouse gas (GHG) emissions, developments in biomass production and utilization play a decisive role: On the one hand, biomass will become increasingly important as a fuel and raw material for conventional and novel products and on the other, land and forest management practices and land use change can strongly influence natural carbon stocks.

1.2 The project “BioTransform.at”

This paper is prepared as part of the project “BioTransform.at – Using domestic land and biomass resources to facilitate a transformation towards a low-carbon society in Austria”, supported by the Austrian Climate and Energy Fund within the Austrian Climate Research Programme.

This project aims at contributing to answer the following core research question:

- To what extent can domestic biomass contribute to the establishment of a low-carbon society in Austria, taking into account GHG emissions from all relevant sources (i.e. fuel combustion, land use and according carbon stock changes, industrial processes etc.), the impacts of climate change on biomass supply as well as adaptation measures?

Further research questions of the project, which are not within the scope of the present paper but will be the subject of future publications arising from the project, include:

- Which synergies and trade-offs between increasing domestic biomass production, adapting to climate change and the GHG balance of the land use system can be identified?
- What are the social and political implications of the transformation towards a low-carbon society?
- What are the different stakeholder positions and perceptions?

Figure 1 shows a schematic illustration of the subject of investigation. Besides biomass supply, conversion and utilization paths indicated in the figure, conventional reference systems (like fossil-based electricity or transport fuel supply and consumption) and reference products (like steel or concrete in the construction sector) are modelled in an integrated and dynamic way.

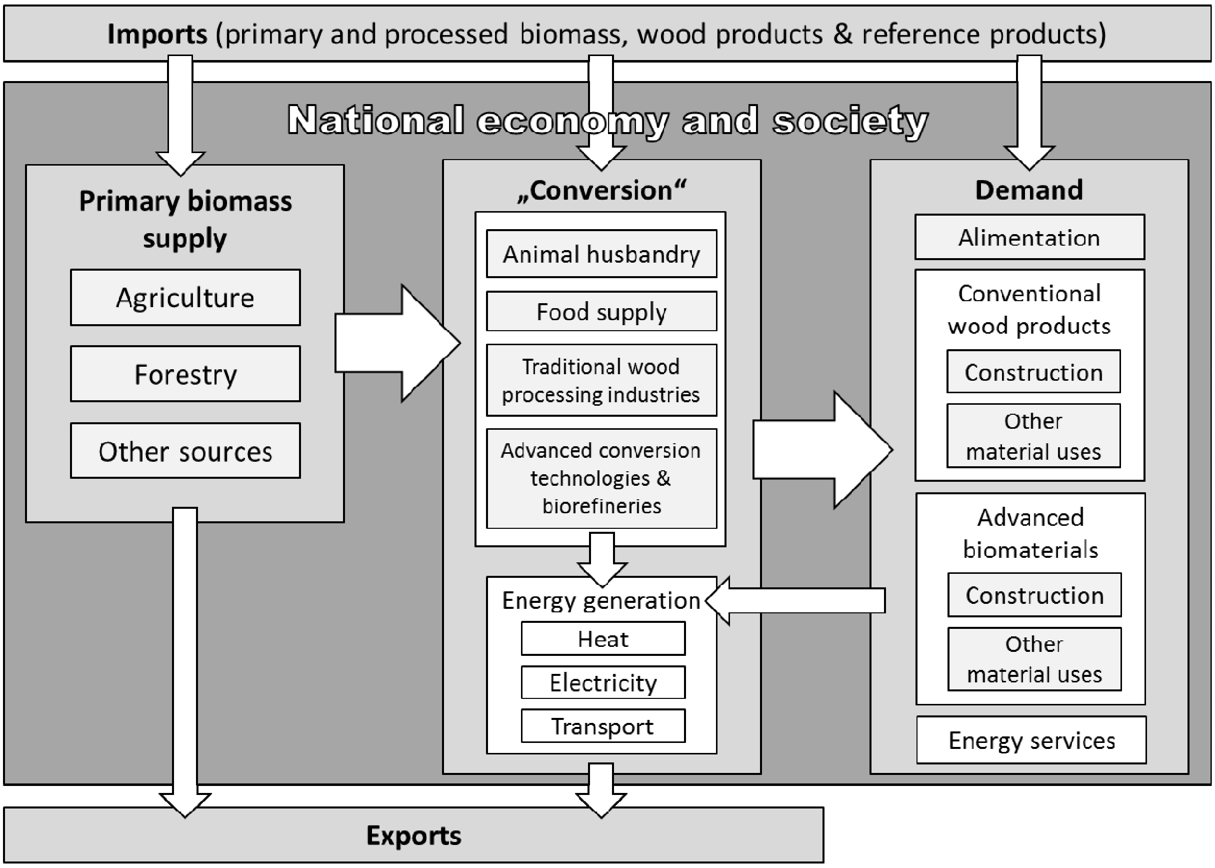

Fig. 1. Schematic illustration of the subject of investigation of the project "BioTransform.at"

This paper presents **preliminary results with regard to selected aspects** of the project.

2 Research question of this paper

In this paper, the focus is on biomass use in the energy system, the forest sector (including forestry, the wood processing industries and wood products supply and use) and wood-based products. This focus is justified for the following reasons:

- The Austrian bioenergy sector is strongly interlinked with the sawmill industry, the paper and panelboard industries. Resource competition between energy and material uses will continue to be a major issue.
- Structural changes in the wood processing industries would have a considerable impact on industrial (bio-) energy consumption as well as biomass fuel supply (e.g. sawmill residues available for heat or CHP plants; wood pellets supply etc.).
- Conventional wood products hold a great potential for substituting fossil-based and carbon-intensive materials (e.g. in the construction sector).
- Despite the fact that a large share of the wood industry's energy demand is covered with biomass-based autoproduction, these industries – especially the paper and pulp industry – consume considerable amounts of fossil and wood-based energy.

- Carbon sequestration in forests can have a major impact on the national greenhouse gas balance.

The objective of this paper is to investigate the GHG emissions in different scenarios of wood supply and utilization, in order to identify reasonable strategies for GHG mitigation.

3 Methodology

3.1 Programming environment

The model is implemented in the programming environment of TIMES ("The Integrated MARKAL-EFOM System", see [3]), which has been developed by ETSAP[1], an implementing agreement of the International Energy Agency, and is being used worldwide for the development of energy scenarios. TIMES is a tool that allows for the development of demand-driven bottom-up linear optimisation models. In this kind of models, the energy system is modelled by the possible pathways of energy carriers and the technologies used in the various stages of the transformation from primary up to useful energy. Due to the model's bottom-up structure, technical aspects like conversion efficiencies and availability as well as economic factors like investment and operation costs can be taken into account explicitly.

3.2 The forest sector module

Within this work, a forest sector module has been developed which includes wood supply from inland forests and other sources, the conventional wood processing industries, international trade with raw wood and wood-based products as well as wood and paper recycling. The geographical scope of the model is Austria. Apart from the main wood flows in Austria as well as relevant cross-border streams (see [4]) for an illustration of the main wood flows in Austria), the forest sector module includes interfaces to the energy sector: Energy consumption of the wood-processing industries as well as the supply with wood-based fuels (e.g. industrial wood residues, wood pellets, waste liquor of the paper industry) are endogenously modelled.

The optimization objective is to minimize greenhouse gas emissions, subject to different exogenous scenario settings. These scenario settings include assumptions concerning future forest management strategies, options and barriers for enhanced use of wood products, recycling rates for wood-based products etc. Based on different scenario settings, a business-as-usual (BAU) and four alternative scenarios (AS1 to AS4) are being developed and subsequently evaluated with regard to the resulting carbon flows and net GHG emissions.

While wood imports and exports are basically taken into consideration, possible effects of international trade streams are not within the scope of the model. More specifically, changes in carbon stocks through wood imports and exports are included, but material or fuel substitution through exported biomass (taking place outside of Austria) is not considered. In

[1] **E**nergy **T**echnology **S**ystems **A**nalysis **P**rogram

other words, GHG mitigation achieved by other countries by importing wood from Austria is not taken into account.

3.3 Methodology related to carbon flows and greenhouse gas balancing

The main principle applied with regard to GHG balancing is to calculate the relevant carbon flows as consistently as possible, regardless of current accounting rules under the Kyoto Protocol (for the second commitment period, which started in January 2013; “Kyoto rules”). As a consequence, GHG accounting in the model is deliberately **not** consistent with Kyoto rules. The main reason is that several Kyoto rules regarding GHG accounting from forestry and wood utilization are disregarding certain aspects which are in fact highly relevant. The most relevant differences are:

- Contrary to Kyoto rules, wood fuels are not per se carbon neutral. In fact, carbon neutrality can only be assumed if sequestration through regrowth and combustion are the same in each time interval. In general, the timing of carbon flows through sequestration in forests and CO2 emissions from burning needs to be considered. This is adequately reflected in the model algorithms.
- GHG emissions accounted under forest management are determined on the basis of a forecast (“reference level”) under Kyoto rules. Hence, if forests develop according to this forecast, emissions from stock changes are considered zero, regardless of actual developments. In the model, actual stock changes (and according emissions and sequestration) are considered.
- Wood-based products (“harvested wood products”) have been introduced as a new carbon pool in the accounting rules of the second commitment period (see [5] for a comparison of pre- and post-2012 accounting rules). Additions to this pool are based on consumption statistics of sawnwood, wood-based panels and paper. Removals are calculated assuming a first-order decay using (default or individual) half-lives. In the model, the life-cycle of wood – from standing stock over harvested raw wood and wood products to waste wood – is simulated as consistently as possible. To this end, fixed (average) lifetimes of wood products are assumed for each type of product. After the end of this lifetime, the material is assumed to be recycled or lost to natural decay. The according shares are determined by recycling rates.
- Contrary to Kyoto rules, wood imports and exports are consistently considered as additions to and removals from the carbon pools of raw wood and wood-based products.

To sum up, GHG balances calculated within the model are deliberately not in line with accounting rules under the Kyoto protocol, nor does the model determine “Kyoto-optimized” development paths.

4 Data and scenario parameters

The presented scenarios are largely predetermined by exogenous assumptions. The most relevant data sources, scenario parameters and assumptions are:

- The model has been calibrated using historic developments in wood supply and consumption, international trade with raw wood and wood-based products etc. The according time series have been extracted from FAOStat [6]. Future developments are generally limited by growth constraints.
- Gaps in statistical data have been filled using data from wood flow analyses [1] and base-year data from the European Forest Sector Outlook study II (EFSOS II) [7].
- Removals from forests and according carbon stock changes are by default assumed to follow the EFSOS II Reference scenario until 2030 (The time horizon of publicly available EFSOS II scenarios is 2010 to 2030). After 2030 they are assumed to remain constant.
- Also, future production of the wood industries is assumed to follow EFSOS II projections until 2030 and remain constant from 2030 to 2050. Inland consumption of paper is also assumed to remain constant in all scenarios.
- Recycling rates and the consumption of wood products are by default assumed to remain constant.
- Parameters defining industrial energy consumption (embedded energy of products) are based on LCA data on wood and reference products (primarily from the GEMIS-database [8] and have been calibrated to be consistent with national energy statistics [9].

To investigate the effects of certain measures and developments on the GHG balance, the following scenario-specific assumptions were made in the alternative scenarios:

- **AS1 “Wood energy+”**: Removals from forests and according carbon stock developments are assumed according to the EFSOS II Wood energy scenario [7].
- **AS2 “Recycling+”**: Recycling rates are assumed to increase to 90 % until 2020.[2]
- **AS3 “HWP stock+”**: The utilization of wood-based products (“harvested wood products”) is allowed to increase (i.e. the default constraint on wood products consumption is dropped, so that increasing GHG mitigation through material substitution is possible).
- **AS4 “HWP stock+ & recycling+”**: This is a combination of AS2 and A3.

These scenarios should be seen as illustrative examples and certainly do not reflect the full range of possible developments and measures in the forest sector.

5 Results

The following figures illustrate the main results of this work: carbon flows resulting from all relevant fields in the alternative scenarios in comparison to the BAU scenario, expressed as cumulative CO_2-equivalents, starting in 2010. Additional GHG emissions (and declines in

[2] This is in fact considered to be a very optimistic assumption, but suitable for illustrating the benefits of enhanced recycling.

stocks) compared to BAU are shown as positive numbers; GHG emission reductions and stock increases compared to BAU as negative numbers.

Figure 2 shows the differences to the BAU case broken down by the relevant carbon sinks and sources in each alternative scenario. The considered sinks and sources are: Stock changes in forests, stock changes in wood products and raw wood, emissions from fossil and wood-based fuels, natural decay of wood, energy consumption of the wood industries and embedded energy of reference products (functional equivalents to wood products)

AS1 is characterized by a significant increase in wood use for energy. Due to additional removals from forests, the forest carbon stock shows a smaller increase than in the BAU scenario (and all other alternative scenarios). During the period 2010 to 2050, this corresponds to approximately 100 million tons CO_2-equivalents (Mt CO2e) of GHG emissions. The additional wood removals from forests result in a larger increase of the (temporary) carbon stock of raw wood compared to BAU. The additional removals which enter the raw wood stock are entirely used for energy purposes, resulting in a corresponding release of carbon into the atmosphere (88 Mt CO2e during 2010 to 2030 and 207 Mt CO2e. during 2010 to 2050). Since wood replaces natural gas for energy generation, the “fuel substitution” is higher than in the BAU case. This implies approximately 112 MT CO2e less emissions from fossil fuels, which outweigh the reduced carbon sequestration in forests on the longer term.

AS2 differs from the BAU scenario in an assumed increase of wood and paper recycling rates. This affects the quantity of waste wood available for energy uses (leading to additional fuel substitution), reduced GHG emissions from decaying wood products and a higher share of secondary pulp in paper production. The resulting energy savings in the wood industries are small yet notable, and correspond to a cumulated GHG reduction of 2.9 Mt CO2e from 2010 to 2050.

The third alternative scenario, AS3, implies an increase in domestic wood products use. The quantities of raw wood and wood products which leave the stock via exports is declining significantly, compared to the BAU case, thereby creating a considerable net carbon sink. However up to 2050, the material substitution effect (wood products replace other, more carbon intensive products) is resulting in even larger GHG benefits: -167 Mt CO2e up to 2050. As parts of these additional wood products end up as waste wood during the considered period, GHG emissions from natural wood decay, waste wood combustion and fuel substitution are also slightly higher than in the BAU scenario.

Being a combination of the two aforementioned scenarios, AS4 shows the combined effects of AS2 and AS3. However, due to additional wood products being used domestically (effect of AS3), an increased wood recycling rate (AS2) is creating additional benefits: The GHG mitigation from fuel substitution during 2010 to 2050 is more than 60 % higher in this scenario than in the AS2 scenario.

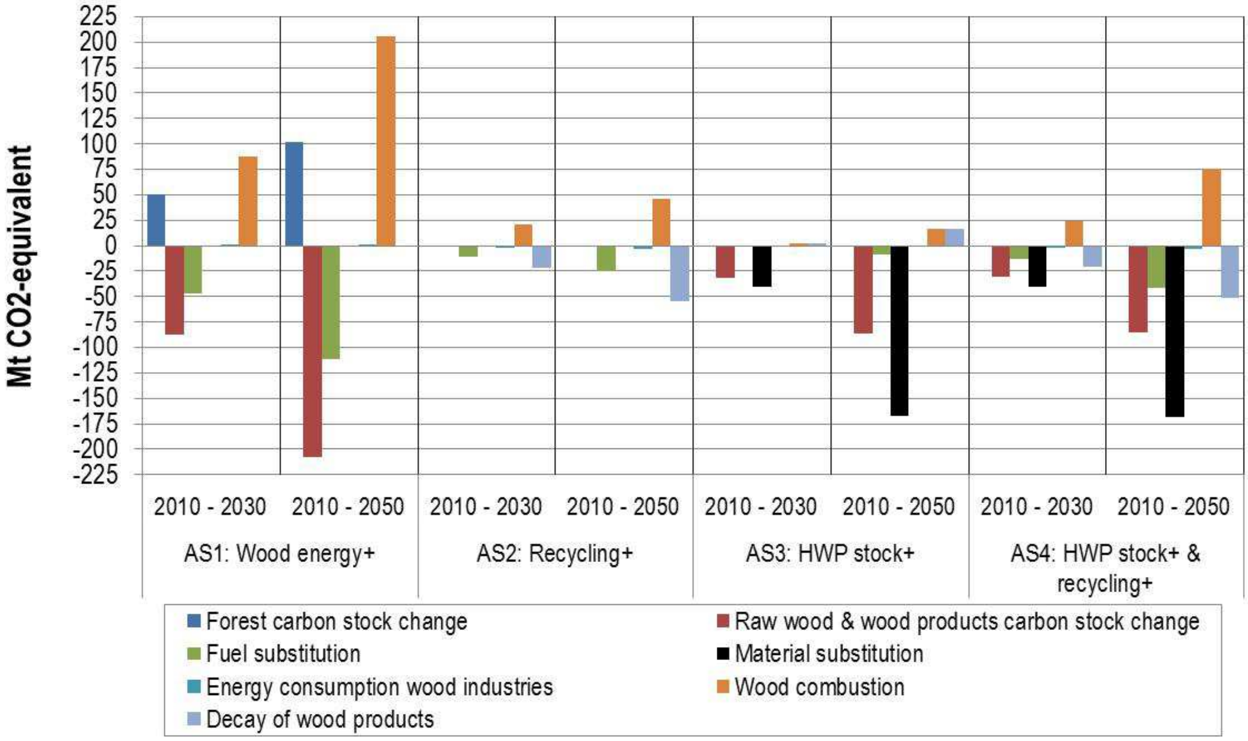

Fig. 2. Differences in cumulative greenhouse gas emissions between the Business-as-usual and the alternative scenarios AS1 to AS4.

Figure 3, showing the time series of cumulative net greenhouse gas emissions between the Business-as-usual and the alternative scenarios, illustrates the strong positive effect of material substitution: In AS3 a cumulative reduction of about 230 Mt CO2e is achieved during 2010 to 2050. Combined with enhanced recycling (as assumed in AS4) another 44 Mt CO2e are saved in comparison to the BAU scenario.

In AS2 the cumulative GHG savings due to enhanced recycling amount to 37 Mt CO2e until 2050. Increasing recycling rates yield positive effects without any delay and result in lower GHG emissions than the BAU scenario throughout the whole simulation period. By contrast, the cumulative net GHG emissions in AS1 are higher than in the BAU case until 2032. It is only until 2026 that increased wood removals for energy yield positive net effects, and it takes another six years to compensate the negative short- to medium-term effects of increased forest wood removals through fuel substitution. (In other words, 2026 is the first year when the net GHG emissions in AS1 are lower than in the BAU scenario, and 2033 is the first year when cumulative net GHG emissions in AS1 are lower than in BAU). This effect has been investigated in numerous studies (see [10]) and is sometimes referred to as "carbon debt" of bioenergy.

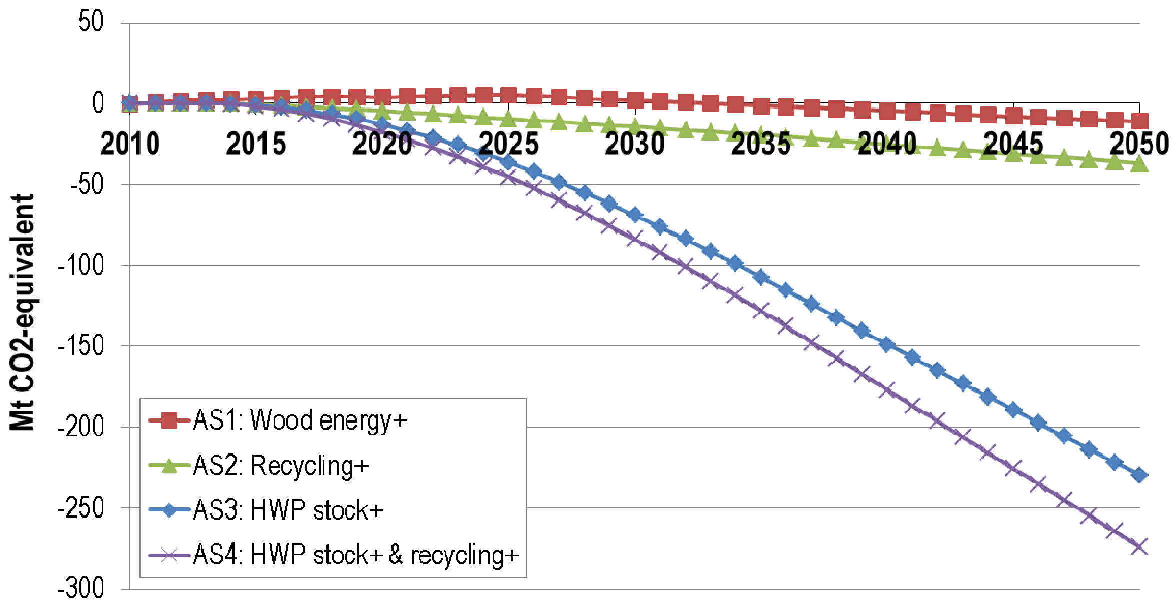

Fig. 3. Differences in cumulative net greenhouse gas emissions between the Business-as-usual and the alternative scenarios AS1 to AS4. (Negative values mean that GHG emissions are lower in the respective scenario than in the BAU case.)

6 Discussion and conclusions

Integrated scenario development and analysis is considered to be a suitable approach for analysing different strategies for GHG mitigation. With the developed model, the complexity of material and energy flows in the forest and energy sector can be handled, and possible development paths simulated in a dynamic and consistent way.

The preliminary results presented here show that substituting carbon-intensive materials with long-lived wood products is a highly effective way of GHG mitigation (AS3). In contrast, if wood removals from forests are strongly increased for energy purposes, this results in an initial loss of carbon stocks in forests. In the presented “wood energy+” scenario (AS1), it takes more than 20 years to repay this “carbon debt” by substituting fossil fuels with wood fuels (i.e. only after 2030, the wood energy scenario shows a better GHG balance than the BAU scenario). The net GHG mitigation until 2050 in this scenario is almost negligible compared to that of the scenarios with increased material substitution (AS3 and AS4).

The Wood energy scenario according to EFSOS II (which is the basis for AS1) is, with regard to Austrian standards, a highly unlikely forest management scenario: Besides a 70 %-increase in harvest residue utilization compared to the Reference case, it is assumed that 4.1 million m^3 of stump wood are extracted in 2030. Such practices can actually be ruled out under current framework conditions, not only for ecological reasons – there are simply no national bioenergy or renewable energy policy targets in place which could justify such a dramatic expansion of forest biomass use for energy. Current policy targets and according action plans foresee only a moderate increase in biomass use (see [11]), which can also be achieved in the EFSOS II Reference scenario.

The scenarios AS2 and AS4 illustrate the benefits of enhanced recycling of wood products. While it is indisputable that higher recycling rates would basically be favourable, the amount of GHG mitigation that could be achieved is in fact highly uncertain. One major difficulty in modelling waste wood recycling is that statistical data about waste wood recycling and utilization are not fully conclusive. Due to various uncertainties, waste wood streams can only be estimated. Disposal on landfills can practically be ruled out for legislative reasons and data on (separately collected) waste wood are basically available. Still, the amount of waste wood ending up in dedicated biomass or waste treatment plants is considered uncertain. Moreover, it can only be guessed what share of former wood products currently remains unused and is lost to natural decay. Based on waste statistics and estimates on typical lifetimes, the current recycling rate for waste wood was assumed 50 % here. The scenarios AS2 and AS4 are based on the assumption that this share can be increased to 90 %. Depending on actual recycling rates, the current share of waste wood in municipal solid waste, and what can realistically be achieved through improved waste management, potentials for GHG mitigation through recycling might differ significantly from the results in AS2 and AS4.

As mentioned before, all results described in this paper are based on preliminary data which can be subject to revision in the further course of the project. Most significantly, wood removals from forests and forest stock changes are based on the EFSOS II scenarios, which are only available until 2030 and therefore had to be extrapolated until 2050.[3] All the scenarios apart from AS1 (which is based on the Wood energy scenario) are based on the Reference scenario. Hence, while the extrapolation of forest scenarios is considered unproblematic with regard to the scenarios with a common forestry scenario (BAU, AS2, AS3 and AS4), developments of forest carbon stocks and fuel substitution after 2030 in AS1 is considered fairly uncertain.

The way how imports and exports of wood and wood products are taken into account in carbon balancing is highly relevant. As mentioned before, changes in carbon stocks through wood imports and exports are included, but material or fuel substitution through exported biomass is not considered. This is justified for the following reasons: (1) In order to model the effects of fuel and material substitution, reference products (or systems), representing the situation in the respective country, need to be defined. While this is problematic enough for the country under consideration, defining reference systems for each importing country is not feasible within the context of this work. (2) If reference systems were available for all relevant countries, optimization would result in maximum wood exports to the country with the "worst" reference systems, as these exports would result in the highest GHG benefits within the system boundaries of the model (e.g. wood CHP replacing electricity in the country with the highest share of lignite-based power plants). (3) The objective of this work is to identify optimal strategies and options for reducing GHG emissions in Austria; to include indirect effects of international trade would ultimately lead to the recognition that any measures in this small country are virtually irrelevant in the global context.

[3] The final results will be based on the project's own forest management scenarios simulated with the forest ecosystem model PICUS v1.6.

Further uncertainties that need to be investigated in more detail include barriers to an increased domestic use of wood products (especially in the construction sector), and embedded energy and life-cycle emissions of reference products. The results of the scenarios AS3 and AS4 are in fact highly sensitive to these parameters, and general assumptions about functionally equivalent substitutes are certainly associated with large uncertainties. However, from a review of literature data on “displacement factors” of wood products[4], it can be concluded that the results with regard to material substitution are within a typical range of results from scientific studies focussing on this aspect (cp. [12]): For AS3 an average displacement factor of 2.67 was calculated for the whole simulation period, while displacement factors in literature are typically in the range of 1 to 3, with an average of 2.1).

These scenarios presented in this paper are preliminary results of a model which is still under development. The scenarios and simulation results are not definitive. First of all, they are intended to provide insight into the capabilities of the modelling approach.

Literature

[1] European Commission, 2011. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions; A Roadmap for moving to a competitive low carbon economy in 2050. Brussels.

[2] European Commission, 2012. Communication from the Commission to the European parliament, the Council, the European economic and social committee and the committee of the regions. Innovating for Sustainable Growth: A Bioeconomy for Europe. COM(2012) 60 final. Brussels.

[3] Loulou, R., Remme, U., Lehtila, A., Goldstein, G., Kanudia, A., “Documentation for the TIMES Model Part II. Energy Technology Systems Analysis Programme, 2005 www.etsap.org/tools.htm (last access in October 2014)

[4] L. Strimitzer, K. Nemestothy, „Wood flows in Austria 2012“, Austrian Energy Agency, Austrian Chamber of Agriculture, 2014 http://www.klimaaktiv.at/english/renewable_energy/woodflows_austria.html (last access in January 2015).

[5] D. Frieden, N. Pena, D.N. Bird, „Incentives for the use of forest biomass: A comparative analysis of Kyoto Protocol accounting pre- and post-2012“, Del. N.04 of the project SMART FORESTS, 2012, http://www.smartforests.at/ (last access in January 2015

[6] FAO, „Website of ForesSTAT - Forestry statistics of FAOSTAT“, 2014. http://faostat3.fao.org/download/F/*/E (last access in January 2015)

[7] UNECE/FAO, 2011. European Forest Sector Outlook Study II 2010-2030. http://www.unece.org/efsos2.html (last access in January 2015)

[4] Definition of „displacement factor“ [12]: “A displacement factor can express the efficiency of using biomass to reduce net greenhouse gas (GHG) emission, by quantifying the amount of emission reduction achieved per unit of wood use. [A displacement factor of, for example, 2.1 means] that for each ton of carbon in wood products substituted in place of non-wood products, there occurs an average GHG emission reduction of 2.1 [tons of carbon].”

[8] U. Fritsche, K. Schmidt, „Global Emission Model of Integrated Systems (GEMIS). Manual“, Öko-Institut (Institute for Applied Ecology), Darmstadt, 2008.

[9] Statistik Austria, „Website of Statistik Austria - Useful Energy Analysis“, 2011. http://www.statistik.at/web_en/statistics/energy_environment/energy/useful_energy_analysis/index.html (last access in January 2015).

[10] A. Agostini, J. Giuntoli, A. Boulamanti, „Carbon accounting of forest bioenergy. Conclusions and recommendations from a critical literature review“, European Commission Joint Research Centre, Institute for Energy and Transport, JRC Technical reports, 2013.

[11] BMWFJ/BMLFUW, „National Renewable Energy Action Plan 2010 for Austria“, June 2010.

[12] R. Sathre und J. O’Connor, „Meta-analysis of greenhouse gas displacement factors of wood product substitution“, Environ. Sci. Policy, Vol. 13, Nr. 2, p. 104–114, Apr. 2010.

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Further information and reports are available at: http://www.energyagency.at/projekte-forschung/energie-klimapolitik/detail/artikel/biotransformat-perspektiven-fuer-die-etablierung-einer-auf-inlaendischen-ressourcen-basierenden.html

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