TRANSFORMATION PATHS TO A LOW-CARBON BIOECONOMY IN AUSTRIA

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ABSTRACT: The economic and societal challenges related to a significant reduction in greenhouse gas (GHG) emissions and establishing a bioeconomy are considerable, and it is necessary to gain a clear view of how a transformation can be accomplished. There is currently little knowledge on the feasibility and implications of such a transformation on a national level and the possible contribution of domestic biomass resources.

In this work, a modeling approach for developing integrated transformation scenarios is presented. It is implemented in the optimization environment TIMES and comprises a complete representation of the Austrian energy system, the forest sector, agricultural land use and production, the livestock sector, food supply and demand. The model is basically intended to represent all relevant material and energy flows between these sectors. The core objective is to develop integrated scenarios and identify efficient GHG mitigation options.

This paper presents exemplary simulation results for the case of Austria, developed with a preliminary model version. Besides a Reference scenario (RS), the following alternative scenarios (AS) are presented: AS1 AgriBioenergy is based on the assumptions of high yield increases and other measures to increase agricultural bioenergy production. It shows a development where large shares of arable land become available for energy crop production or short rotation plantations. AS2 ForestBioenergy illustrates that the net GHG effect of increased wood removals from forests for the purpose of energy production is initially negative, as carbon stocks become lower than in the RS. Only after about three decades, the net GHG effect becomes positive in this scenario. AS3 MaterialSubstitution illustrates that substituting carbon-intensive materials with long-lived wood products is a highly efficient way of GHG mitigation.

Keywords: low-carbon economy, biobased economy, scenarios, optimization model, bioenergy, greenhouse gases

1 INTRODUCTION

1.1 Motivation

With the “Low Carbon Roadmap” [1] and the “Bioeconomy Strategy” [2], the European Union has declared its commitment to establish a low-carbon bioeconomy until 2050. The economic and societal challenges of such a transformation are considerable, and it is necessary to gain a clear view of how it can be accomplished. While the Roadmap and accompanying studies provides some insight into possible pathways on EU level, 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 also 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, rising biomass demand might cause land use and land cover change and result in loss of natural carbon stocks.

1.2 GHG emissions and sinks in Austria

Figure 1 shows the historic development of GHG emissions in Austria. Energy supply clearly accounts for the largest part of GHG emissions [3]. Climate mitigation policies are therefore of course focused on substituting fossil fuels and fossil-based technologies with renewable ones. Still, in the context of land use and biomass production and utilization, other sources (as well as sinks) for GHG emissions must be taken into consideration:

Emissions from agriculture, which are primarily due to animal husbandry (enteric fermentation and manure management) and fertilizer use, accounted for an average of almost 8 million tons CO_2-equivalent (Mt CO2e) per year. During 1990 to 2012, these emissions were equivalent to 13 % of the total net GHG emissions.

Especially during 1997 to 2001, Austrian forests were a considerable net sink of GHG: Carbon stock changes compensated as much as 29 % of the energy-related emissions during this period, illustrating the high relevance of forest management strategies. On the other hand, increased wood removals in the last decade resulted in enhanced substitution of fossil fuels and fossil-based materials. These effects are not directly discernible from the GHG balance, but nonetheless highly relevant. With regard to the potential of material substitution, emissions from “industrial processes” give some indication: More than 10 Mt CO2e per year are caused by industrial processes and more than half of that by metal production. An increased use of wood for construction (and other purposes) could help replace carbon-intensive products and materials such as steel and concrete, thereby reducing GHG emissions from industrial processes and raising medium to long-term carbon stocks.

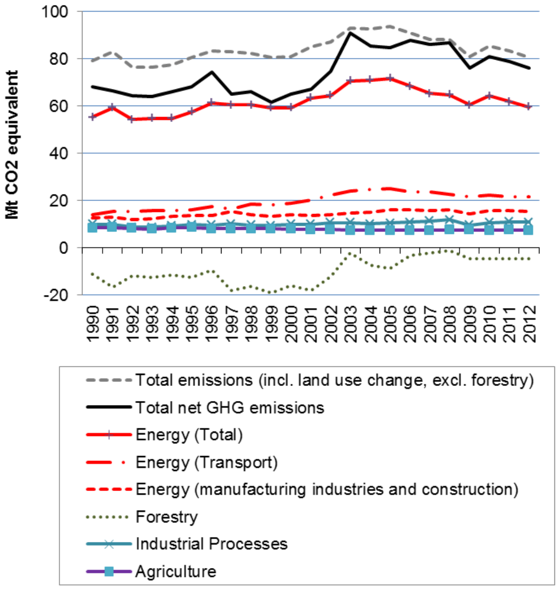

Figure 1. Historic development of GHG emissions in Austria [3]

2 RESEARCH QUESTION

This work is dedicated to the development of scenarios to a low-carbon bioeconomy in Austria, and to identifying efficient ways of GHG mitigation through biomass use.

It 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", and presents a modeling approach and exemplary simulation results, developed with a preliminary version of the model.

Recognizing the importance of profound knowledge of the current structure of biomass supply and use, this paper also presents a complete flow diagram of biomass streams in Austria, which has been developed within the project.

Further aspects, which are investigated within the project "BioTransform.at", but are not within the scope of the present paper, include: (i) Synergies and trade-offs between increasing domestic biomass production, adapting to climate change and the GHG balance of land use, (ii) Social and political implications of the transformation towards a low-carbon society, and (iii) Stakeholder positions and perceptions regarding the long-term target of establishing bioeconomy.

3 METHODOLOGICAL APPROACH AND DATA

3.1 Scope and basic structure of the optimization model

Figure 1 shows a schematic illustration of the scope of the model and the focal area of the research. The drivers behind all activities and processes represented in the model are the basic human needs food, materials and energy services. They can either be satisfied with biomass or (with the exception of food) fossil and mineral resources. Considering the whole supply chain from production/extraction to energy service or (in the case of material needs) final disposal as waste, biomass-based options are usually – but not necessarily – associated with lower GHG emissions than fossil-based options.

Similarly, the transformation of mineral resources to products and construction materials (e.g. steel, concrete) is very energy- and carbon-intensive, compared to wood-based materials and products. Therefore, the enhanced use of biomass – for energy as well as materials – is usually considered to be a core element of a transformation to a low-carbon economy. In the field of energy services, other renewable energy sources, which are of course also essential for a major decarbonizing the energy system, are also represented in the model and Figure 1. However, the focus of the modeling approach is on biomass and the wide variety of options for reducing greenhouse gas emissions without compromising food supply.

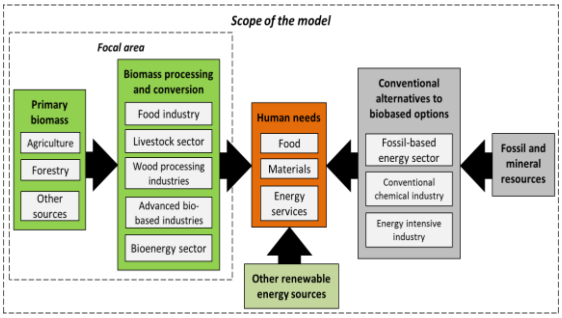

Figure 2. Schematic illustration of scope of the model and the focal area of the research

In more detail, the focus of the model includes biomass primary production in agriculture, forestry and from other sources, biomass processing and conversion (food industry, the livestock sector, the sawmill, panelboard and paper and pulp industries, advanced biobased industries (e.g. bioplastics production) and the bioenergy sector. Needless to say, there are numerous interactions between the different sectors and industry branches which need to be considered. For example, material flows between the wood processing industries (e.g. sawmill residues being used in the panelboard, paper and pulp industry), waste streams from agriculture to the bioenergy sector and byproducts from biomass processing like waste liquor of the pulp industry being used for energy production must be taken into consideration. In fact, the sectors show as separate items in the box labeled "Biomass processing and conversion" in Figure 1 are strongly overlapping.

3.2 Programming environment

The model is implemented in the programming environment of TIMES ("The Integrated MARKAL-EFOM System", see [4]), which has been developed by ETSAP, an implementing agreement of the International Energy Agency. TIMES is a tool that facilitates the development of demand-driven bottom-up linear optimization models, and is being used worldwide for the development of energy scenarios. The model is designed to minimize aggregated system costs (usually total costs of an energy system, including fuel costs, investment, operation and maintenance costs etc.).

However, TIMES is also a suitable tool for modeling both material and energy flows, calculating greenhouse gas balances and minimizing greenhouse gas emissions subject to certain framework conditions and exogenous constraints; this approach is applied in this work. By considering GHG emissions from fossil fuel combustion, land use change, management practices, animal husbandry and embedded emissions of imported goods, options for climate mitigation and potential trade-offs are modeled in a very comprehensive way.

3.3 Data and exogenous assumptions

Data used for analyzing biomass flows in Austria as well as for calibrating the model have primarily been obtained from online databases provided by international institutions and official national statistics. Data on wood supply and consumption, international trade with raw wood and wood-based products etc. have been extracted from the FAO online database [8]. Gaps in statistical data have been filled using data from national wood flow analyses [6] and base year data from the European Forest Sector Outlook study II (EFSOS II) [9].

Data on agricultural production, livestock, feed supply and consumption etc. are provided by the national statistical authority Statistik Austria [11] as well as Eurostat [12]. Data on international trade (including agricultural products, livestock etc.) have been downloaded from the Eurostat database [13]. In addition to these sources, supply balance sheets have been used [14], since they provide information on the utilization structure for most agricultural commodities and products.

In order to derive detailed input-output ratios between feed inputs and animal product outputs, agricultural products used as feed according to the supply balance sheets (including roughage) were allocated to livestock classes, based on food balance sheets for Austria. These input-output ratios remain constant in all scenarios.

For the model of the energy sector, the national energy balance [10] and the "Useful Energy Analysis" [15] were the main sources of data. The former provides detailed information on energy supply, transformation and consumption, while the latter gives further insight into the structure of energy consumption by type of end use.

Developments in energy demand are partly based on scenarios developed in previous studies and are included as exogenous scenario parameters. This is true for the transport fuel demand (which is loosely based on the scenarios described in [17]), residential heating and cooling as well as heating and cooling in the services sector (see [18] for a description of the modeling approach). Energy demand in the industry, agriculture and the services sector (with the exception of heating and cooling) are modeled with a top-down approach; sector-specific scenarios of economic development are the drivers behind energy demand, taking into account recent trends in energy intensities, which differ for each sector and useful energy category (e.g. steam generation, industry ovens, stationary engines).

3.4 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 [19] 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.

GHG emissions from agriculture are largely neglected here. With regard to emissions from livestock and manure management, this is unproblematic because only differences to a reference scenario are considered and assumptions about dietary habits and livestock numbers are consistent throughout all scenarios. Emissions from land-use change are not relevant, as it is assumed that land-use patterns remain constant in all scenarios. Only for biofuels, GHG emissions from agricultural activities and processing are simplistically attributed to fuel consumption, based on typical savings compared to conventional fuels stated in EU Directive 2009/28/EC.

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 CURRENT STRUCTURE OF BIOMASS SUPPLY AND USE IN AUSTRIA

As a first step for calibrating the model to the base year, a comprehensive analysis of biomass streams in Austria was carried out (This work was published in [5]). The main results of this analysis are flow diagrams, which provide insight into the current relevance of different sources and utilization paths, as well as into the complexity of biomass flows within Austria's economic system. Fig. 3 shows the biomass stream on dry mass basis in 2011.

The most relevant biomass streams (on dry mass basis) are made up by wood flows related to the wood processing industries. Roundwood flows to the sawmill industry represent the largest streams, followed by the paper and pulp and the wood panel industry. Energy uses directly or indirectly related to the wood processing industries (i.e. heat and power generation in autoproduction plants, waste liquor utilization in the paper industry, pellet production from sawmill residues and wood residues sold for energy generation) together account for 45 % of all biomass used for energy (dry mass basis). Therefore, the wood processing industries are highly important elements of biomass supply and consumption in Austria. More specifically, the sawmill industry supplies large quantities of wood chips and other residues to the paper, pulp and panel industry. In the figures, this is represented by the recycling loop of the wood processing industries. A more detailed analysis of the wood flows in Austria with a focus on the interrelations between then different branches is provided in [6] and [7].

Agricultural biomass consumption is dominated by animal husbandry. On dry mass basis, animal husbandry is the second largest (and on a wet matter basis by far the largest) node in the flow diagram. Biomass from grassland, accounting for 4.7 million tons dry mass (Mt_{dry}), was almost as important as fodder crops from arable land (5.2 Mt_{dry}) in 2011.

Human food consumption is significantly lower than the flows of animal feed. Liquid biofuel supply (primarily biodiesel and ethanol, accounting for 6.75 % of all road transport fuels), is of relatively little importance in the overall picture. Still, in the market segment of plant oil the additional resource demand for biodiesel production had a strong impact on the supply balance: The self-sufficiency decreased from about 60 % around the year 2000 to about 30 % in recent years.

The figure illustrates the high significance of international biomass trade. Apart from wood, large quantities of agricultural commodities and paper are both imported and exported. Austria is a net exporter of paper products (net exports of paper and paperboard accounted for 2.4 Mt_{dry}) and a net importer of recovered paper (0.9 Mt_{dry}). Cross-border trade with refined wood fuels (primarily wood pellets) has increased significantly during the last ten years and amounted to about 0.7 Mt_{dry} being both imported (primarily from the Northern neighbouring countries) and exported (primarily to Italy) in 2011 [7].

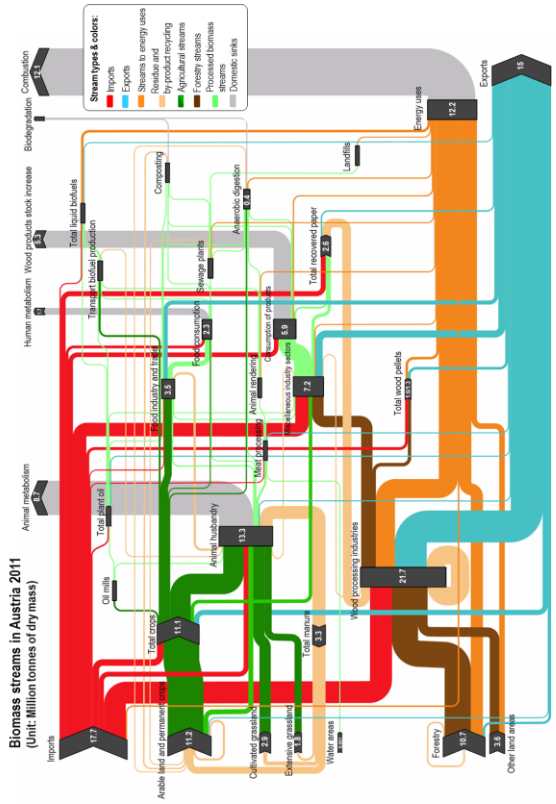

Figure 3. Biomass streams in Austria in the year 2011 [5]

5 SIMULATION RESULTS

In the following sub-sections, the simulation results of four scenarios are presented: The **Reference scenario** is based on conservative assumptions regarding primary biomass production in forestry and agriculture: Removals from forests and according carbon stock changes are 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. Agricultural yields are assumed to increase by 10% until 2030 and 15% until 2050. About 40,000 ha of arable land are assumed to be left fallow for ecological reasons. International trade with wood products, agricultural products, food, feed etc. is generally fixed to average values of recent years.

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

Alternative scenario 1 (**AS1 AgriBioenergy**) is based on clearly more optimistic assumptions regarding yield increases (+35% until 2030, +50% until 2050). In contrast to the Reference scenario, the option to use (surplus) straw for energy recovery in heat and CHP plants is available. Furthermore, no fallowing of arable land for ecological reasons is assumed.

In **AS2 (ForestBioenergy)** removals from forests and according carbon stock developments are assumed to follow the EFSOS II Wood energy scenario [9].

In **AS3 (MaterialSubstitution)** the utilization of wood-based products (sawnwood, panelboard) in construction etc. 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).

These scenarios should be seen as illustrative examples and certainly do not reflect the full range of possible developments and options. Scenario-specific assumptions, parameters and uncertainties will be further discussed in section 6.

5.1 Reference scenario (RS)

In the Reference scenario, biomass utilization for energy increases from about 240 PJ in 2010 to about 275 PJ in 2020 (Fig. 4). The additional biomass primarily originates from forestry. During 2020 to 2030 the total biomass consumption remains relatively constant, but woody biomass is increasingly used in the form of pellets and torrefied biomass. While pellets are especially suitable for substituting fossil fuels in residential heating, torrefied biomass is primarily used in the industry, as a direct substitute for coal.

Further figures illustrating developments in the Reference scenario are included in the Annex.

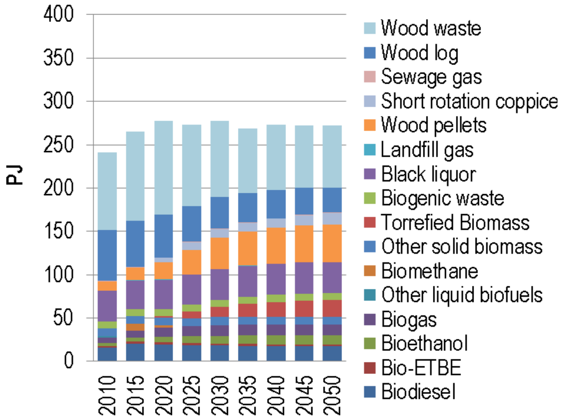

Figure 4. Biomass primary energy consumption in the Reference scenario

5.2 Alternative scenario “AS1.AgriBioenergy” (AS1)

AS1 is characterized by a significant increase in biomethane production (until 2030) and short rotation coppice (after 2030). The reason for this development is that under the assumptions of this scenario (high yield increases, no fallowing), a large share of arable land become available for energy crop production or short rotation plantations. Furthermore, about 10 PJ of straw are used for energy in this scenario. The total biomass primary energy consumption increases to more than 350 PJ. As in the RS, there is a shift from wood chips and wood log to pellets and torrefied biomass.

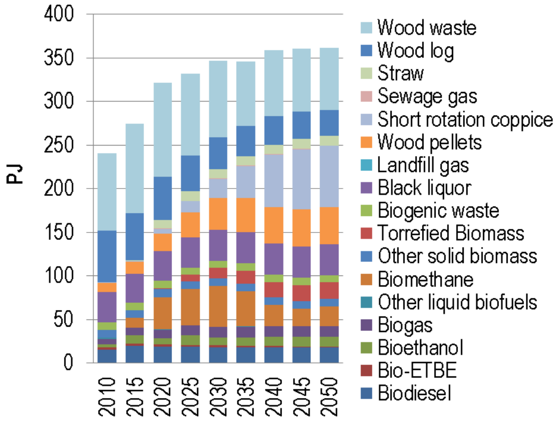

Figure 5. Biomass primary energy consumption in the AgriBioenergy scenario

5.3 Alternative scenario “ForestBioenergy” (AS2)

AS2 shows a significant increase in forest biomass consumption. (As in the national energy statistics, forest wood chips, industrial wood residues and waste wood are summarized under “wood waste”.) With a maximum biomass consumption of about 340 PJ in 2030, the total size of bioenergy use is clearly lower than in AS1. Still, an increase of about 100 PJ from 2010 to 2030 is considerable.

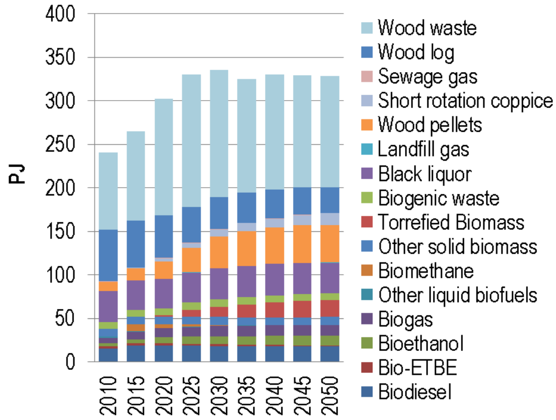

Figure 6. Biomass primary energy consumption in the ForestBioenergy

5.4 Alternative scenario 3 “MaterialSubstitution” (AS3)

The development of biomass primary energy consumption in AS3 is almost identical to the RS. There is only a slight increase in wood waste consumption (see Fig. 8), which is due to additional amounts of wood products being utilized in the inland and leaving the stock of wood products after the end of the product lifetime. Therefore, more waste wood becomes available for energy generation in this scenario.

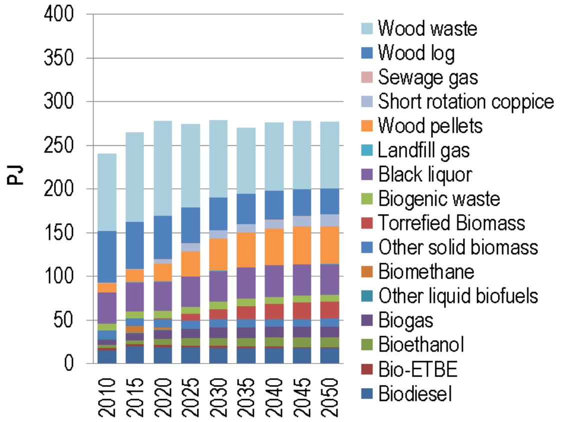

Figure 7. Biomass primary energy consumption in the MaterialSubstitution scenario

5.5 Scenario comparison: Energy

Fig. 7 illustrates the difference between biomass primary energy consumption in the RS and the alternative scenarios in 2030 and 2050, broken down by biomass categories.

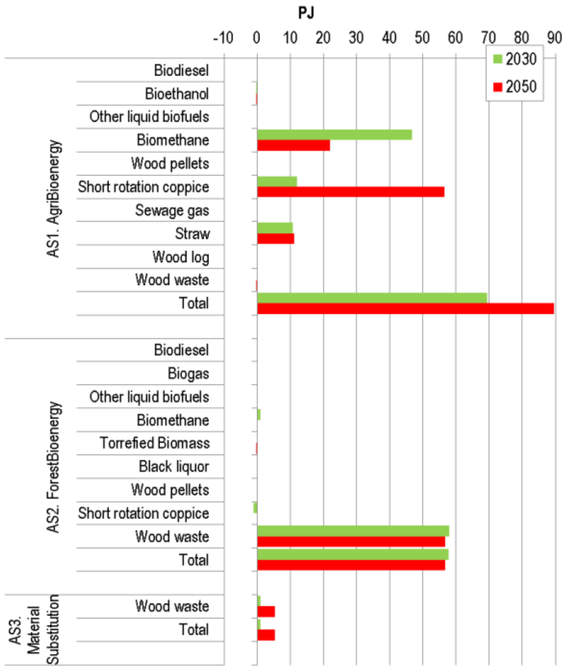

Figure 8. Difference between biomass primary energy consumption in the alternative scenarios and the Reference scenario.

Fig. 9 shows the development of total primary energy consumption in the four scenarios, broken down by biomass, fossil fuels and other renewable energy sources. Apparently, none of the four scenarios describes a transition to a low-carbon economy, as fossil fuels (primarily natural gas) account for a large share of primary energy consumed in 2050. Considering the size of fossil fuel consumption (between about 500 and 600 PJ), it is obvious that actual transformation paths can only be achieved if energy efficiency increases much faster and progress in other renewable energy sources is significantly higher than what is assumed in the present scenarios. Despite the fact that the alternative scenarios shown here only represent exemplary development paths and further increases in bioenergy might be possible under different framework conditions (e.g. changes in dietary habits, resulting in less agricultural land being used for feed production), it is clear that domestic biomass supply for energy cannot increase by a factor of 3 or more until 2050.

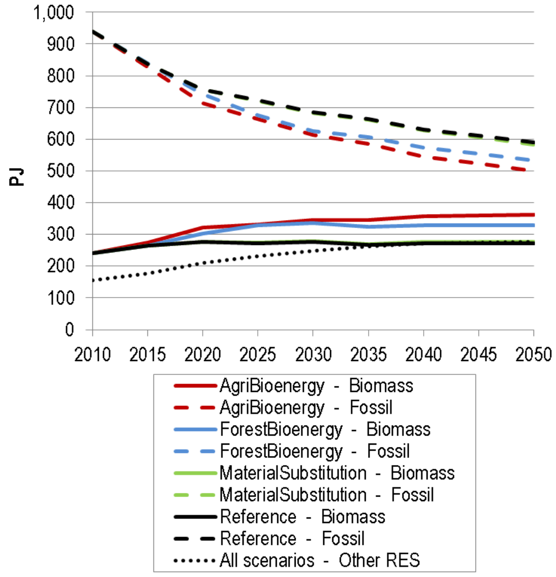

Figure 9. Development of primary energy consumption in the four scenarios, broken down by biomass, fossil fuels and other renewable energy sources (RES)

5.6 Scenario comparison: GHG emissions

Figure 10, showing the time series of cumulative net greenhouse gas emissions between the Reference and the alternative scenarios, illustrates the efficiency of material substitution in GHG mitigation: In AS3 a cumulative reduction of almost 280 Mt CO2e is achieved during 2010 to 2050.

By contrast, the cumulative net GHG emissions in AS2 are higher than in RS until 2045. It is only until 2026 that increased wood removals for energy yield positive net effects, and it takes two decades 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 AS2 are lower than in the RS, and 2045 is the first year when cumulative net GHG emissions in AS2 are lower than in the RS). This effect has been investigated in numerous studies (see [10]) and is sometimes referred to as “carbon debt” of bioenergy.

It needs to be stressed that this carbon debt refers to the difference of net GHG emissions between two scenarios. Compared to a base year, there still might be net carbon sequestration in forests in the ForestBioenergy scenario. The “debt” arises from a reduction of carbon stocks in forests, relative to the Reference scenario (and not necessarily a carbon stock decrease compared to a base year).

The time it takes to pay back the carbon debt highly depends on which fuels are being substituted with the additional amount of biomass as well as technologies used. It is therefore influenced by numerous scenario parameters and cannot be generalized easily.

In AS1, the cumulated GHG savings compared to the RS amount to more than 100 Mt CO2e until 2050. However, this result is based on the implicit assumption that the assumed high yield increases are achieved through breeding progress and without increasing fertilizing intensity.

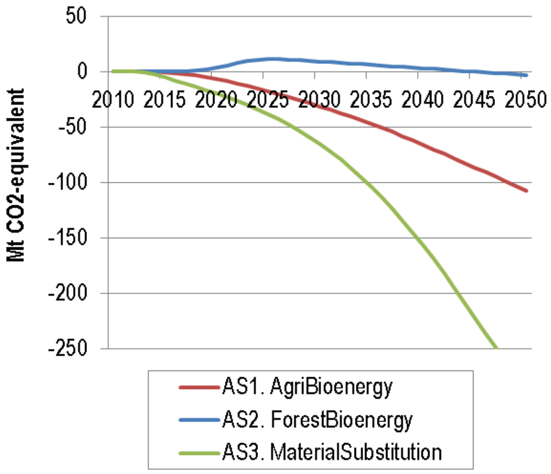

Figure 10. Differences of cumulated net GHG emissions in the alternative scenarios, as compared to the Reference scenario (Negative values mean that GHG emissions are lower in the respective scenario than in the Reference.)

6 DISCUSSION AND CONCLUSIONS

Integrated scenario development and analysis is considered to be a suitable approach for analysing different options for GHG mitigation and identifying efficient strategies. With the developed model, the complexity of material and energy flows related to biomass production, transformation and utilization for the different human needs 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 lower forest carbon stocks, compared to the RS. In the presented “ForestBioenergy” scenario (AS2), it takes more than 20 years to repay this “carbon debt” by substituting fossil fuels with wood fuels (i.e. only after 2045, this scenario shows a better GHG balance than the reference scenario). The net GHG mitigation until 2050 in this scenario is almost negligible compared to that of the scenarios with a significant expansion of agricultural bioenergy and increased material substitution (AS1 and AS3, respectively). However, to conclude that a focus on agricultural biomass is generally preferable to forest biomass would definitely be wrong, because positive GHG effects of agricultural bioenergy use can easily be offset (e.g. by higher emissions from fertilizer use). Furthermore, other potential negative environmental effects (e.g. on biodiversity) need to be considered in this context.

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 [20]), which can also be achieved in the EFSOS II Reference scenario.

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. The scenarios AS1 and AS3 are based on the same forestry scenario as BAU (EFSOS II Reference), so the extrapolation of forest scenarios is considered relatively unproblematic with regard to these scenarios, as long as the evaluation of GHG balances is focussed on deviations from the BAU case. Contrarily, AS2 is based on a different forestry scenario than BAU. Thus, concerning the comparison of AS2 to BAU (Fig. 9), developments of net GHG emissions after 2030 must be seen very critically, as extrapolation of forest removals and carbon stocks is a very crude approach that does by no means capture the dynamics and complexity of forest ecosystems (1).

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: (a) 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. (b) 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). (c) 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.

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 AS3 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 (2), 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 about 2.7 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.

7 NOTES

(1) The final results will be based on the project's own forest management scenarios simulated with the forest ecosystem model PICUS, which has been developed at the Institute of Silviculture at the University of Natural Resources and Life Sciences Vienna.

(2) Definition of „displacement factor“ [21]: “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 REFERENCES

[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] Eurostat Database, 2015. Greenhouse gas emissions (source: EEA), http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en (accessed February 2015)

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

[5] Kalt G., 2015. Biomass streams in Austria: Drawing a complete picture of biogenic material flows within the national economy. Resources, Conservation and Recycling 95 (2015) 100–111.

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

[7] Kalt, G., Kranzl, L., 2012. An assessment of international trade related to bioenergy use in Austria—Methodological aspects, recent developments and the relevance of indirect trade. Energy Policy 46, 537–549.

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

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

[10] Statistik Austria, 2015. Website of Statistik Austria - Energy balances, http://www.statistik.at/web_en/statistics/energy_environment/energy/energy_balances/index.html (accessed November 2013)

[11] Statistik Austria, 2015. Farm structure, cultivated area, yields, http://www.statistik.at/web_en/statistics/agriculture_and_forestry/farm_structure_cultivated_area_yields/index.html (accessed January 2015)

[12] Eurostat, 2015. Website von Eurostat. Pflanzliche Erzeugnisse - jährliche Daten [WWW database]. URL http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_cpp_crop&lang=de (accessed November 2015)

[13] Eurostat, 2015. Website of Eurostat. EU27 trade since 1988 by HS2-HS4, bit.ly/1qTLkN5 (accessed January 2015)

[14] Statistik Austria, 2015. Website of Statistik Austria - Supply Balance Sheets, http://www.statistik.at/web_en/statistics/agriculture_and_forestry/prices_balances/supply_balance_sheets/index.html (accessed January 2015)

[15] Statistik Austria, 2015. Website of Statistik Austria – Useful Energy Analysis, http://www.statistik.at/web_en/statistics/energy_environment/energy/useful_energy_analysis/index.html (accessed January 2015)

[16] 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.

[17] Kloess, M., Müller, A., “Simulating the impact of policy, energy prices and technological progress on the passenger car fleet in Austria—A model based analysis 2010–2050”, Energy Policy 39 (2011) 5045–5062

[18] Müller, A., 2015. Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock (PhD-Thesis). Vienna University of Technology.

[19] 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

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

[21] 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.

9 ANNEX

The following figures show developments in energy consumption and electricity supply in the Reference scenario.

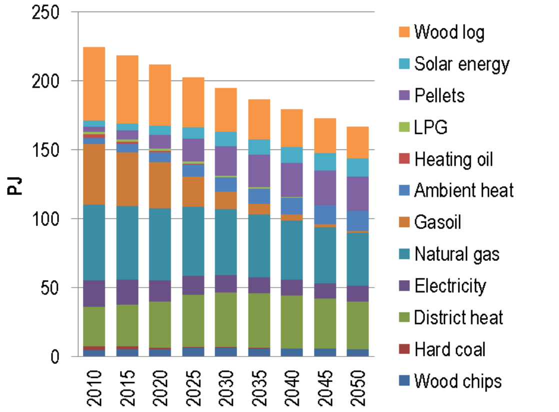

Figure 11. Residential heating and cooling in the Reference scenario

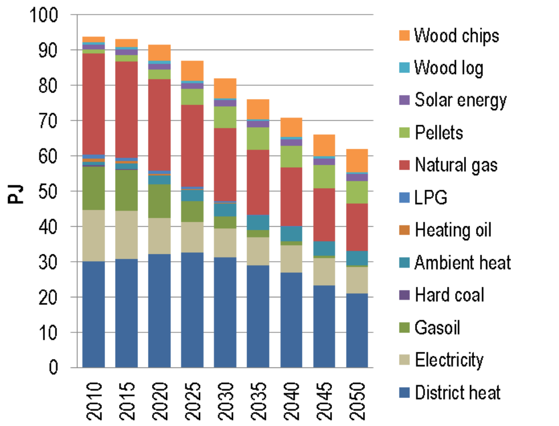

Figure 12. Heating and cooling in the services sector in the Reference scenario

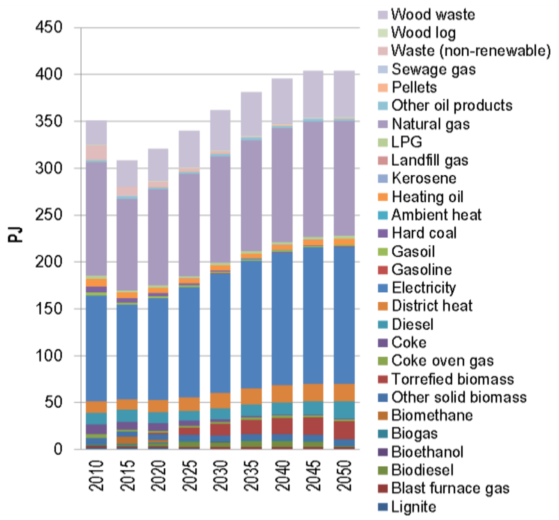

Figure 13. Energy consumption of the industry in the Reference scenario

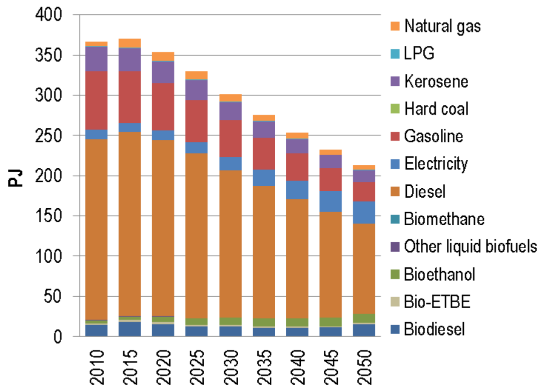

Figure 14. Energy consumption of the transport sector in the Reference scenario

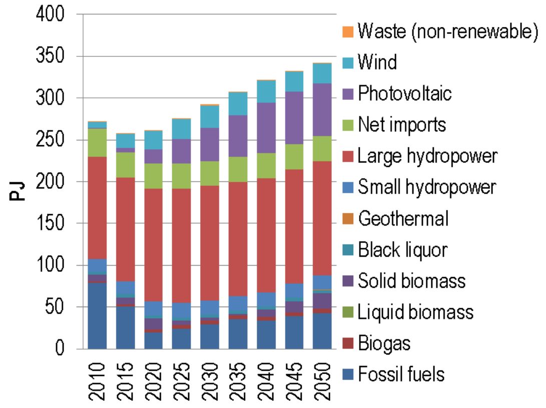

Figure 15. Development of electricity supply in the Reference scenario

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