PUBLIZIERBARER ENDBERICHT

A) Projektdaten

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B) Project overview

1 Kurzfassung

Ausgangssituation und Fragestellung
Im Kontext von Klima- und Energiestrategien sowie des erklärten Ziels der EU, bis 2050 die Transformation zu einer Bioökonomie zu bewerkstelligen, nehmen biogene Ressourcen eine Schlüsselrolle ein. Mittels Biomasse können fossile Energieträger ebenso wie energieintensive Produkte ersetzt und die Abhängigkeit der Wirtschaft von fossilen Rohstoffen reduziert werden. Die Transformation zu einer Bioökonomie kann jedoch auch negativen Auswirkungen einer wachsenden Biomassenutzung zur Folge haben. Insbesondere besteht die Gefahr, dass Treibhausgas-(THG-) einsparungen im Energieberich durch Landnutzungsänderungen und zunehmende Nutzungsintensitäten (teilweise) kompensiert werden und es zu einer zunehmenden Biomasse- und Landnutzungskonkurrenz kommt. Transformationsszenarien zu einer Bioökonomie müssen diesem Umstand Rechnung tragen. Es müssen sämtliche Nutzungsarten (Nahrungs- und Futtermittel, stoffliche und energetische Nutzung) berücksichtigt und ein ganzheitlicher Ansatz der THG-Bilanzierung („full carbon accounting") verfolgt werden.
Im Rahmen des Projektes „BioTransform.at" wurde analysiert, ob bzw. wie auf Basis inländischer Biomasse bis 2050 die Transformation zu einer „low-carbon bioeconomy" in Österreich möglich ist. Ergänzend zur technischen/bio-physischen Machbarkeit wurden auch sozio-politische Implikationen einer solchen Transformation untersucht.

Methodik
Zentrales Element des methodischen Ansatzes ist ein integriertes Optimierungsmodell, implementiert im Modellierungsframework „TIMES-VEDA". Darin werden alle relevanten Aufkommens- und Nutzungsarten von Biomasse und Umwandlungsprozesse (in der Tierhaltung, dem Nahrungsmittelsektor, der Herstellung konventioneller und fortschrittlicher biobasierter Produkte und der Energieversorgung) sowie das Energiesystem in seiner Gesamtheit abgebildet. Die geographische Systemgrenze ist Österreich und der Betrachtungszeitraum 2010 bis 2050. Als Zielfunktion wird die Minimierung der THG-Emissionen zugrunde gelegt, wobei dynamische Einschränkungen (in Bezug auf Anlagenzubau, Brennstoffumstellung, Technologiediffusion uvm.) und exogen vorgegebe Rahmenbedingungen einzuhalten sind. Ökonomische Aspekte werden außer Acht gelassen (spekulative Annahmen zu Preis- und Kostenentwicklungen bis 2050 sind damit hinfällig). Die resultierenden Szenarien stellen also keine kostenoptimalen Entwicklungspfade dar, sondern solche, die unter den gegeben Randbedingungen zur stärksten Reduktion an THG-Emissionen führen.
Zur Szenarienentwicklung ist eine profunde Kenntnis des Status quo der Biomasseflüsse in Österreich erforderlich. Aus diesem Grund wurde (auf Basis von Versorgungs- und Energiebilanzen, Außenhandels- und Produktionsstatistiken uvm.) ein vollständiges Biomasse-Flussbild erstellt, das zur Kalibrierung des Gesamtmodells herangezogen wurde. Einen weiteren zentralen Modellinput stellen Szenarien der Waldbewirtschaftung dar, die mit dem Simulationsmodell PICUS v.1.4 erstellt wurden und Zeitreihen der Biomasse-Aufkommensmengen und der Kohlenstoffbestände bis 2050 lieferten. Indikatoren für Ökosystem-Dienstleisungen, die für die Waldszenarien ausgewertet wurden, geben Aufschluss über Nachhaltigkeitsaspekte der unterschiedlichen analysierten Bewirtschaftungsszenarien.
Zukünftige Entwicklungen beim Energieverbrauch sind im Rahmen der Szenarienentwicklung weitgehend exogen vorgegeben, basierend auf dem Szenario „WAM plus 2015" (WAM+), das im Rahmen des nationalen THG-Monitorings erstellt wurde. Die Nutzung von Ackerflächen wird modellendogen festgelegt, wobei die Anforderungen der Ackerfrüchte, die natürlichen Gegebenheiten sowie Fruchtfolgebeschränkungen Berücksichtigung finden.
Rund 75 % der derzeitigen THG-Emissionen Österreichs sind im Modell abgebildet. Für die übrigen Kategorien werden die zukünftigen Entwicklungen gemäß dem WAM+Szenario unterstellt. In Bezug

auf Biomasse werden Emissionen aus Verbrennung und natürlichem Zerfall mit Kohlenstoffbindung durch Biomassewachstum gegengerechnet und so eine Netto-THG-Bilanz gebildet.
Sozio-politische Dimensionen wurden mit Hilfe von leitfadenbasierten Interviews und Stakeholder-workshops identifiziert und aus politikwissenschaftlicher Perspektive untersucht.

Ergebnisse und Schlussfolgerungen
Die mit dem Gesamtmodell erstellten Szenarien zeigen, dass die technische Machbarkeit einer Transformation zu einer „low-carbon" Bioökonomie auf Basis inländischer Ressourcen grundsätzlich gegeben ist – unter der Voraussetzung, dass der Energieverbrauch drastisch reduziert, die Nutzung anderer erneuerbare Energieträger stark ausgeweitet und Biomasse effizient eingesetzt wird. Es zeigt sich auch, dass hinsichtlich des Ausmaßes der Biomassebereitstellung und -nutzung recht unterschiedliche Entwicklungspfade möglich sind. Technisch wurde dies durch Variation der exogenen Annahmen für die Bereiche Ernährungsgewohnheiten, Nahrungsmittelverluste, Landnutzungsänderungen, Waldbewirtschaftung, landwirtschaftliche Ertragsentwicklungen und energetische Nutzung landwirtschaftlicher Reststoffe umgesetzt. Sowohl in einem in Bezug auf diese Parameter „intensiven" (Szenario B) als auch in einem „alternativen" Szenario (C) wird das Ziel einer THG-Reduktion von mindestens 80 % im Vergleich zur „Kyoto-Baseline" erreicht, nicht jedoch in einem Referenzszenario A. In Szenario B („Intensiv") erfolgt – in erster Linie durch Ertragssteigerungen und Mobilisierung landwirtschaftlicher Reststoffe für energetische und stoffliche Nutzung – eine Zunahme des Biomasseaufkommens von 2010 bis 2050 um rund 30 %. In Szenario C („Alternativ") beträgt die Zunahme hingegen nur 12 %; stattdessen erfolgt eine stärkere Reduktion des Konsums von Fleisch und Milchprodukten, von Nahrungsmittelverlusten und des Verlustes landwirtschaftlicher Flächen. In der Folge kann ein Gutteil der landwirtschaftlichen Primärproduktion in stoffliche und energetische Verwertungsschienen umgeleitet werden, und die mit Tierhaltung in Verbindung stehenden THG-Emissionen gehen deutlich zurück.

Die modellierten Auswirkungen des Klimawandels auf die land- und forstwirtschaftlichen Produktionspotentiale sind in Summe für Gesamtösterreich betrachtet gering. Allerdings wurden Störungen, die nach Expertenmeinung durch eine Zunahme an klimawandelbedingten Extremereignissen in Zukunft häufiger auftreten werden, nicht berücksichtigt. Die regional differenziert zur Wirkung kommenden Auswirkungen der analysierten Bewirtschaftungsszenarien zeigen, dass Vorrat und damit der gespeicherte Kohlenstoff sensitiv auf Bewirtschaftungsformen reagieren: In Bezirken mit Bergwäldern kommt es zu einer Zunahme der Vorräte, in Bezirken in Tieflagen zu einer Abnahme. Klimawandelbedingungen verstärken diese Effekte. Betrachtet man andere Waldökosystemleistungen wie etwa Schutzwirkung gegen gravitative Naturgefahren, zeigt sich ebenso ein differenziertes Bild. Es kann zu Zunahmen und Abnahmen kommen. Und es gibt Wechselwirkungen zwischen Bewirtschaftungskonzepten und Klimaeffekten. Besonders sensitiv reagieren Indikatoren, die Schutzwirkung gegen Steinschlag anzeigen. Hier kann es in klimasensitiven Regionen (tiefere Lagen, südliche und östliche Landesteile) durch verstärkte Baummortalität zu deutlich eingeschränkter Schutzwirkung kommen. Unter solchen Bedingungen müssten zur Aufrechterhaltung der vollen Funktionalität gezielte Bewirtschaftungsmassnahmen gesetzt werden. Der Stakeholderprozess offenbarte überaus kontroverse Standpunkte zum Thema Bioökonomie und den sozio-ökonomischen Implikationen einer Transformation. Die Notwendigkeit von Verbrauchsreduktionen wird in erster Linie von Vertretern aus Zivilgesellschaft und Forschung hervorgehoben, in nationalen Strategien werden Fragen der Suffizienz hingegen kaum thematisiert.

2 Executive Summary

Initial situation and research question

In the context of the EU's climate and energy targets as well as its ambitions to establish a bioeconomy until 2050, biomass will be of crucial importance; for reducing greenhouse gas (GHG) emissions and the dependence on fossil resources in energy supply as well as for replacing energy- and carbon-intensive products. A transformation towards a bioeconomy might lead to rising demand and competition for biogenic resources and increasing pressure on land; it might lead to land use change and result in environmentally harmful intensification of agriculture, possibly

resulting in an increase in non-energy related GHG emissions and a decline of natural carbon stocks.

It is therefore essential that long-term national scenarios toward bioeconomy transformation encompass all relevant GHG sources and sinks ("full carbon accounting") and all biomass uses (food supply, animal husbandry, material uses and energy generation). Following this principle, the project aims at answering the following core question: To what extent can domestic biomass contribute to the establishment of a low-carbon bioeconomy in Austria until 2050? This question is first answered in terms of technical/bio-physical constraints and then analysed regarding socio-political implications.

Methodology

The core element of the methodology is an integrated optimization model implemented in the programming environment "TIMES-VEDA". The subject of investigation includes all relevant types of primary biomass, conversion processes (wood processing industries and advanced biomaterial production, food supply, animal husbandry, energy generation) and a complete representation of the energy sector. The geographical scope is Austria and the considered timeframe 2010 to 2050. The optimization target is to minimize greenhouse gas (GHG) emissions under given dynamic constraints (imposing limits on fuel switch rates, technology diffusion, crop rotation and many more), while economic aspects are disregarded. This approach is appropriate for deriving scenarios with maximum emission reduction without the necessity to assume concrete policy measures and highly uncertain parameters like fuel and raw material prices or technology cost developments.

Input data to this "overall model" include statistical data derived from commodity balances, foreign trade, energy and production statistics and many more. Based on these data, a complete picture of biomass streams in Austria is prepared, illustrated as flow diagram and implemented in the model, as starting point for scenarios until 2050. Forest management scenarios, simulated with the dynamic forest ecosystem model PICUS v1.45 provide a set of ecosystem service indicators as exogenous parameters to the overall model. Future development of energy consumption is also basically predetermined exogenously, following the 2015 "WAM plus scenario" (WAM+) developed in the context of Austria's GHG reporting obligation. The structure of arable land use (crop shares) is endogenous, but subject to constraints imposed by natural conditions (generated with a GIS-based approach), requirements of crops and crop rotation.

GHG emission categories comprising about 75 % of Austria's current emissions are considered in the model. Projections for the remaining categories are adopted from WAM+. Regarding biomass, net GHG emissions are calculated as the balance of CO_2 removals due to biomass growth and emissions from combustion and decay.

Stakeholder perceptions and socio-political aspects are investigated via stakeholder interviews and workshops, and are systematically analysed and discussed using discourse theory and interpretative policy analysis as a methodological framework.

Results and conclusions

The overall scenarios demonstrate that transformation to a low-carbon bioeconomy until 2050 is technically feasible without increasing net biomass imports; but only if energy consumption is reduced significantly, other renewable energy sources are employed intensively and biomass and bioenergy are utilized in an efficient way. The scenarios also illustrate that – with regard to biomass supply and consumption – quite different pathways are possible. Technically, this has been achieved by exogenously assuming different future developments in dietary habits, land use change, forest management, average crop yields, food losses and bioenergy from crop residues. GHG reductions of at least 80 % compared to Austria's Kyoto baseline are achieved in an "intensive" as well as an "alternative" scenario with regard to these parameters: In Scenario B ("Intensive") large additional amounts of biomass are mobilized. Total domestic biomass consumption increases by more than 30 % from 2010 to 2050, mainly due to yield increases and an enhanced use of crop residues for energy and material uses. In Scenario C ("Alternative") the increase is only 12 %, but due to a greater shift towards no- and low-meat diets, lower food losses and reduced loss of agricultural land, primary biomass can be diverted to bioenergy and

biomaterials production. GHG emissions related to food supply (or rather animal husbandry) are also clearly lower in C than in B. Scenario A is a reference scenario where the "-80 %-target" is not achieved.

Effects of the assessed climate scenarios on domestic wood supply and agricultural production potentials are moderate on aggregated national scale. However, more distinctive positive and negative effects are discernible on regional scale. The inclusion of natural disturbances (which have not been considered in this study) may lead to additional negative impacts under conditions of climate change. Climate change adaptation through targeted forest management practices can yield positive medium- to long-term effects on ecosystem services.

Stakeholder positions are characterized by a wide range of socio-political visions of bioeconomy transformation. Visions presented in strategy papers of state authorities do not sufficiently reflect a need to reduce consumer demand. Public discourse should therefore be opened up to include issues of sufficiency.

3 Background and objectives

With its 2011 'Low Carbon Roadmap' [1], the European Union has committed itself to establish a low-carbon economy until 2050. Starting with 1990 as base year, the roadmap shows a pathway towards an 80% reduction in domestic greenhouse gas (GHG) emissions by 2050. Furthermore, in February 2012 the EU launched a strategy for "A Bioeconomy for Europe" [2], which aims at driving the transition from a fossil-based economy to a sustainable bioeconomy. This strategy addresses crucial societal challenges such as food security, natural resource scarcity, dependence on fossil resources, climate change and sustainable economic growth. The 'bioeconomy', according to the strategy, encompasses 'the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy' [2].

Biomass will be of crucial importance for reducing GHG emissions and the dependence on fossil resources; not only in energy supply – as the EU's 'Energy Roadmap 2050' [3] and the National Renewable Energy Action Plans indicate (cf. [3], [4]) – but also with regard to the replacement of energy- and carbon-intensive products. Already today forestry and the wood processing industries are key elements of Austria's economy. Biomass is currently the most important renewable energy source [5] and is usually considered to be of high importance for the establishment of a sustainable energy system (cf. [6], [7]).

A transformation towards a bioeconomy might lead to rising demand for biogenic resources and increasing pressure on land; it might promote land use change and result in environmentally harmful intensification of agriculture, possibly resulting in an increase in non-energy related GHG emissions and a decline of natural carbon stocks (cf. [8]). It is therefore essential to apply a model with full carbon accounting (cf. [9], [10], [11], [12]) and consider all relevant GHG sources and sinks, namely emissions from agriculture, land use, land use change and forestry (LULUCF) as well as artificial carbon stocks like wood products.

While EU documents and accompanying studies provide some insight into transformation 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) and the possible contribution of locally available biomass resources. This work aims at contributing to fill this research gap by answering the following core question: **To what extent can domestic biomass contribute to the establishment of a low-carbon bioeconomy in Austria until 2050?**

To this end, it is investigated whether pathways leading to a reduction of GHG emissions by at least 80 % are feasible without an increase in biomass net imports. Austria's base year emissions under the Kyoto Protocol, which correspond to the historical GHG emissions in 1990 without consideration of LULUCF, are considered as the reference level. Apart from an 80 % reduction of GHG emissions, a significant increase in biomass use as material as well as enhanced cascading utilization chains are envisaged, in order to justify the term 'bioeconomy transformation' (cf. [2]).

4 Contents and results of the project

Methodology

The core element of the methodology is an integrated optimization model ("overall model") comprising all relevant types of primary biomass, conversion processes (wood processing industries and advanced biomaterial production, food supply, animal husbandry, energy generation) and a complete representation of the energy sector. The model was implemented in work package 5 (WP5). WP2 and WP3 mainly included preparatory work, such as providing input data and exogenous scenarios to the overall model. However, most results from these work packages deserve separate attention and are therefore included as separate sections of chapter 2.2.4 (Results).

In addition to the modelling approach, covering the technical/bio-physical aspects of a bioeconomy transformation, social aspects, barriers and opportunities were investigated via stakeholder involvement and systematically analysed in terms of institutional and political theory (WP4). WP6 was dedicated to drawing conclusions and recommendations (see 2.3). An in-depth analysis regarding the efficiency of material substitution with biomass in GHG mitigation was also carried out within this work package.

Modelling environment of the overall model

The overall model is implemented in the programming environment of TIMES-VEDA (cf. [13], [14], [15]). The TIMES model generator (The Integrated MARKAL-EFOM System) was developed for deriving long term energy scenarios and conduct energy and environmental analyses. It uses linear programming to generate a least-cost energy system, optimized according to certain constraints, in order to explore possible energy futures based on scenarios [13].

The optimization target of the presented modelling approach is to minimize GHG emissions. This approach is appropriate for deriving scenarios with maximum emission reduction without the necessity to assume concrete policy measures and highly uncertain parameters like fuel and raw material prices or cost developments for conversion technologies. In the resulting scenarios, biomass is utilized in a way that is most efficient in reducing GHG emissions under the given constraints. Certain constraints are equal in all scenarios, such as dynamic constraints on technology diffusion, on fuel switch and market diffusion of individual bio-based products. Others are scenario-specific parameters (see section below).

The time resolution of the model is 5 years, with three time slices for the seasonal and two for the day-night level (cf. [15]). These 'sub-annual' time slices are, however, only relevant for the electricity and the district heat sector, where generation profiles (especially from fluctuating renewable energy sources) and consumption patterns (load profiles) are relevant for capacity utilization and plant deployment.

Agricultural biomass supply and use in the scenarios is to a large extent determined by food and feed requirements, which by convention must be satisfied without increasing imports. Yield development and dietary habits are the main factors determining the agricultural land resources available for growing crops for bioenergy and material uses. How the remaining land and biomass resources are utilized is determined endogenously based on GHG balances of the value chains and their fossil-based counterparts.

Structure of the overall model and data

The model comprises two main elements: An 'energy module', which is a representation of the Austrian energy system, and a 'biomass module', which includes all relevant aspects of biomass supply, processing and consumption. The two modules are interlinked in several ways: through biomass being used in the energy sector (i.e. being converted from mass to energy flows), through biofuel plants producing animal feedstuff as by-product or industrial energy demand depending on developments in wood processing industries.

The scope of the biomass module goes beyond technical uses of biomass (i.e. for energy or materials) but also considers biomass flows induced by food consumption. For this purpose, specific per capita diets, such as vegetarian or reduced meat diet have been defined according to

dietary guidelines [16] as well as their relative shares within the population (cf. supplementary material). As for other categories this final demand is converted into a corresponding demand for primary biomass, based on different conversion factors, in particular feed balance sheets. Primary biomass supply is linked to representations of agricultural land use, land use change and forest management.

The base year is 2010. Biomass flows and foreign trade streams, energy supply and consumption, installed plant capacities, land use structure etc. are calibrated to statistical data. The main data sources for the energy module include the national energy balance [5], the 'useful energy analysis' [17] and statistical data provided by the Austrian energy regulator [18]. Data used for calibration of the biomass module are from foreign trade statistics [19], commodity balances [20] statistics on agricultural production [21], on wood supply and consumption [22] and many more. Sources regarding biomass flows are to a large extent identical to the data used to map biomass flows in Austria in [23]. A complete list of data sources is provided in this publication.

Data for 2015 have not been available at the time the simulations were carried out. However, certain developments from 2010 to 2015 have been defined exogenously based on projections derived from developments until 2014. This approach ensures that relevant trends which took place after 2010 are represented in a realistic way. The following sectors and flow data are predetermined until 2015: the bioenergy sector (generation capacities and utilization), wood flows (production and consumption of the wood processing industries), bio-based product supply and consumption (biopolymers, bio-based insulation material etc.) as well as individual parameters in other sectors. Data on life-cycle emissions of conventional and bio-based products have been adopted from publicly available databases ([24], [25]), scientific publications ([26], [27]) and environmental product declarations ([28], [29]).

Projections for biomass supply

Forest management scenarios are simulated with the dynamic forest ecosystem model PICUS v1.45 [30,31] (see below). The simulation results – time series for wood removals (differentiated by wood assortment classes) and forest stock development (and corresponding net carbon sequestration or emissions) – are exogenous parameters to the optimization model. Impacts of forest management on ecosystem services indicators are analysed for each management scenario, in order to quantify broader sustainability aspects of different management practices (see below). Effects of climate change on wood supply quantities and carbon stock developments are also analysed.

The structure of arable land use (crop shares) is endogenous, but subject to constraints imposed by natural conditions and requirements of crops. The data on natural conditions are generated with a GIS-based approach [32] and subsequent clustering of the present agricultural land into classes with specific suitability profiles. GIS data have been obtained from the Digital Soil Map of Austria (cf. [33], [34]) and climate data from the project 'Safe our Surface' [35]. Crop requirements are based on the FAO's 'Ecocrop database' [36]. Land use change between agricultural land (arable land, extensive and intensive grassland, mountain pastures), forest land and settlement areas is predetermined exogenously, based on historic developments and scenario assumptions regarding policy intervention.

Energy demand in the various sectors is also mostly predetermined exogenously on the level of final energy consumption, based on the scenario "WAM plus 2015" (WAM+) developed in the context of Austria's GHG reporting obligation.

Greenhouse gas accounting

GHG emissions are evaluated according to the IPCC's common reporting framework (CRF). The CRF categories represented in the model are CRF1A (Energy; excluding fugitive emissions), CRF3 (Agriculture) and CRF4 (LULUCF). GHG accounting is partly implemented in the biomass module and partly in the energy module. Following a 'full carbon accounting principle', the GHG balance of biomass utilization is calculated as the balance of GHG removals (due to carbon sequestration in forest wood, agricultural crops etc.) and emissions (from biomass combustion and natural decay). Carbon sequestration or emissions due to carbon stock changes in forests and artificial carbon

pools are therefore fully incorporated, and accounting of harvested wood products according to IPCC Guidelines [37] is obsolete. GHG emissions/removals due to land use changes are calculated based on functions that consider typical amounts of carbon stored in biomass and soil per unit area. These functions are calibrated with information from [38] and [39]. Calculation of GHG emissions from agriculture (manure management, enteric fermentation, soils etc.) is based on emission factors derived from [38] and linked to livestock and crop production. Options for reducing specific GHG emissions (per livestock unit etc.) by changing agricultural practices are thereby neglected. Default emission factors according to IPCC Guidelines [40] are applied in the energy module.

According to Decision 2/CMP.7 [41], accounting of forest management in the second commitment period of the Kyoto Protocol shall be done on the basis of a Forest Management Reference Level (FMRL) [37]. The FMRL is a value of net emissions/removals against which the actual net emissions/removals are compared. Since no FMRL has been defined for the timeframe beyond 2020 (cf. [42]), it is not possible to calculate emissions/removals from forest management for scenarios until 2050 in a way consistent with IPCC Guidelines.

Instead, the forest carbon stock in the base year 2010 is considered as reference value and net carbon stock changes between the base year and each model year translated into average annual CO_2 emissions/removals It is reasonable to determine average values, because carbon stock changes often vary considerably from one simulation period to the next.

Forest management scenarios and ecosystem service indicators

Austria´s forests as well as ownership structure are complex. To represent forest conditions in Austria 42 mixture types were derived from the Austrian Forest Inventory (AFI). These 42 mixture types were spatially modified. In total 2749 different forest simulation entities represent Austria´s forests in the initial year of analysis (2000). Three ownership categories were distinguished: small-scale owners A and B (assuming contrasting management intensity), and large-scale owners including the Austrian Federal Forests (ÖBf AG). For each of the three owner categories three different general approaches were defined: BAU (business as usual management), AM1 (alternative management 1, aiming at increased stocks in mountain forests), AM2 (Alternative Management 2, aiming at conversion of secondary conifer forests in lowlands into either Douglas fir forests or mixed broadleaved forests depending on site conditions). The three management regimes were operationally defined for each of the 42 mixture types over a time period of 100 years.

These management regimes for different owners and forest types were then combined with utilization scenarios which defined the share of the forest in each ownership category which were actually managed. Three of such utilization scenarios were defined (high, standrad, low) based on general information from the AFI and related national literature.

The main ecosystem services in this study were biomass production and carbon sequestration. Additionally, a focus was on protective services against gravitational hazards (avalanches, landslides, rockfall). Table 1 displays used indicators and provides a brief description.

Table 1. Indicators used for describing ecosystem services [58].

Acronym	Description
Biomass harvest	Harvested quantity roundwood and other biomass assortments, structured into conifers, broadleaves and dimensional assortments [m^3]
Carbon	C-Pools in living tree biomass and deadwood [t]
BA	Basal area of living trees in 130cm height above ground **[m²/ha]**
BHD	Mean diameter at breast height in 130cm height above ground (BHD); **[cm]**

Acronym	Description
DSP	Tree species diversity calculated as "True Diversity" according to [59] for all trees >5cm BHD. $DSP = \exp(H)$ $H = -\sum_{i=1}^{S} p_i \ln(p_i)$
DSI	Structural diversity calculated as mean of horizontal and vertical diversity. We used BHD categories of 4cm width, height classes of 2m width for trees larger 4m in height. $DSI = \frac{H_{DBH} + H_H}{2}$ $H_{DBH} = -\sum_{m=1}^{N_{DBH}} p_m \ln(p_m)$ $H_H = -\sum_{n=1}^{N_H} p_n \ln(p_n)$
Canopycover	Crown cover percentage as area share covered by tree crowns from trees with BHD>5cm.
LPI	Landslide protection index: **(1) bad:** Canopycover < 30% **(2) moderate:** 30% ≤ Canopycover < 60% **(3) good:** Canopycover ≥ 60%
API	Avalanche protection index: based on [60] and [61]. The index varies between 0 und 1, (1 represents maximum protection). For evergreen stands: $API = \min\left[\frac{G}{(0.2901 * \overline{DBH} + 1.494) \times (0.1333 * s - 3)}; 1\right]$ For sommergreen stands and mixed stands (incl. larch): $API = \min\left[\frac{G}{(0.2901 * \overline{DBH} + 1.494) \times (0.1333 * s - 3)}; 1\right]$
RPI	Rockfall Protection Index: based on Rockfornet [62, 63]. A value of RPI = 0.99 means that 99% of all rocks passing a forest patch will be stopped assuming 250m slope length.
BBgen	Number of fully developed beetle generations (*Ips typographus L.*) per year [n]
Bbvol	Damaged timber volume by bark beetle infestations [Vfm ha^{-1} yr^{-1}]
Rejuvenation (0-5cm BHD)	Stem number per hectar in BHD-categories 0 - 5cm

Results

Current biomass streams in Austria (WP2)

An objective of WP2 was to map biomass streams within the Austrian economic system, taking into account all types of uses. Contrary to material flow accounts (MFA), internal streams (e.g. due to biomass processing and transformation, recycling and reuse of residues and by-products, stock

changes of end-consumer products) were explicitly taken into consideration and quantified. This approach revealed gaps and inconsistencies in statistical data, facilitated conclusions about quantities not recorded in statistics and was an important step towards scenario development.

The following figure shows one of the main results: The biomass flows in Austria's national economy in 2011 in tonnes of dry mass. The same diagram is available on wet mass basis (see D 2.2/[23]).

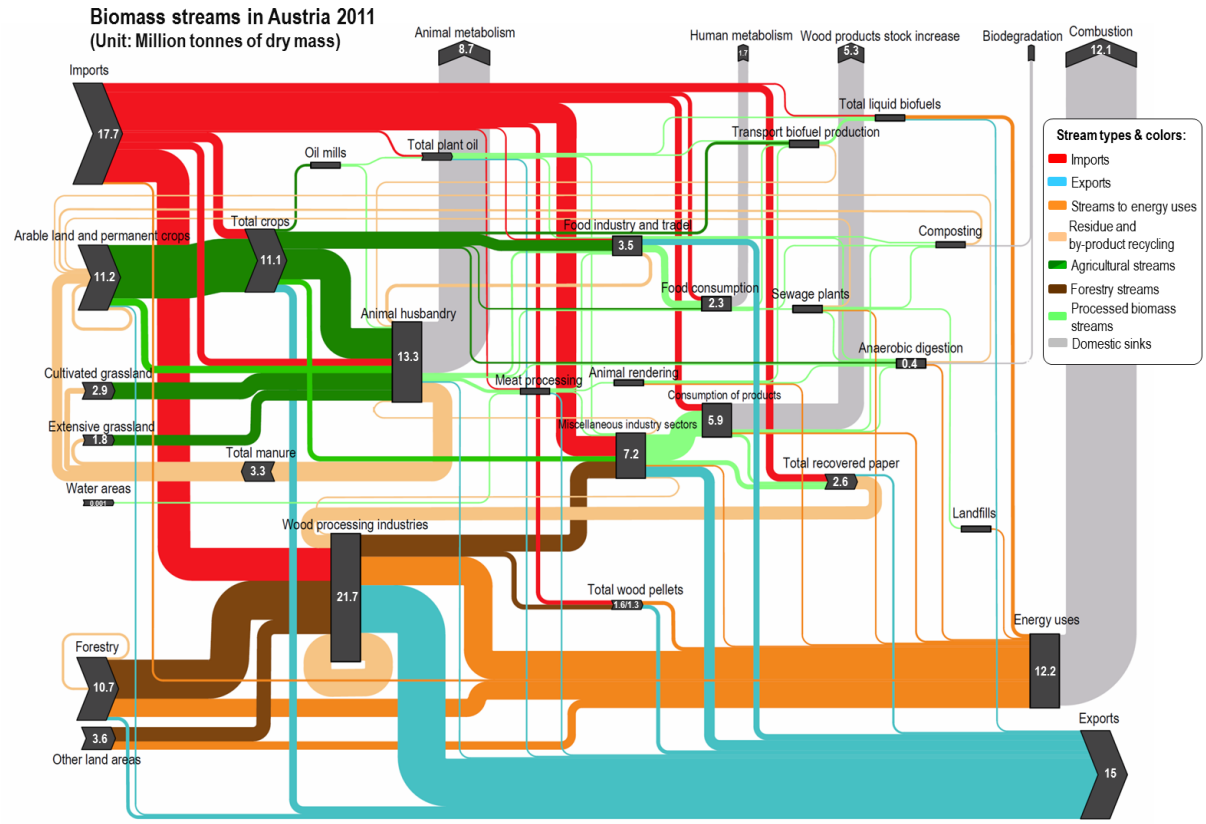

Figure 1. Dry biomass streams in Austria in the year 2011

Scenarios towards bioeconomy transformation ("main scenarios")

Exogenous scenario assumptions

Numerous exogenous scenario assumptions and developments are adopted from an existing scenario titled "WAM plus 2015" (WAM+), which has been developed in the context of Regulation (EU) 525/2013 [44]. (The scenario name suggests that it is even more ambitious than a scenario **w**ith **a**dditional **m**easures.) The rationale behind this approach is to facilitate direct comparability with national scenarios which are widely accepted, to be able to focus on biomass-related issues and not overburden the present scenario development with the whole spectrum of possible developments in the energy sector.

Although developed in the context of Austria's GHG reporting obligation, the **WAM+Scenario** is not included in the official report [45], but described in a separate document in German language only [46]. Data tables on exogenous scenario developments and underlying sector-specific storylines and modelling approaches are therefore provided in the supplementary material.

Exogenous scenario assumptions and developments adopted from the WAM+Scenario include energy demand, economic and population development as well as future deployment of renewable energy technologies with the exception of bioenergy. The scenario assumes very ambitious energy efficiency and renewable energy policies, rising environmental awareness and a general trend to sustainable development.

In contrast to significant growth of most renewable energy technologies like wind and solar power, biomass consumption for energy declines considerably until 2050 in the WAM+Scenario. This is partly explained with an increasing biomass demand for material uses. However, considering that bioenergy in Austria is largely based on by-products and residues, and the fact that the share of biomass ending up in products is relatively small in comparison to total biomass use (cf. [23]), increasing consumption of bio-based products may well be accompanied by a growing bioenergy sector. This has not been investigated in detail in the WAM+Scenario, as its focus was on the energy sector. With the integrated modelling approach presented here, it is possible to carry out in-depth analyses regarding future pathways for biomass production and utilization. Therefore, developments in bioenergy use are not adopted from the WAM+Scenario but are subject to the model's optimization algorithm, and fossil fuel substitution and GHG mitigation in the energy sector can differ significantly in the WAM+ and the scenarios presented here.

Scenario-specific settings

Three scenarios are presented. Since bioeconomy transformation in the context of this work is intended to be established without additional biomass imports, a general assumption for all scenarios is that imports of each biomass commodity remain constant at the level of the respective calibration year. The same assumption is made for exports, meaning that the **external trade balance of each biomass commodity remains constant**. This assumption is considered suitable for investigating the core questions of the project.

The scenarios differ in terms of six influencing parameters relevant for the future supply potential and demand for domestic biomass. The developments of these parameters include trend extrapolations and business as usual assumptions on the one hand, and more speculative assumptions considered feasible in case of targeted policy intervention on the other. These exogenous parameters are developments in dietary habits, land use change, forest management, average crop yields, food losses and assumptions regarding bioenergy production from crop by-products (which represent a considerable unused potential for energy production).

Scenario A ('Reference') is considered as a scenario in which the main historical trends concerning these parameters will remain unchanged until 2050; i.e. no serious initiatives or policy intervention take place to reduce food losses, change dietary habits and to utilize crop by-products for energy; average crop yields continue to increase, albeit only moderately. In scenario B ('Intensive') higher agricultural yield increases and additional wood removals from small private forests are assumed, and crop by-products are assumed to be available as bioenergy source. Scenario C ('Alternative') is characterized by the aim to avoid intensification in biomass production. This is implemented as a more pronounced shift to healthy and no- or low-meat diets compared to Scenario A and B, reduced land use change after 2020, reduced food losses, constant average crop yields and forest management with longer rotation periods. These exogenous scenario parameters are summarized in Table 2.

Table 2. Scenario-specific exogenous parameters

Exogenous scenario parameters	**Scenario A: 'Reference'**	**Scenario B: 'Intensive'**	**Scenario C: 'Alternative'**
Dietary habits	Trend (slight reduction in average meat consumption)		More pronounced shift to healthy and no/low-meat diets
Land use change (between forest, arable land, grassland types and settlements)	Trend (cf. supplementary material to D 5.2)		LUC reduced by 50 % during 2021 to 2030; no more LUC between land categories after 2030
Forest management	'Business as usual'	Increased removals from small private forests	Longer rotation periods than in BAU
Average crop yields	Moderate increase	Significant increase	constant
Food losses	Constant		Reduction by 50% until 2050

Exogenous scenario parameters	Scenario A: 'Reference'	Scenario B: 'Intensive'	Scenario C: 'Alternative'
Crop by-products used for energy	NO	YES	NO

Simulation results

The **GHG** categories – following the IPCC's common reporting framework (CRF) –represented in the model are CRF1 (Energy), CRF3 (Agriculture) and CRF4 (LULUCF). These categories accounted for about 47 Tg CO_2-equ. in Austria's Kyoto base year 1990 and between 55 to 64 Tg CO_2-equ./a during the latest ten years available in statistics [47]. Around 75 % of Austria's total GHG emissions are attributable to these categories.

In Scenario A they decrease to 38.6 Tg CO_2-equ. in 2030 and 11.8 Tg in 2050 (Fig. 2, left). This corresponds to a reduction by 17 % and 75 %, respectively, compared to 1990. In Scenario B the emission reduction in the considered CRF categories in 2050 is 87 % and in Scenario C 92 %. By comparison, the reduction achieved in the WAM+Scenario until 2050 is approximately 50 %.

Assuming GHG emission developments in CRF1B, CRF2 and CRF5 according to the WAM+Scenario (cf. [46]), pathways for total GHG emissions are derived (Fig. 2, right). In 2030 total emission reductions relative to the Kyoto base year emissions [48] are in the range of 34 to 38 %. In 2050 they are 72 % in Scenario A, 80 % in Scenario B and 83 % in Scenario C. Hence, the intended emission reduction target is achieved in the 'intensive' as well as in the 'alternative' scenario.

In contrast to the WAM+Scenario, Scenario A, B and C show a temporary increase of GHG emissions until 2020. This comes from the forestry sector and is due to the age structure of Austrian forests in combination with management practices assumed in the simulations with PICUS. Due to different scenario-specific assumptions regarding management practices, net GHG emissions/removals in 2020 vary between the scenarios, but in every case harvesting rates are projected to temporarily exceed the wood increment around 2020. Such a trend is also assumed in the FMRL projection [37]. On the longer term, forests again become a net GHG sink in all scenarios.

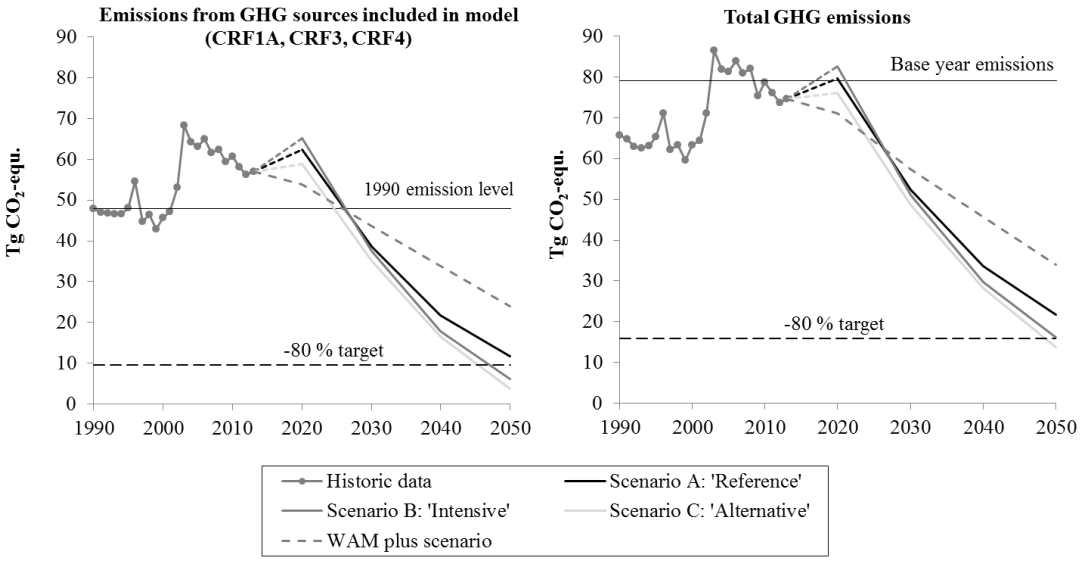

Figure 2. Development of GHG emissions in the scenarios

Due to high energy efficiency gains assumed, all three scenarios show a significant reduction in **primary energy consumption** after 2015 (Fig. 3): From about 1,270 PJ to 770 PJ in 2050. In Scenario A the share of biomass increases from 20 % in 2015 to 34 % in 2050. In Scenario B and C the biomass share in 2050 is 44 % and 41 %, respectively. Liquid fossil fuels and natural gas show the most pronounced decrease in absolute numbers; partly due to reduced energy consumption and partly due to fuel substitution with biomass. Replacement of natural gas with bio-

based gases is clearly higher in Scenario B and C than in Scenario A (cf. Fig. 5), because more arable land is available for energy crop production in these cases. Coal is practically phased out in all scenarios, while the overall share of the renewable energy sources hydropower, ambient energy, wind and solar power increases to more than 40 % in all scenarios. The decline of the non-biomass fraction of municipal solid waste (MSW) is especially pronounced in Scenario B and C, as fossil-based products and material is replaced with bio-based equivalents (cf. Fig. 6), creating a shift in the structure of MSW.

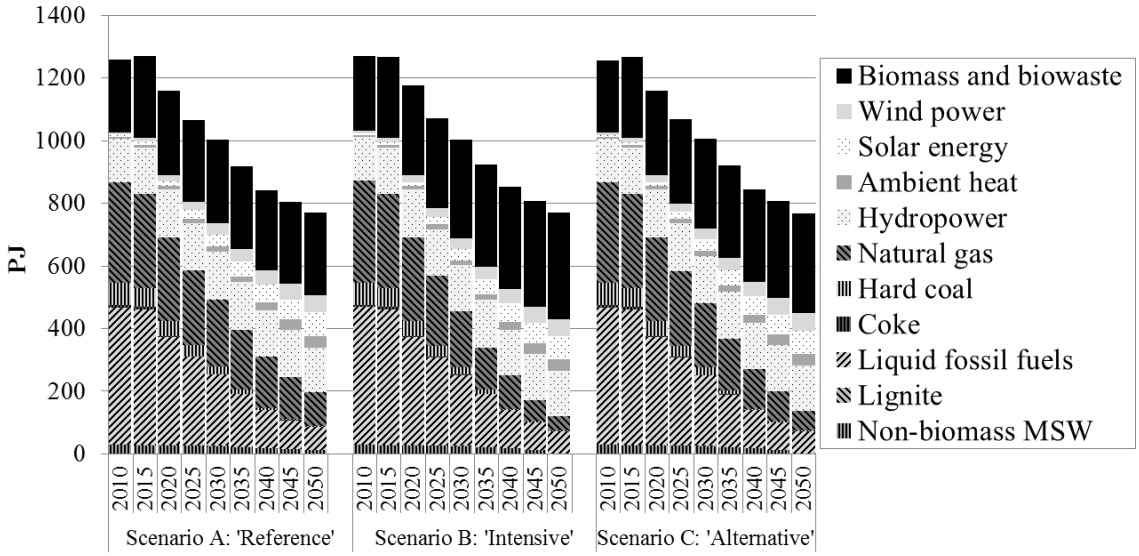

Figure 3. Development of primary energy consumption for in the scenarios

Fig. 4 shows the development of **total domestic biomass use** as food, feed, energy and material (see [23] for a detailed analysis of the status quo of biomass use in Austria). "Food" includes all biomass intended for direct human consumption, so the reduction in food losses in Scenario C is reflected in the figure. "Feed" is broken down by field crops being directly used as animal feed, biomass from grassland and by-products (like press cake or ethanol by-products). In Scenario A and B small reductions in average meat consumption are compensated by population growth, so total biomass consumption for food and feed remains almost constant. Scenario C shows a decrease in feed consumption by about 30 %, due to a greater shift towards no- and low-meat diets.

Biomass used for energy is broken down by forest wood-based fuels and other resources (biogenic waste, agricultural crops and by-products) in Fig. 4; the increase in bioenergy is almost exclusively based on the latter in all scenarios. Wood processing residues are partly diverted to material uses (mainly the production of insulating boards), resulting in a relatively constant consumption of forest wood for energy.

The share of material in total biomass consumption increases from 17 % in 2010 and 2015 to 23 % in Scenario A, 21 % in Scenario B and 26 % in Scenario C until 2050. As a consequence of more resource efficient diets and reductions in food losses, the total increase in biomass consumption is significantly smaller in the 'alternative' scenario than in the 'intensive' scenario. This result underlines the high resource efficiency of no-meat and 'healthy' diets in comparison to the meat-rich diet of an average Austrian. Dietary habits could apparently be an important lever to reduce pressure on land use intensification in a bioeconomy transformation.

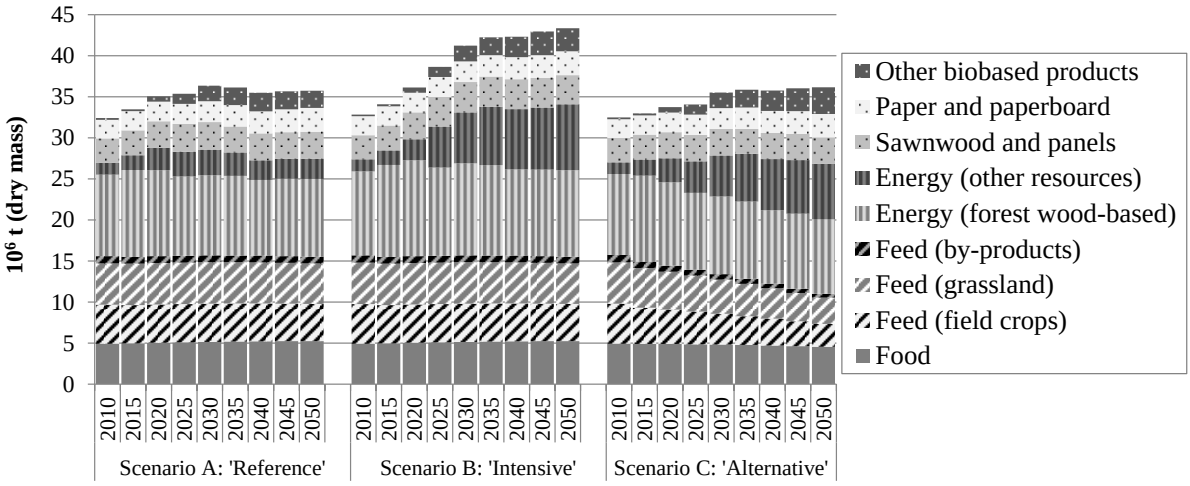

Figure 4. Development of total biomass use in the scenarios

The following figures show the developments in **domestic biomass consumption for energy** (Fig. 5) **and material uses** (Fig. 6) in more detail. Regarding bioenergy, a prominent trend common to all scenarios is the shift towards higher refined fuels such as lignocellulose-based transport fuels and natural gas substitutes (biomethane from anaerobic fermentation, synthetic natural gas from biomass gasification), while the shares of 'wood log' and 'wood waste' (forest wood chips, industrial wood residues etc.) decline significantly. The main reason is that conventional biomass use for residential heating is becoming less important due to rapidly improving thermal quality of the building stock, and biomass is increasingly used for fuel substitution in the transport and industry sectors.

Biogenic natural gas substitutes injecting into the grid provide an opportunity to make use of existing infrastructures and facilities (especially in industry) and improve the flexibility of bioenergy (temporally and in terms of application fields). Liquid second generation biofuels primarily replace fossil fuels used in heavy-duty transport, where options for electrification and modal shift are most limited. Conventional liquid biofuels are almost entirely replaced by second generation biofuels on the longer term in all scenarios. The bioenergy developments in the three scenarios mainly differ regarding the contribution of biomethane and in terms of the amount of black liquor and straw used for energy.

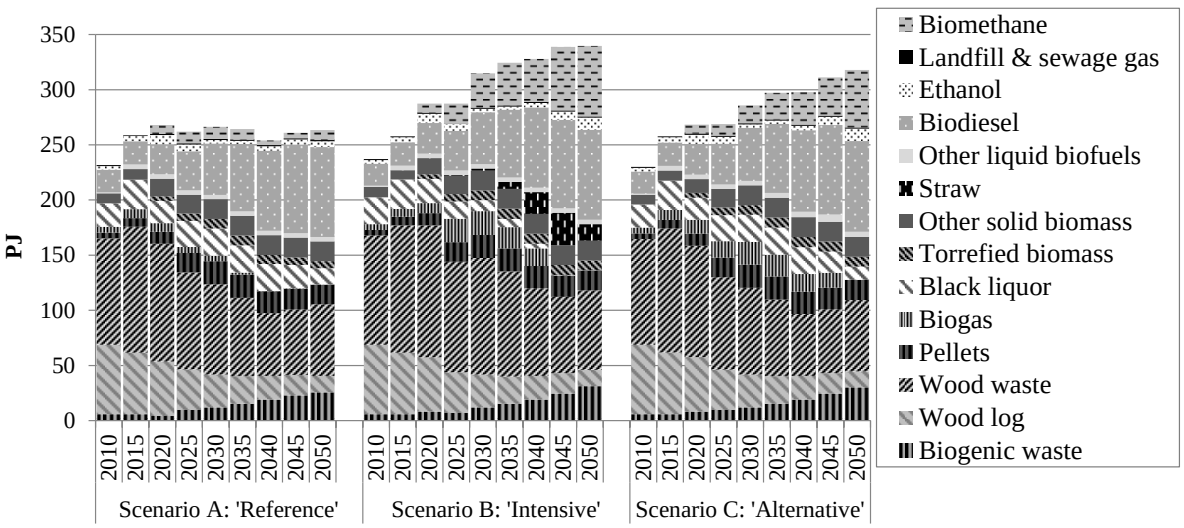

Figure 5. Development of biomass use for energy in the scenarios

Material use of biomass is currently dominated by conventional wood uses (sawnwood and wood panels) in building construction, packaging, furniture manufacturing etc. as well as paper and paperboard. In the scenarios other uses become increasingly important, especially insulation material and bioplastics made from sucrose and glucose. Further applications, which are less relevant in terms of raw material consumption, include plant oil used as lubricant, for detergents and surfactants, lignin used as asphalt binder and different conventional uses of starch (as additive in paper production and other manufacturing processes). Fig. 6 shows the development of domestic consumption for these applications. The relative increase in total biomass used as material until 2050 ranges from 50 % in Scenario A to about 70 % in Scenario B and C. The main differences between the scenarios arise from domestic wood supply and availability of arable land for biomaterial production.

'Material substitution' is often highly efficient in reducing GHG emissions (cf. [49], [50], [51], [52]). The carbon storage effect and the fact that cascading biomass use (e.g. energetic use of bio-based products ending up as biogenic waste) is usually more efficient in GHG mitigation than direct combustion of biomass are the main reasons why growth rates in material uses are generally higher than in bioenergy in the scenarios.

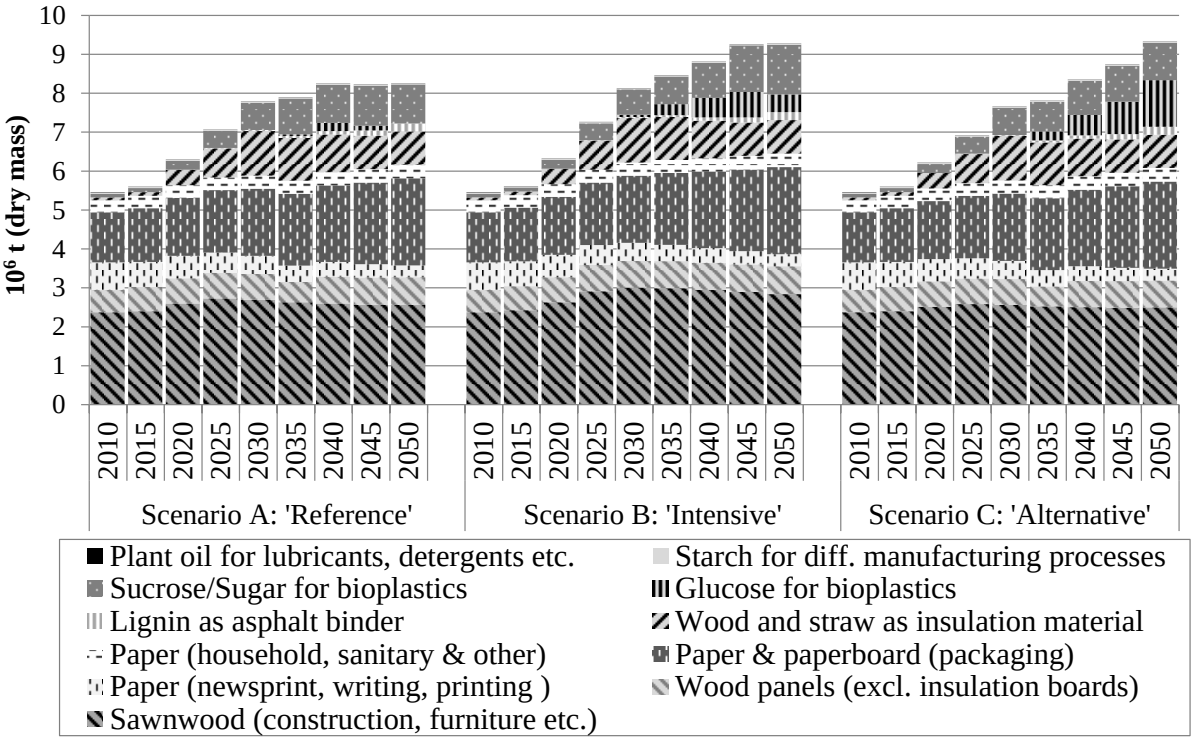

Figure 6. Development of biomass consumption for material uses in the scenarios

Discussion and interpretation of the scenarios

With the definition of GHG emissions (instead of aggregated costs) as optimization target, economic aspects are disregarded in scenario development. Hence, technologies and value chains which are effective in reducing GHG emissions are deployed regardless of their economic performance. Several conversion technologies which are vastly applied in the scenarios would certainly require considerable financial support, even if strong technological progress is achieved (cf. [8]) and fossil fuel prices rise significantly (e.g. the production of natural gas substitutes and second generation biofuels). A critical aspect with regard to competitiveness of such technologies is the relatively high share of feedstock costs in total production costs (cf. [53]) – In the context of a bioeconomy transformation with rising demand for biomass for various applications, it is questionable whether biomass or fossil fuel prices will grow at a higher rate. A strong fiscal

instrument in the form of a general GHG tax could be an effective way to overcome this difficulty and maybe stimulate a development similar to the presented scenarios. If or how such an instrument could actually be implemented is beyond the scope of this work; but there are several obvious reasons that implementation on a purely national level is highly unlikely.

Considering the sheer number of technologies, applications and products, it is clear that the presented modelling approach is only feasible at a high aggregation level and that it is not possible to consider all types of products and value chains. The aim was to focus on those which are likely to be of some significance from a quantitative point of view; the identification and selection of such value chains is a challenge by itself and does of course have an impact on model outcomes. Especially with regard to material uses, the results presented here are intended as a first, yet very important step towards bioeconomy scenario development on a national level. Only with such an integrated approach it is possible to capture the complexities and sectoral interdependencies that are inherent to strategic bioeconomy research.

Spatial visualisation of agricultural land use and conflict potentials (WP4)

Based on the agricultural production in the main scenarios at the end of the simulation period, spatial maps for optimal land use have been prepared. Fig. 7 shows an exemplary map for Scenario B. The maps illustrate a spatial distribution of crops on arable land and of grassland (intensive or extensive; mountain pastures are not included) which is in accordance with natural conditions (temperature, precipitation, soil depth, slope etc.) and crop requirements.

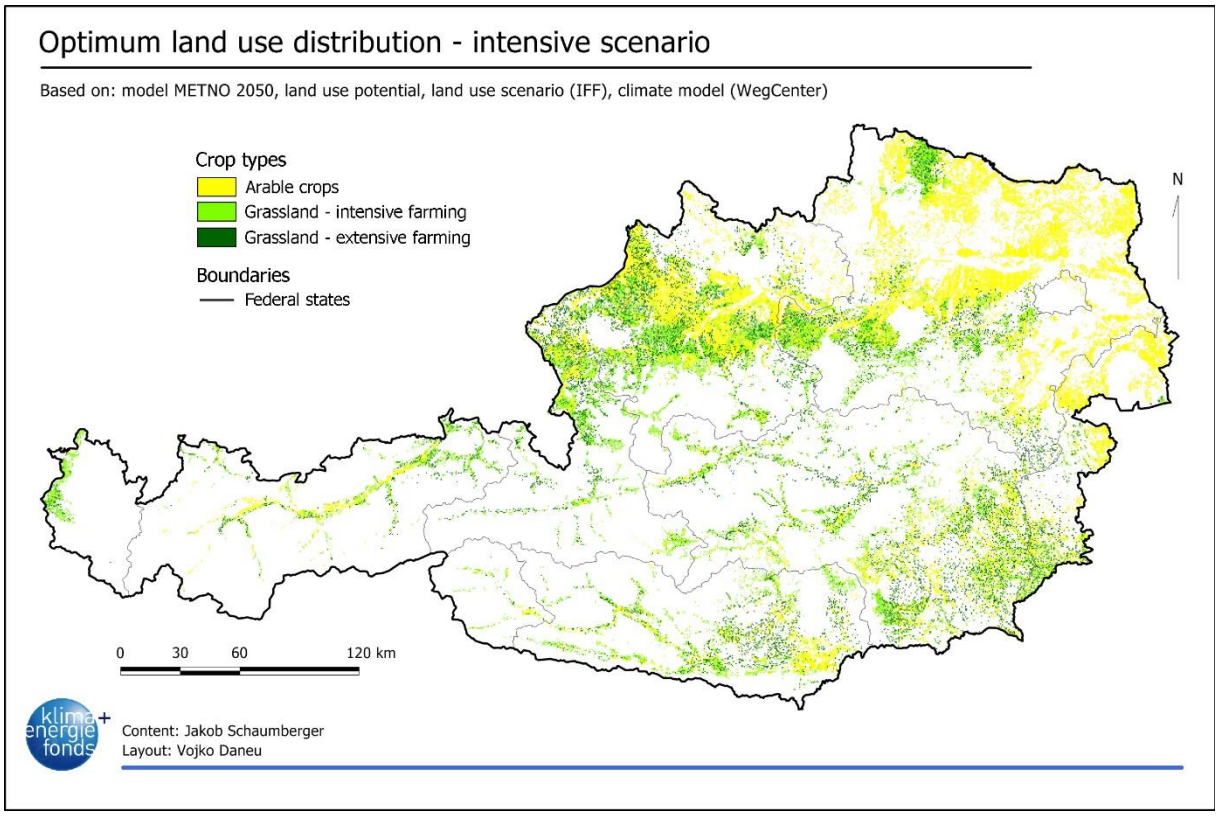

Figure 7. Optimum land use distribution for Scenario B "Intensive"

Within the scope of this project the term "conflict potential" is defined as potential of conflict which arises if several crops with high values of land use potential compete for the same location. Such valuable locations can be cultivated with various different crops - the decision in favour of a particular crop will prevent the cultivation of another crop. If cultivation area is scarce then a conflict situation is created particularly in this area.

The conflict potential was calculated for each grid cell for the final 10-year-period of the considered timeframe (2041-2050) for two climate scenarios ("ETHZ" and "METNO"). Fig. 8 shows the result for the climate scenario "METNO". Locations with high/very high conflict potential as depicted in red and purple colour.

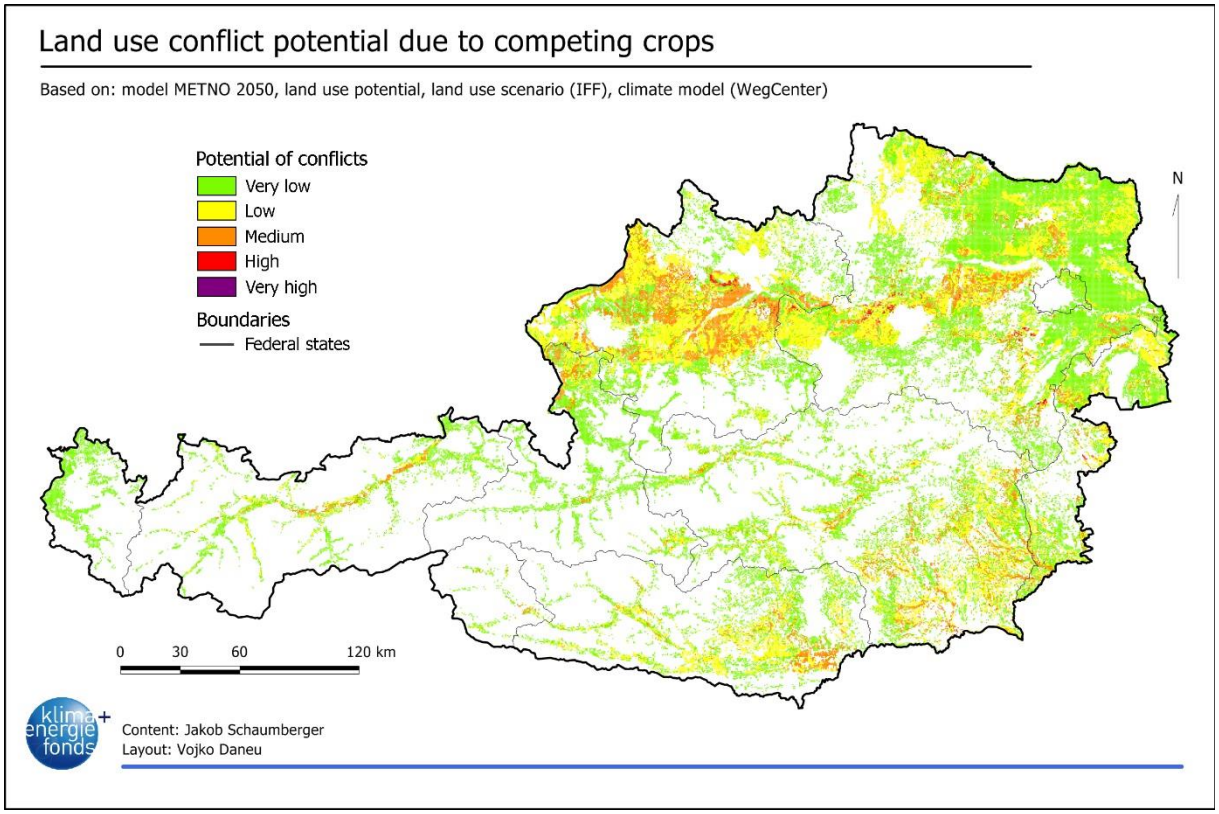

Figure 8. Land use conflict potential for the period 2041-2050 (climate scenario METNO 2050)

Autarky scenarios (WP5)

In addition to the "main scenarios" presented above, transformations scenarios towards a *self-sufficient* low-carbon bioeconomy in Austria ("autarky scenarios") have been developed. They are based on the assumption that all biomass foreign trade from and to Austria is reduced to zero until 2050. Effects on economic development, which are likely to be negative, are disregarded.

The autarky scenarios demonstrate that despite Austria's current role as net importer of biomass, biomass imports are not essential for achieving a bioeconomy until 2050 from a bio-physical and technical perspective. There are sufficient domestic biomass resources available to satisfy the biomass demand in the presented scenarios. Biomass throughput of the socio-economic system is clearly lower in the autarky scenarios than in the lead scenarios (see Fig. 9); mainly because the production of the wood industries (paper and pulp, sawmill and wood panel industries) decline significantly if only domestic resources are processed and only the domestic market is served. This decline also leads to a lower industrial energy demand and less biomass being used for energy because of a reduced availability of wood processing residues and waste liquor (see Fig. 10). Furthermore, the assumed decline of foreign trade with agricultural products (and cattle/beef in particular) results in feed-crop and forage areas being released for energy crop and raw material production.

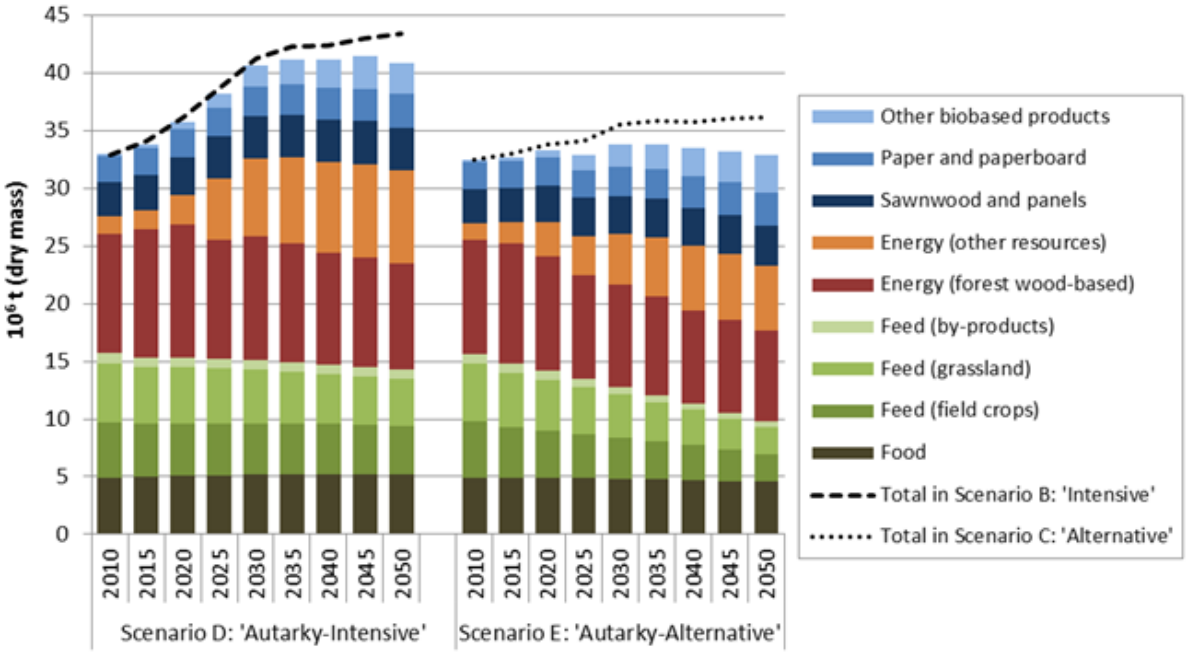

Figure 9. Development of total biomass use in the autarky scenarios

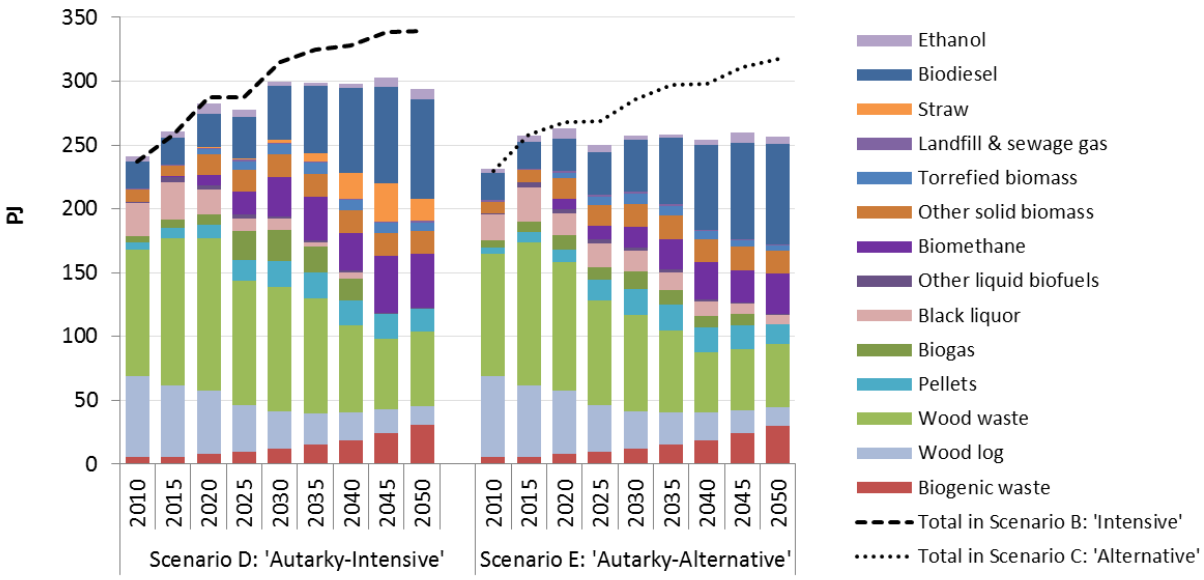

Figure 10. Development of biomass use for energy in the autarky scenarios

Austria's cross-border biomass trade – Recent developments and outlook in the context of climate change (WP2 & 3)

On product weight basis, the total biomass imports to Austria increased from less than 20 million tons (Mt) to more than 27 Mt during the period 2000 to 2013. The latter is equivalent to about 20 million tons of dry mass (Mt_{dry}). Biomass exports from Austria showed a considerable increase during 2000 to 2007 (from about 17 Mt to more than 24 Mt). Since then there has been a decreasing trend (down to about 23 Mt, corresponding to slightly more than 16 Mt_{dry}).

The most relevant category in both imports and exports is "wood and wood products". In 2013 this category accounted for 45 % of biomass imports and 33 % of exports (based on product weight). The second most important category in exports is "paper and paperboard" (21 %; 7 % in imports).

This is due to Austria's large and export-oriented wood-processing industries, which are importing vast amounts of raw wood and exporting large shares of their production. Recently declining biomass exports are also a result of developments in the wood sector: Domestic roundwood supply has been decreasing since 2008 and sawnwood production has fallen by 25 % from 2007 to 2013. Austria's trade volumes of agricultural commodities are clearly lower than those related to the forest sector. All unprocessed agricultural products together accounted for approximately 18 % of biomass imports and 17 % of exports (based on product weight).

A sub-task of WP3 was to assess how Austria's biomass trade flows might develop in the future, considering the effects of climate change. The main findings of this task (based on literature analysis) are: On a global scale decreasing crop yields in lower latitudes and somewhat increasing yields in higher latitudes are expected [54]. Together with increasing water scarcities this will have a substantial impact on global food production patterns. Furthermore, disturbances due to extreme weather events are expected to become more frequent and severe due to climate change. Global trade will therefore probably become even more important for securing food supply.

With regard to Europe, yield growths are expected in northern parts and little change or low losses in the southern parts. In contrast to the rest of the world, demographic development in Europe is expected to lead to declining consumption. Therefore the EU's potential role as an increasingly important crop exporting region is discussed in [54] and other publications.

With regard to wood (products) trade impacts of climate change are expected to play a minor role (at least if disturbances are neglected). It is expected that future changes in trade flows will mainly be determined by the following factors: (1) Changing demand/supply balances, (2) technological progress and (3) policies regarding trade and related framework conditions.

Food and farming futures in Austria (WP3)

If the agro-food system further develops along past trends, with further increasing crop yields, further abandonment of extensive grassland and perennials and approximately constant per capita diets and food wastes, GHG emissions related to food production increase by +9% (+1.08 MtCO2-eq./yr) from 2010 to 2050. This projection does not consider a possible change of CO2 emission related to a change of technologies using fossil fuels (e.g. more efficient machinery, transport, etc.).

The adoption of healthier diets with less calories and a smaller share of animal products could reduce GHG emissions related to food production considerably. Assuming a development along past trends for agricultural productivities and constant fossil technologies, GHG emissions in 2010 could be reduced by -65% (-7.80 MtCO2-eq./yr) until 2050 by a switch to healthier diets. Halving food wastes could reduce GHG emissions from agriculture and food production by an additional -15% (-1.85 MtCO2-eq./yr) under otherwise similar conditions. 45% of this reduction in emissions is associated with a reduction of activities related to food production, while 55% can be attributed to GHG removals by (an assumed) afforestation of spare land.

A complete switch to integrated or organic agriculture, associated with lower crop yields and additional areas for legumes, is only possible in terms of land balances if this is paralleled by a switch to healthy diets with less calories and a smaller share of animal products and, in most cases, an additional reduction of food wastes. A complete transition to integrated/organic agriculture, healthy diets and low food wastes until 2050 could reduce GHG emissions related to food production by -36% (-4.35 MtCO2-eq./yr) for organic agriculture to -54% (-6.47 MtCO2-eq./yr) for integrated agriculture. Other than the according scenario with high yield agriculture, most of these reductions are permanent, as they are associated with a reduction in activities related to food production rather than afforestation of spare land.

For organic and integrated cropping systems, the preservation of extensively used grassland and the expansion of extensively used perennials enlarge the number of scenarios possible in terms of land balances. This points to the importance of preserving extensive grassland and perennials as resource base, especially if cropping systems with lower crop yields are used.

Stakeholder positions towards bioeconomy transformation (WP4)

Most stakeholders consider a bioeconomy transformation as a primarily technology- and research-focussed endeavor. Opinions regarding priorities in such a transformation process differ to some extent; they include, for example, attaining technology leadership which is quite consensual, while facilitating green growth and combatting climate change as primary targets of a bioeconomy are more controversial. Most stakeholders, however, agree that achieving sustainable development should be a main target.

The stakeholder process revealed some highly controversial topics. The competition for biomass resources has already been in the center of public and political debate in recent years; mainly in connection with subsidies for bioenergy plants. The debate centers on whether stronger policy intervention and regulatory measures are needed to promote an efficient and "cascading" use of biomass and to what extent and for what applications bioenergy should be promoted and subsidised. Trade-offs between intensified biomass production and environmental protection is another example for controversial issues. Many stakeholders consider a bioeconomy transformation as a crucial step towards sustainable economic development, while others point out potential threats to the environment.

Barriers to a bioeconomy transformation mentioned by stakeholders can be categorized as economic, political-institutional and socio-cultural barriers. Economic barriers are related to a lack of competitiveness of biobased industries and bioenergy. Political-institutional barriers arise from insufficient political will, political inertia and the difficulty to achieve structural change against vested interests. People's opposition against imposed changes in lifestyles, consumer behaviour etc. and measures limiting individual freedoms can be summarized as socio-cultural barriers.

Regarding the question, what political instruments should primarily be applied to achieve a bioeconomy transformation, a heterogenous picture emerges. While some stakeholders propose far-reaching measures others are more reluctant and place themselves on the side of more liberal and voluntary measures. The most prominent measures proposed include an ecological tax reform (with different tax bases, like CO_2 in fossil fuels, resources (also other than fossil ones), land use, consumption of meat and animal products), changes in the subsidy regime (like cancelling of ecologically counter-productive subsides), and promotion of research activities.

Institutional and policy aspects (WP4)

There are several diverging visions or narratives of what a bioeconomy could or should entail, and what the resulting society should or could look like. Based on stakeholder process described above, different socio-political choices associated with diverging visions of the bioeconomy have been explored in WP4. Visions differ mainly along one or both of two dimensions: the type and scale of technology envisioned and the possibility or desirability of further economic growth. We therefore constructed a two-dimensional field consisting of four quadrants: (A) combines a vision of large-scale industrial (bio-) technology with a belief in unbounded "green growth". We termed this quadrant "Sustainable Capital". Quadrant (B) combines a vision of agro-ecology and decentralised technological solutions with a belief in continued economic growth. We named it "Eco-Growth". (C) combines a vision of agro-ecological production systems with a sufficiency-perspective, which calls for overall reductions in consumer demand. This quadrant is named "Eco-retreat". Quadrant (D), finally, collects narratives that combine a vision of large-scale industrial (bio-) technology with the conviction that overall reductions in certain types of consumption are inevitable and that infinite economic growth is neither possible nor desirable. We termed this quadrant "Planned Transition".

Seven selected national and supra-national policy documents on the bioeconomy have been analysed, all of which were found to be located in the "Sustainable Capital" quadrant. Only the Swedish document stresses the necessity of reductions in overall demand, but hesitates to suggest measures that could curtail consumer sovereignty. An analysis of stakeholder positions in Austria offered a more differentiated picture: while all industry representatives were also positioned in (A), the majority of researchers interviewed expressed views that clearly put them in quadrant (D). These researchers emphasise the structural changes that a transition to a land-based resource base entails. For example, societal deliberations and decisions are necessary to decide "how much surface we are willing to dedicate to which form of production". The scarcity of land as the most

critical resource in a bioeconomy will require new mechanisms and institutions of participatory resource planning. It may also require societal choices as to the limitation or reduction of consumer demand in certain areas. Unbounded economic growth is not very likely in a land-bound economy, nor is it any longer desirable, according to the relative majority of researchers. Civil society stakeholders typically expressed even more sceptical views as to the continuation of the growth paradigm in a bioeconomy.

Carbon accounting of material substitution with biomass (WP6)

In a "full carbon accounting approach" the replacement of carbon-intensive products with bio-based substitutes ("material substitution with biomass") can be highly efficient in reducing GHG emissions, as simulation results indicate. In optimal applications of long-lived bio-based products the benefits of material substitution are threefold: (1) Energy consumption and GHG emissions from production processes can be reduced, (2) biogenic carbon is stored over a considerable period of time instead of being released into the atmosphere and (3) bio-based products can be used as renewable fuel or secondary raw material at the end of their lifespan ("cascading biomass use"). However, GHG balancing according to current default IPCC methods does not follow a full carbon account approach. This raises the question, whether material substitution with biomass can be recommended as GHG mitigation measure under current accounting approaches.

In an additional analysis carried out under WP6, potential benefits of material substitution in comparison to fuel substitution have been analysed for two case studies (CS1/2). GHG savings are calculated according to default IPCC approaches (Tier 2 method assuming first-order decay) and with more realistic approaches based on distribution functions. In CS1, high savings are achieved by using wood residues for the production of insulating boards instead of energy. The superiority of material substitution is due to the establishment of a long-term carbon storage, the high emission factor of wood in comparison to natural gas and higher efficiencies of gas-fired facilities.

The biomass feedstock in CS2 is lignocellulosic ethanol being used for bio-ethylene production (material substitution) or replacing gasoline (fuel substitution). GHG savings are mainly due to lower production emissions of bio-ethylene in comparison to conventional ethylene and significantly lower than in CS1 (per unit of biomass consumed). While CS1 is highly robust to parameter variation, the long-term projections in CS2 are quite speculative.

To create adequate incentives for including material substitution in national climate strategies, shortcomings of current default accounting methods must be addressed. Under current methods the GHG savings in both case studies would not (fully) materialize in the national GHG inventory. The main reason is that accounting of wood products is confined to the proportion derived from domestic harvest, whereas imported biomass used for energy is treated as carbon-neutral. Further inadequacies of IPCC default accounting methods include the assumption of exponential decay and the disregard of advanced bio-based products.

5 Conclusions and recommendations

Conclusions regarding current biomass utilization

The analysis of current biomass flows in Austria revealed that biomass imports to Austria surpassed exports by about 15 % in 2011 (based on dry mass). The distribution of biomass among the different uses depends on whether direct consumption or final uses are considered. In the latter case, which is considered more appropriate, inland biomass consumption was distributed as follows: 7 % human food, 18 % raw material, 38 % energy and 37 % animal feed. Exports are primarily composed of wood products.

Contrary to common assumption, energy recovery is still usually the ultimate step of cascadic biomass use rather than primary purpose, or based on by-products. Judging from wood quantities being processed and consumed and foreign trade data, domestic wood supply according to felling reports (and stated as "domestic extraction used" in official data) is clearly underrated. Conversely, domestic feed production according to MFA data is inconsistent with official animal feed statistics and appears to be overestimated by at least 30 %.

Conclusions regarding forest management

Effects of the assessed climate scenarios on domestic wood supply and agricultural production potentials are moderate on aggregated national scale. However, more distinctive positive and negative effects are discernible on regional scale. The inclusion of natural disturbances (which have not been considered in this study) may lead to additional negative impacts under conditions of climate change. Climate change adaptation through targeted forest management practices can yield positive medium- to long-term effects on ecosystem services

Conclusions regarding the feasibility of a bioeconomy transformation in Austria

The transformation scenarios B and C illustrate pathways to a low carbon economy, whereas A is a reference scenario where the intended GHG reduction of -80 % compared to the Kyoto baseline is not achieved. All three scenarios are characterized by increased material use for conventional and novel applications as well as enhanced cascading biomass use. Therefore, the scenarios B and C can be described as transformation paths to a low-carbon bioeconomy.

The results illustrate that transformation is feasible from a bio-physical and technical perspective without increasing biomass net imports. However, the requirements in terms of energy efficiency and saving, application of advanced biomass conversion technologies and other renewable energy sources are high; without massive policy intervention in all these fields, the necessary developments are highly unlikely from today's point of view.

Conclusions regarding diets and food supply

In view of the results, a change to diets with a lower share of animal products is thus of high importance. Changing diets not only have the potential to decrease GHG emissions in food production substantially, they also yield co-benefits related to health [55], other environmental aspects [56] and – especially on a global scale – food security. How such a dietary transition can be facilitated is a question that calls for further interdisciplinary research about the complex interrelation between diets/food, individual behaviour and societies.

On the side of agricultural productivities, scenarios with increasing crop yields have the potential to reduce GHG emissions by the generation of spare land for carbon sequestration, however high crop yields often come with the price of negative environmental effects [57]. This points to the importance to develop and promote cropping systems that combine high productivities with ecological principles, such as those applied in organic agriculture.

Conclusions regarding stakeholder positions and policy aspects

Our exploration of official policy papers, stakeholder positions and model results revealed a wide range of socio-political visions and narratives of the bioeconomy. Only some of them, it seems, are in accordance with the objective to decarbonise society until 2050. Interestingly, the official visions presented in strategy papers of state authorities do not reflect a need to reduce consumer demand in critical areas like mobility or animal products.

The exploration of socio-political choices showed, first and foremost, that the discourse on the transition to a sustainable bioeconomy must be opened up to include also those visions that are not harboured within the elite-driven narratives of "green growth". An honest and transparent societal deliberation on the options of transiting to a bioeconomy must include issues of sufficiency (active reduction of consumer demand), new institutions for resource planning and allocation and the all-important question of how to decouple societal prosperity from the apparent necessity of economic growth.

Taking into account the diversity of stakeholders' positions towards several aspects of a bioeconomy transformation, a realistic outcome might be that future Austrian bioeconomy strategies will focus on less controversial areas and put an emphasis on promotion of research activities in fields where already technological strengths exist or are to be expected. It is probable that strategies will be oriented towards those of other European countries (like Germany or Scandinavian countries) and will not propose any far-reaching policy measures in the field of environmental sustainability.

Conclusions regarding carbon accounting of biomass use

Despite the fact that material substitution with biomass can be a highly efficient way of reducing GHG emissions, there is currently no incentive to promote it as climate mitigation strategy. This has to do with inadequacies of the currently applied „HWP accounting" method, which generally favours the use of imported biomass for energy over material substitution. HPW pools being calculated on the basis of domestic production rather than actual consumption, the assumption of exponential decay instead of more realistic distribution functions, and the fact that certain bio-based products are not considered under default "Tier 2 method" is creating distorted incentives.

Another relevant aspect in connection with material substitution is that emissions from production processes are included in the producer country's GHG balance and not the country where products are consumed. Hence, GHG savings from reducing production emissions by replacing carbon-intensive materials for biomass do not necessarily materialize in the country where material substitution takes place. Quite the contrary: establishing a bio-economy to substitute carbon-intensive imported products and materials for bio-based alternatives is likely to have an adverse impact on the national GHG balance, even if the global effect is clearly positive.

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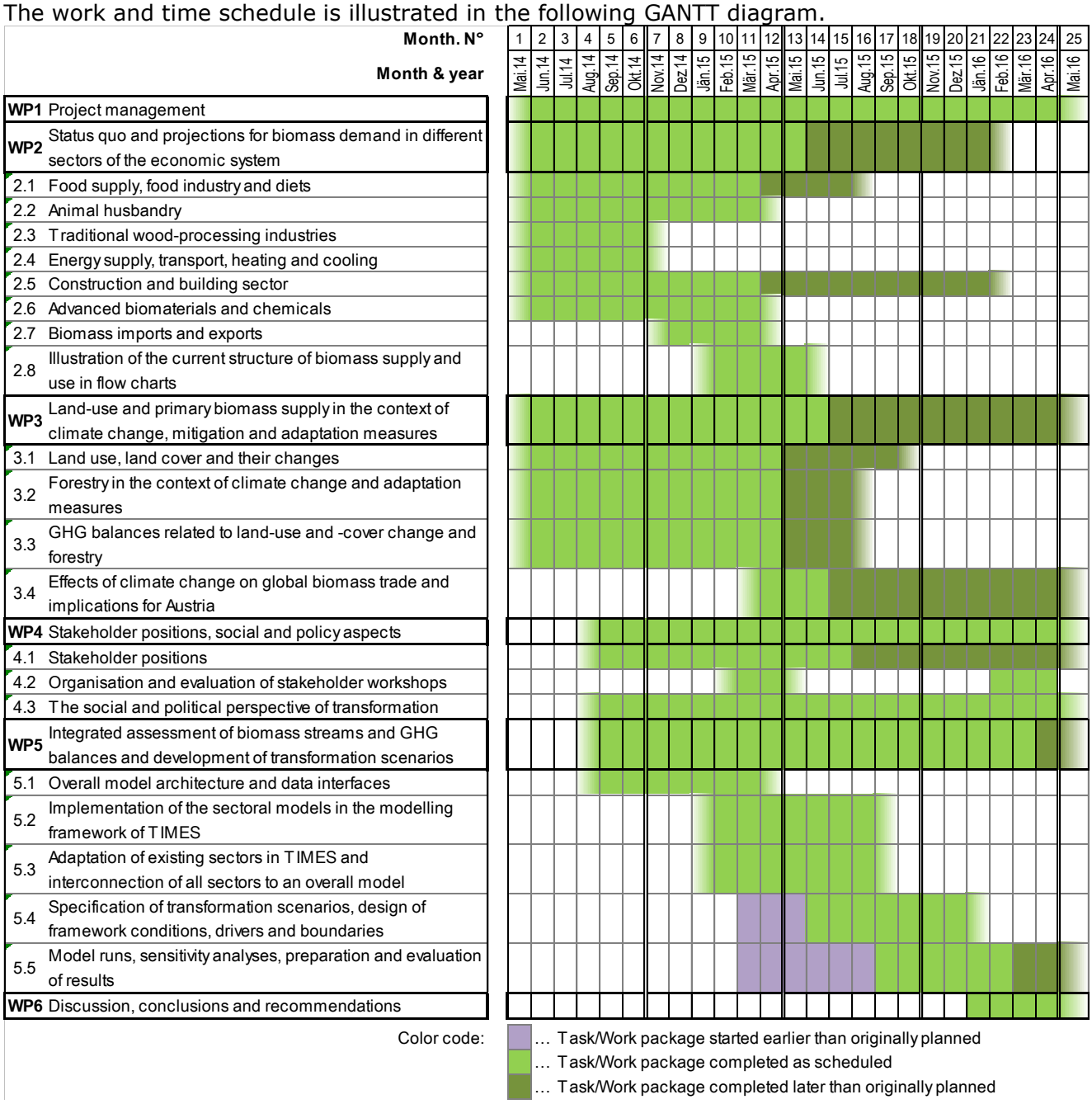
C) Project details

6 Methodology

The methodology is presented under section 4 "Contents and results of the project". Further information on methodological approaches is available from project deliverables available at http://tinyurl.com/biotransformat.

7 Work and time schedule

The work and time schedule is illustrated in the following GANTT diagram.



8 Publications and dissemination activities

The project deliverables according to the proposal are listed below. Public deliverables have been completed and made available for download on the website of the project coordinator (http://tinyurl.com/biotransformat):

- D 2.1: "International biomass trade of Austria"
- D 2.2: "Biomass streams in Austria – Drawing a complete picture of biogenic material flows within the national economy"
- D 3.1: "Climate change and its effect on Austrians cross-border biomass trade – A literature review"
- D 3.2: "Land use potentials and land use requirement scenarios for 2050"
- D 3.3: "GHG emissions associated with different food and farming futures in Austria"
- D 4.1: Report "Stakeholderpositionen zur Bioökonomie"
- D 4.2a: Protokoll zum 1. Stakeholder Workshop
- D 4.2b: Protokoll zum 2. Stakeholder Workshop
- D.4.3: "A transition to which bioeconomy? An exploration of diverging socio-political options"
- D 5.1: Technical model documentation
- D 5.2: "Transformation scenarios towards a low-carbon bioeconomy in Austria"
- D 6.1: Final report (this document)

Two peer-reviewed scientific papers have been published during the project duration:

- Kalt Gerald, 2015. *Biomass streams in Austria: Drawing a complete picture of biogenic material flows within the national economy*. Resources, Conservation and Recycling 95, 100–111. doi:10.1016/j.resconrec.2014.12.006 (corresponding to D 2.2)
- Kalt Gerald, Höher Martin, Lauk Christian, Schipfer Fabian, Kranzl Lukas, 2016. *Carbon accounting of material substitution with biomass: Case studies for Austria investigated with IPCC default and alternative approaches*. Environmental Science & Policy 64 (2016) 155–163

Deliverable 5.2 has been **submitted** to the Elsevier journal *Energy Strategy Reviews* and is currently being revised based on a first set of (minor) reviewer suggestions.

Three further submissions to scientific journals are planned/in preparation, based on the deliverables D 3.3 and D 4.3 as well as work performed under Task 3.2:

- Lauk C., Theurl M., Kastner T., Scholz F., Hausknost D. *GHG emissions associated with productivity vs. sufficiency oriented food and farming futures: The case of Austria.* Submission planned for the Journal Climatic Change.
- Hausknost D., Schriefl E., Lauk C. *A transition to which bioeconomy? An exploration of diverging socio-political options*. Submission planned for journal Sustainability
- Rammer W., Lexer MJ. *Effekte von Biomassenutzungsszenarien auf die Schutzfunktionalität österreichsicher Wälder. Eine Simulationsstudie*. (in preparation for Austrian Journal of Forest Science)

Two stakeholder workshops were held during the project at at the premises of the Institute of Social Ecology in Vienna:

- 1st stakeholder workshop: 11.5.2015
- 2nd Stakeholder workshop: 18.3.2016

Detailed minutes on both workshops are publicly available (D 4.2a and b).

Stakeholder interviews: A total of 28 stakeholder interviews with experts from research institutions, representatives of NGOs, ministries, other public institutions and interest groups was conducted (cf. D 4.1).

Three presentations at external events (scientific conferences) were held:

- 9. Internationale Energiewirtschaftstagung an der TU Wien – „Energiesysteme im Wandel: Evolution oder Revolution?" (11 – 13 February 2015). Title of the contribution "Simulating the transformation to a low-carbon bioeconomy with an integrated model of the energy system and the forest sector"
- 23rd European Biomass Conference and Exhibition, Vienna. (1 – 4 June 2015). Title of the contribution "Transformation paths to a low-carbon bioeconomy in Austria"
- Österreichischer Klimatag 2016 (6 – 8 April 2016): "Scenarios towards a low-carbon economy in Austria – The potential role of biomass and implications with land use, food supply and biobased industries"

The first two contributions have also been published as papers in the **conference proceedings**:

- Kalt G., Baumann M., Höher M., "Simulating the transformation to a low-carbon bioeconomy with an integrated model of the energy system and the forest sector", 9. Internationale Energiewirtschaftstagung an der TU Wien, 2015, Vienna.
- Kalt G., Baumann M., Höher M., Kranzl L. et al., "Transformation paths to a low-carbon bioeconomy in Austria", 23rd European Biomass Conference and Exhibition, 1-4 June 2015, Vienna.

Further reports/publications:

- Article „Transformation towards a low-carbon bioeconomy in Austria" published in: „Biobased future - Mitteilungsblatt über Biomasse für Energie und Industrie in einer nachhaltigen Wirtschaft" (Nummer 6 – Juli 2016)