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Can Austria „feed" itself in a post-fossil world?

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Abstract

It is widely assumed that bioenergy will be of growing importance in the future. While the conflict between bioenergy and food is extensively discussed and recognized, the aspect that this conflict is further exacerbated by the fact that in a post-fossil world, biogenic raw materials will also be increasingly used for the production of synthetic carbon materials is not yet sufficiently addressed. We here present integrated scenarios of potential biomass requirements, which take into account all major current and potential future biomass usages (the production of food, energy, wood materials and synthetic carbon materials) for the case of Austria in 2050 and explore the influencing factors (like crop yields, consumption levels, recycling ratios) that are crucial to fulfill the goal of an autonomous supply with these goods in a post-fossil world.

Keywords: bioenergy, land use, scenarios, nutrition, diets, synthetic carbon materials, carbon polymers, post-fossil economy, growth of consumption

Motivation

The effects and feasibility of a (broad scale) substitution of fossil energy carriers by energy from biomass are a matter of scientific and public controversy (Perlack et al., 2005; EEA, 2006; Mitchell, 2008; Searchinger et al., 2008; Tilman et al., 2009; z.B. de Wit and Faaij, 2010; Haberl et al., 2011). The greenhouse gas saving potential of bioenergy carriers and the potential to exacerbate conflicts between food and bioenergy production are crucial questions in this debate. The aspect that in a post-fossil world, biogenic raw materials will also be used for the production of non-energy materials (synthetic materials, bitumen, solvents, lubricants, fertilizers), now produced from fossil resources, is not yet sufficiently addressed. We address this shortcoming, presenting integrated scenarios of potential biomass requirements which take into account all major current and potential future biomass usages (the production of food, energy, wood materials and synthetic carbon materials).

Research question and methodology

This article starts from the following research question: Under which conditions can Austria supply itself in the year 2050 with food, energy, wood materials and synthetic materials without using fossil ressources? Self-Supply is understood here in the sense that all consumption that directly or indirectly (that is as part of the production process) involves the use of biomass is derived from land available in Austria. We did not consider the substitution of tropical crops such as coffee and cacao. Also, fruits, vegetables and tobacco, which involve a rather negligible part of the total area used for the production of biomass, as well as fish, are not considered. The scenarios include the biomass potentially needed for the biogenic production of synthetic carbon materials such as plastic, bitumen, solvents, lubricants and nitrogen fertilizers. They also include the substitution of the cotton used for textiles consumed in Austria by domestically produced synthetic fibers (cellulose fibers). For the diet scenarios, we distinguish two “physical” trade scenarios: 1) Balanced trade, denoting a balanced net physical trade balance for all products, including a complete self-supply and 2) constant trade, denoting that the net physical trade balance remains at the level of 2005. All other scenarios are constrained to the case of a balanced physical trade balance.

We constructed biomass demand scenarios for 2050 by combining different trajectories of diets (“trend”, “reduced meat”, “vegan”), the biogenic production of synthetic materials (differing in consumption levels, recycling ratios, main source of raw materials), the production of bioenergy (differing in energy demand, energy efficiency, technology choice) and wood materials (differing in consumption levels and recycling ratios) in a biomass flow model, as shown simplified in Figure 1. This results in according demands for food, energy, synthetic and wood materials. In a second step, by the combination of calculated biomass demands with different assumptions on average crop and pasture yields, we derived according potential agricultural area demands. We finally identified feasible scenarios by matching these area demands with areas assumed to be available in 2050. The wood demand is matched accordingly with modeled wood production potentials in 2050. The model and all parameters are described in more detail elsewhere (Lauk et al. 2012).

The range of possible trajectories concerning the considered parameters is rather broad. For example, in the case of yield developments, besides constant yields we include a scenario with highly increasing yields to 2050 on the one hand, which we consider to be at the limit of technical feasibility, and a scenario with completely organic yields to 2050 on the other hand. The scenario with highly increasing yields probably has ecologically problematic implications, such as a significant increase of the use of nitrogen fertilizers, however by including this broad range, we give the opportunity to the users of our study to judge, which of the numerous scenarios they consider to be realistic or preferable.

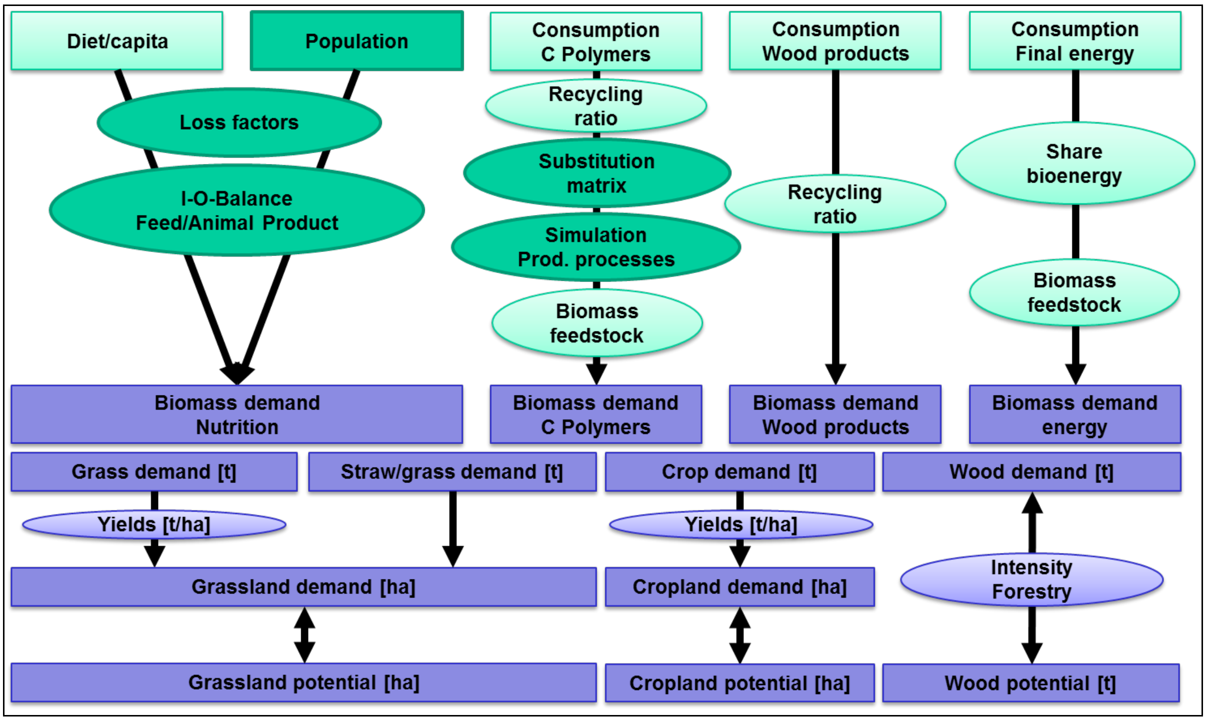

Fig.1: Simplified figure of the biomass flow model used to calculate biomass demands from according end consumptions. For a more detailed description of the model, see Lauk et al. 2012.

The feasibility for all considered scenarios (e.g. combinations of assumptions) is shown as "biophysical option space" for nutrition (table 1), nutrition and material uses (wood and C polymers) combined (table 2) and nutrition, material and energy uses combined (table 3), respectively. The biophysical option spaces are shown separately and in this sequence in accordance with assumed social priorities: Whereas the highest priority of food production doesn't need further explanation, a material use is given priority compared with an energy use of biomass due to 1) the preferential cascading use of biomass, in which the energetic use eventually follows only after its material use (cf. Haberl and Geissler 2000) and 2) the more difficult substitution of biomaterials compared to bioenergy with non-biogenic resources. For example, whereas biofuels are relatively easily substituted with non-biogenic renewable energy technologies, an according substitution of C polymers is indeed possible (e.g. via the production of methanol from hydrogen and CO derived by electrolysis) but involves an extremely energy intensive process.

All scenarios are constructed on a purely biophysical level. Their aim is to show the biophysical feasibility of various scenarios, consisting of combined assumptions regarding the parameters described above. By showing the feasibility of various combinations, it is possible to answer questions like: Is it possible to switch to organic agriculture, while maintaining the current nutrition (or is it possible at all)? Or: Is it possible to double the consumption of C polymers under the condition that the consumption of meat decreases? In this sense, our biophysical option spaces show biophysical constrains of social trajectories. Thus, they potentially form the base of scenarios focused on the social/institutional level, which could explore the social and institutional conditions that have to be fulfilled in order to ensure a biophysically possible pathway.

Diet scenarios

We assumed three different scenarios for the trajectories of the average per-capita diet in Austria in 2050: Trend, Reduced Meat and Vegan. All scenarios ensure a sufficient calorific and protein supply.
Trend: In the "Trend" scenario, historical trends for nutrition are extrapolated into the future by a qualitative assessment. Whereas the per capita consumption of meat remains constant on a high level, there are some shifts within this food category: Consumption of poultry increases by 40%, consumption

of beef decreases by 40% and consumption of pork remains constant. Further, the consumption of milk and milk products rises by 20% and the consumption of fish doubles.

Reduced meat: This scenario is based on the recommendations made by the “Österreichischer Ernährungsbericht” (Austrian nutrition report, Elmadfa et al., 2009), characterized mainly by a reduced consumption of red meat. Thus, it should not be mistaken as a scenario of abstinence but as a scenario leading to a more healthy overall diet. Total consumption of meat is reduced by 60% (-20% beef, -80% pork). The consumption of milk and milk products remains constant, consumption of cereals and potatoes rises by 60%.

Vegan: In this scenario, no animal products (meat, fish, milk and milk products, eggs) are consumed. This scenario was chosen to show the minimum area demand for food production (and the maximum area potential for other land use purposes, respectively). To ensure a sufficient supply of proteins, the consumption of peas, maize and soybeans increases– from a very low baseline – by a factor of 20, the consumption of beans by a factor of 10. The consumption of cereals and potatoes rises by 60%.

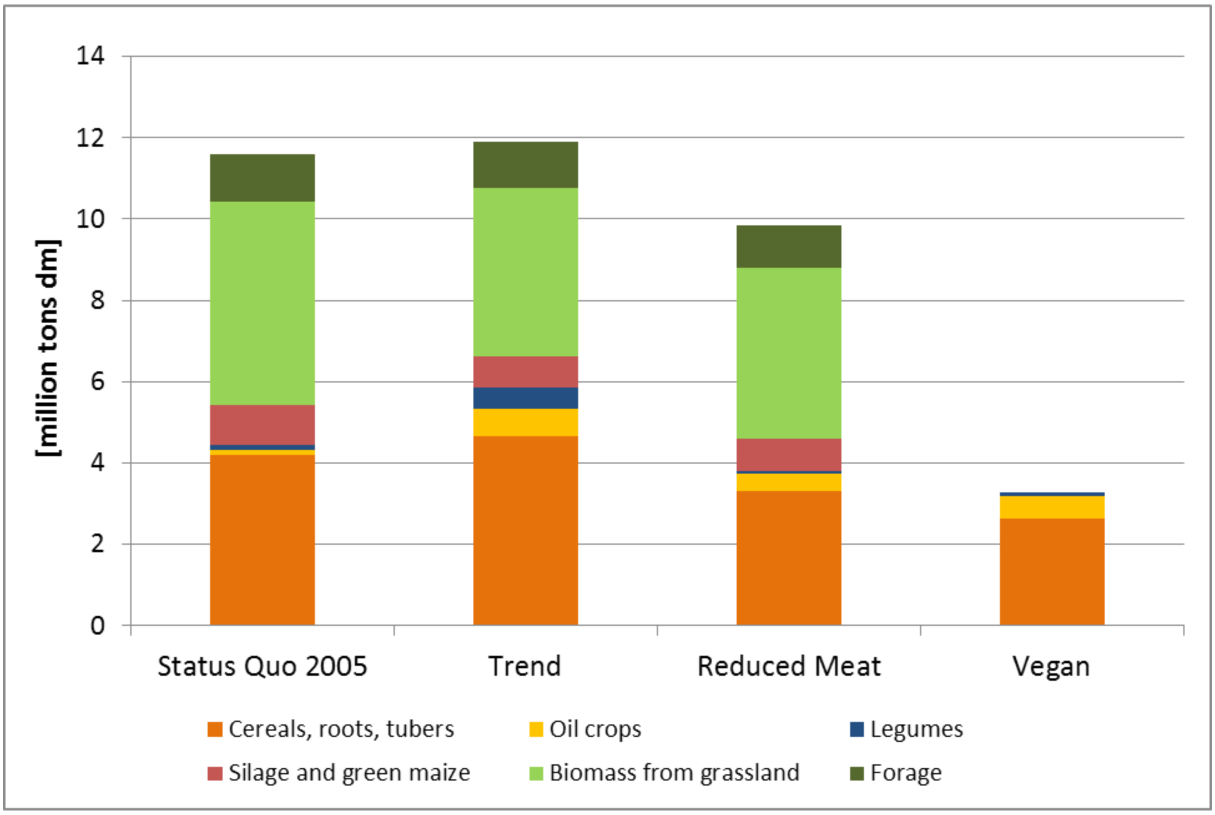

Fig. 2: Biomass requirements for the nutrition of the Austrian population under different diet scenarios in 2050 (Trend, Reduced Meat, Vegan) with a balanced biophysical trade balance. As comparison, the according hypothetical demand for the average per capita diet in 2005 is shown on the left (Status Quo 2005).

Figure 2 shows the biomass demand for different diet scenarios under the assumption of a balanced physical trade balance. With 9.9 Mt dm (dry matter), the biomass demand in the scenario “Reduced Meat” is about 17% lower than the demand in the diet scenario “Trend”. In the scenario “Vegan”, the biomass demand is at 3.3 Mt dm and thus 72% lower compared with the scenario “Trend”, and 67% lower compared with the scenario “Reduced Meat”. This reduction largely consists in a reduction of biomass from grassland and forage land, as large parts of the Austrian milk and beef production are based on these land use types.
The biophysical option space for the nutrition of the Austrian population, excluding all area demand for bioenergy and biomaterials, is shown in Table 1. It shows the biophysical conditions under which all food consumed by the Austrian population can be produced either completely on the land available in Austria (scenario “balanced biophysical trade”), or without increasing the net import of biomass beyond the biophysical net trade in 2005 (scenario “constant biophysical trade”). The table shows the feasibility

of all combinations of these two trade scenarios with scenarios for diets (trend, reduced meat and vegan) and scenarios for yields (increasing, constant and organic). In the yield scenario "increasing", yields of all crops except forage increase by 44% between 2005 and 2050, corresponding to a linear extrapolation of the historical experimental yield potential for wheat, whereas the yield of forage crops and grassland remains constant. In the yield scenario "organic", organic crop yields reach 85% of the current conventional yields, which would amount to an increase by 40% compared to its current levels. In addition, our model assumes that legumes are grown during two years within a five year crop rotation period and that these legumes are fed to animals, reducing accordingly the demand from grassland. These yield scenarios are used for all biophysical option spaces (Tab. 1-3).

	Yields	Increasing	Constant	Organic
Diet	**Trade Balance**			
Trend	Balanced	+	-	-
	Constant	+	+/-	-
Reduced Meat	Balanced	+	+	+/-
	Constant	+	+	+
Vegan	Balanced	+	+	+
	Constant	+	+	+

Tab. 1: Biophysical option space for the nutrition of the Austrian population under different combined developments of diets, trade balances and yields. "+" (green): biophysically feasible – supply of grassland and arable land at least 5% higher than according area demands; "+/-" (yellow): biophysically probably feasible – supply of grassland and arable land +/-5% higher/lower than according area demands; "-": biophysically not feasible – grassland and arable land demand exceeds according supply by more than 5%.

Under the assumption of the growth of crop yields by 44% by 2050 compared with 2005, all considered scenarios become biophysically possible. If crop yields remain constant, meeting the biomass demand in a Trend-scenario becomes already problematic, whereas under the assumption of overall organic agriculture (with lower yields), only the diet scenarios "Reduced Meat" and "Vegan" are biophysically possible. Thus, although it seems possible to secure a sufficiently high food supply with organic agricultural techniques, this would require a considerable decrease of the per capita consumption of meat.

Adding the demand for synthetic materials and wood products

Scenarios regarding the production of synthetic carbon materials (C polymers) differ in consumption levels (growth (+100%, constant, decline (-50%)), recycling ratios (constant, medium (44%), high (75%)) and main biomass feedstock, especially concerning the use of starch versus cellulosic biomass (cereals, straw/grass, wood). It is taken into account that certain materials cannot be recycled or could only be recycled with very high effort (like fertilizers or solvents), so the average recycling ratio is below the ratios mentioned above. A recycling ratio of 75% for synthetics is an extremely optimistic value and implies correctly sorted separation of synthetic materials and the adaptation of additives to the recycling process (Patel et al., 1999, p 164ff.).

Many C polymers can be produced on the basis of different kinds of biomass. In the medium and long term, a larger variety of biomass can be used as feedstock for the production of synthetic materials, due to second generation technologies where cellulose and hemi-cellulose are the basis for the production of e.g. ethanol, which is one important potential raw material for C polymers. The different options concerning biomass feedstock were taken into account by designing four scenarios: a) cereals, represented in this scenario by maize, b) straw/grass, c) wood, d) sugarcane. Sugarcane as main feedstock was chosen to show the potential import demand for biomass and agricultural areas in case that the production of the feedstock for biogenic C polymers takes place in tropical regions such as South America, which is one plausible trend under certain conditions.

Figure 3 shows the potential biomass demand for the biogenic production of C polymers in 2050 according to different consumption levels and recycling ratios, differentiated by biomass fractions, for the case of constant crop yields and grass/straw as main feedstock. It shows a potential additional biomass demand of between 1.8 Mt and 15.3 Mt dm in 2050 from the production of synthetic C polymers consumed in Austria. Thus, the additional potential demand for the biogenic production of C polymers is considerable but strongly depends on the combined development of consumption and recycling ratios. The dependency of the feedstock on this biomass demand is shown for one such scenario in Figure 4. It shows that there is no large difference regarding the total amount of biomass demand between the chosen feedstocks, in particular when considering that the scenario with a focus on cereals involves the production of byproducts that can be used as animal feed, which is not considered in this Figure.

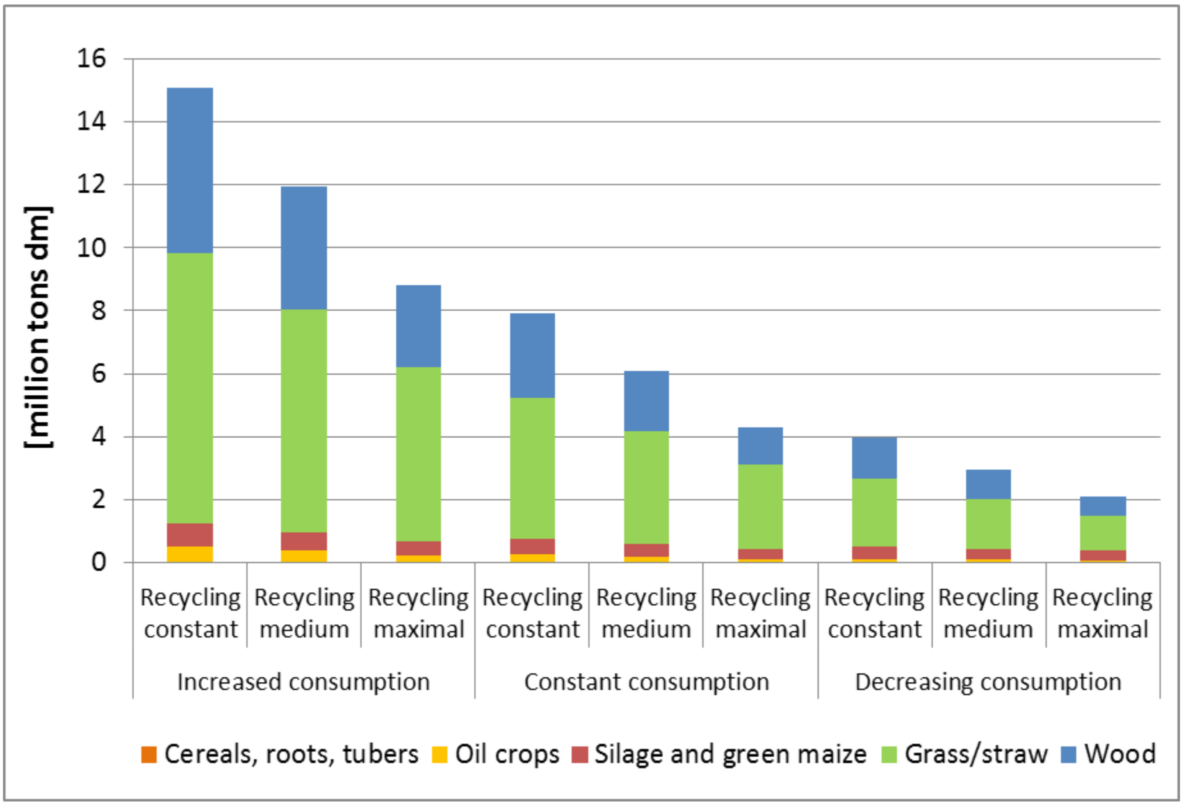

Fig. 3: Biomass demand for the production of C polymers depending on consumption level and recycling ratio for the case of constant crop yields and a focus on grass/straw as feedstock, differentiated between main biomass fractions.

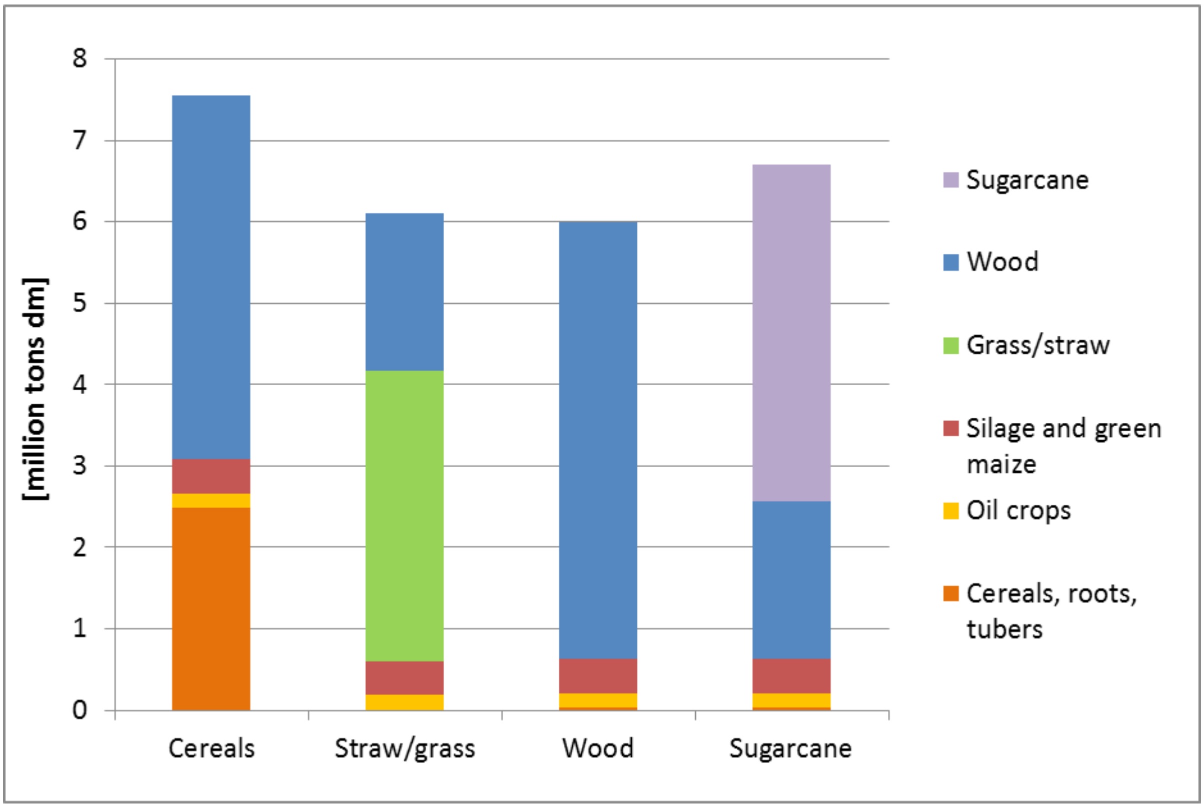

Fig. 4: Biomass demand for the production of C polymers in relation to the main feedstock: Cereals, straw/grass, wood, sugarcane. Constant consumption of C polymers, constant crop yields, medium recycling ratio.

The biophysical option space for the combined production of food, synthetic carbon materials (C polymers) and wood products (without considering use of wood for energetic purposes) is shown in table 2. Scenarios for wood production and demand for (conventional) wood products are taken from Schörghuber et al. (2011) and Kalt (2010).

Under the assumption of an extensive land use (organic agriculture, extensive forestry), a very limited biophysical option space for the combined production of food, synthetic materials and wood products (not shown as figure) remains. Only a very limited consumption of animal products would be possible (below the scenario "reduced meat"), recycling ratios would have to increase drastically (at least to the level defined here as "medium") and the main feedstock would have to be straw/grass or wood. With its high share of forest land, Austria has a high production potential of wood. However, it has to be considered that the increased use of wood for internal consumption would accordingly reduce the export of wood products, which currently is highly important for Austria's economy. When assuming more intensive land use (constant crop yields, intensive forestry), the biophysical option space opens up considerably In case of a constant consumption level of C polymers compared to 2005 and the diet scenario "reduced meat", most of the scenarios with combined demands for food and carbon materials become biophysically possible.

	Focus Feedstock ▶	Maize	Grass/Straw	Wood	Sugarcane
Consumption ▼	**Recycling ▼**				
Growing	Low	-	-	-	-
	Medium	-	-	-	+/-
	Maximal	-	-	+	+
Constant	Low	-	+/-	+	+
	Medium	-	+/-	+	+
	Maximal	+/-	+	+	+
Decreasing	Low	+/-	+	+	+
	Medium	+	+	+	+
	Maximal	+	+	+	+

Tab. 2: Biophysical option space for the production of food, synthetic carbon materials (C polymers) and wood products (excluding the use of wood for energy) for the case of constant yields, intensive forestry and diet scenario "reduced meat". "+" (green): biophysically feasible – supply of grassland and arable land at least 5% higher than according area demands; "+/-" (yellow): biophysically probably feasible – supply of grassland and arable land +/-5% higher/lower than according area demands; "-": biophysically not feasible – grassland and arable land demand exceeds according supply by more than 5%.

Scenarios for energy autonomy

In our definition of energy autonomy, no fossil energy is used in Austria and the whole energy demand is met domestically. This domestic energy production includes the production of energy from facilities installed in Austria (hydropower. windpower, PV, solarthermal installations, geothermal plants, biomass plants and heating systems), as well as biogenic fuels produced on Austrian land (agricultural biomass and wood). Thus, although we focus here on the bioenergy and according biomass demand, this demand was developed within consistent overall energy scenarios for Austria in 2050.

Three main scenarios of energy autonomy are distinguished (Biomass Min, Biomass Med, Biomass Max), differing in total energy and according biomass demands. These differences result from different energy demands or energy service levels for different sectors (space- and water heating, industry, transport, agriculture), residual electricity demands (not used by the other sectors), energy efficiency developments and technology choice (such as share of electric mobility).

The labeling of the three main scenarios ("Biomass Min", "Biomass Med", "Biomass Max") reflects relative differences of biomass demands between these scenarios and should not be interpreted in an absolute way, that is in the sense that the scenario "biomass max" approaches the maximum potential of bioenergy. Thus, even the scenario "Biomass Max" implies a deep transformation of the energy system, including the shift to a high share of electromobility for personal transport

Each of the three main scenarios is subsequently divided into three sub-scenarios (A/B/C) differing in the share of first and second generation transport fuels: in sub-scenario A, there is a large share of first generation fuels (biodiesel, biogas, biomethan from crops), whereas in sub-scenario C a large share of Fischer-Tropsch diesel and synthetic methan produced from wood is prevalent (scenario B is in between).

Figure 5 shows the demand for biomass in the nine energy autonomy scenarios. Biomass demand in the "Biomass Max" scenario is, with 20.7 Mt dm (dry matter), about three times higher than in the "Biomass Min" scenario (6.6 Mt dm).The differing assumptions in the sub-scenarios "B" and "C" result mainly in a higher share of wood use and an according lower use of oil crops for the production of biodiesel.

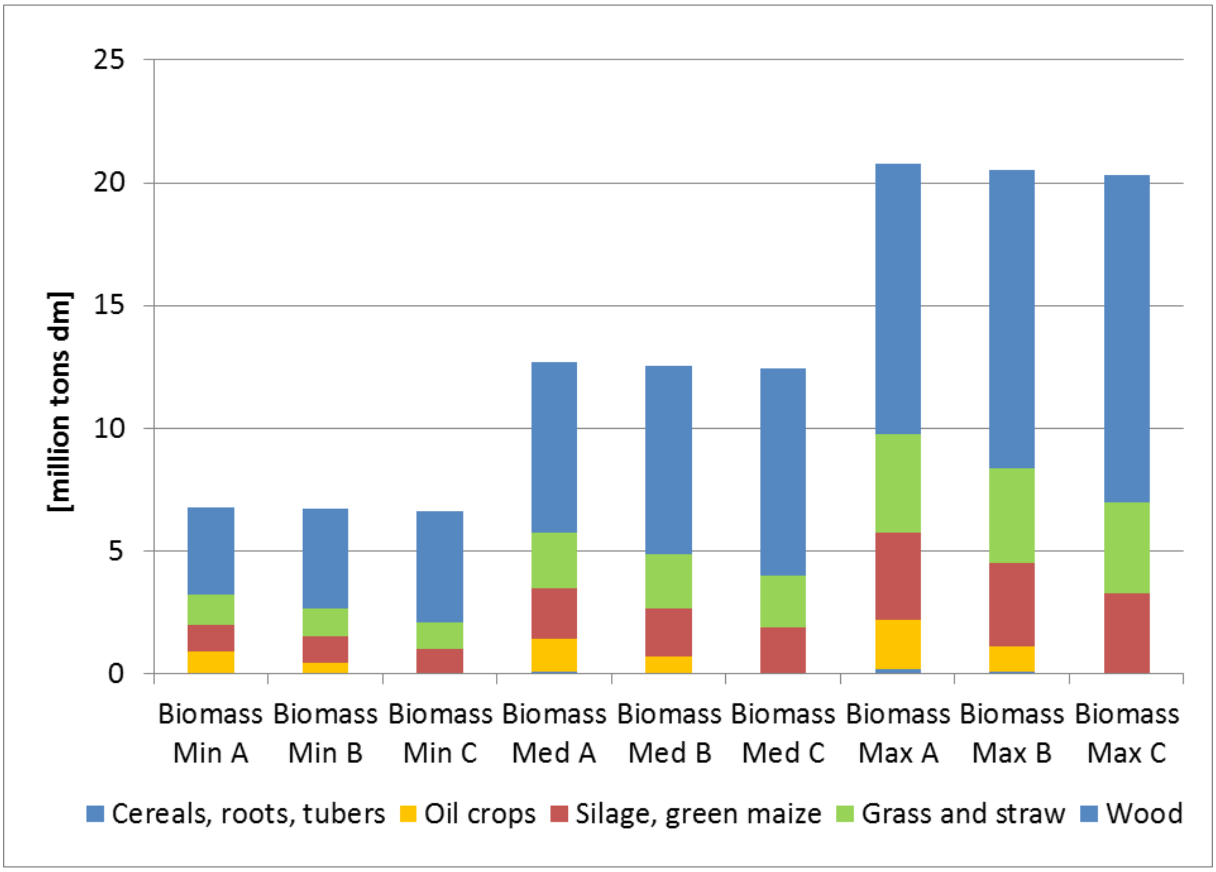

Fig. 5: Biomass demand for nine scenarios of energy autonomy in Austria according to different assumptions on final energy demand (Biomass Min/Med/Max) and the use of second generation biofuels (A/B/C), differentiated between biomass categories.

Combining all biomass usages

In order to keep the total number of scenarios manageable, we restricted the scenarios considering the combined demand for all biomass usages (food, energy, synthetic carbon materials and wood products). In what follows, these restrictions concerning the combined scenarios are defined, together with a short explanation:

- We chose a medium recycling ratio (44%) for all combined scenarios. With a recycling ratio on the current (low) level, almost no combined scenarios are biophysically possible. On the other hand, a high recycling ratio (75%) is rather difficult to implement.
- No scenarios with sugarcane as feedstock for synthetic carbon materials. As this scenario was only included in order to illustrate the potential area demand from the biogenic production of synthetic carbon materials outside Austria, it is not considered further. No results for a constant physical trade balance are shown, that is all results are restricted to a balanced trade balance. This is because 1) this paper focuses on the question of an autonomous supply with resources and 2) our results show that there is no huge difference between these two cases.
- We combine scenarios with a consistent demand development concerning biomass demand for energy and materials. The scenario "Biomass Max" is combined with scenarios with growing consumption level for C polymers. The scenario "Biomass Med" is combined with scenarios with constant consumption levels for C polymers. And the scenario "Biomass Min" is combined with scenarios with declining consumption levels for C-polymers.

Table 3 shows the biophysical option space for scenarios combining all biomass usages. It turns out that most combined scenarios (under the assumptions outlined above) are not biophysically possible. No combined scenarios are feasible with organic (that is declining) crop yields. Only when combining constant crop yields, shrinking consumption (decreasing consumption of C polymers combined with the most ambitious energy scenario), reduced meat or vegan diet and grass/straw/wood as main biomass feedstock, some feasible options open up. If consumption remains constant (constant consumption of C-polymers combined with the medium energy scenario), only the rather extreme scenario with vegan diet and grass/straw/wood as main feedstock is biophysically feasible (assuming constant yields).

Even under the assumption of increasing yields, which are questionable with respect to their technical feasibility and ecological impact, a constant consumption of biogenic energy and materials is only possible when the consumption of meat is reduced considerably. The table shows that there is no trajectory in which a growing consumption of biogenic energy and materials is possible without the net import of biomass.

Yields ▼	Consumption ▼	Focus feedstock ▶ / Diet ▼	Maize	Grass/straw/ wood	Wood
Organic	Decreasing	Vegan	-	-	-
Constant	Growing	Trend	-	-	-
		Reduced meat	-	-	-
		Vegan	-	-	-
	Constant	Trend	-	-	-
		Reduced meat	-	-	-
		Vegan	-	+/-	-
	Decreasing	Trend	-	-	-
		Reduced meat	-	+/-	+
		Vegan	-	+	+
Increasing	Growing	Trend	-	-	-
		Reduced meat	-	-	-
		Vegan	-	-	-
	Constant	Trend	-	-	-
		Reduced meat	-	+/-	-
		Vegan	-	+	+/-
	Decreasing	Trend	-	+/-	+
		Reduced meat	+/-	+	+
		Vegan	+	+	+

Tab. 3: Biophysical option space for combination of all biomass usages (food, energy, synthetic materials (C-polymers) and wood products). “+” (green): biophysically feasible – supply of grassland and arable land at least 5% higher than according area demands; “+/-” (yellow): biophysically probably feasible – supply of grassland and arable land +/-5% higher/lower than according area demands; “-”: biophysically not feasible – grassland and arable land demand exceeds according supply by more than 5%.

Main conclusions

Our study shows that the potential biomass demand for the biogenic production of synthetic carbon materials potentially adds a considerable amount to the overall biomass demand resulting from the use of food and bioenergy. There are rather few possibilities to meet this combined demand from all usages (food, energy, wood materials and synthetic carbon materials) on agricultural and forest land available within Austria. Within our scenarios, there is no biophysical possibility for an increasing consumption of bioenergy and biomaterials and it is questionable whether the biophysical production capacity can be increased beyond the point considered here as feasible.

Excluding the rather extreme case of a vegan diet, a constant consumption of biogenic energy and materials is only possible under the condition of strongly increasing crop yields, a drastic reduction of meat consumption and an increased use of wood, straw and grass for the production of bioenergy and synthetic carbon materials. However, it is questionable, whether crop yields can be increased in the dimension assumed in this case, and this could also have adverse ecologically impacts. Other potential problems of such a scenario include the open questions of the technical feasibility and ecological and social costs of energy and materials derived from wood and straw, as well as the carbon balance of the removal of straw from agricultural fields.

Based on these arguments, we conclude that without additional net imports of biomass, the domestic consumption of energy and materials by the Austrian population can only be met if consumption levels and meat consumption decrease considerably, while yields remain at least on current levels. Future research should pay increased attention to the question of how high yields can be maintained or even increased with ecologically sound production practices as well as the question of the structural growth drivers of the current society as well as, connected to this, the possibilities to overcome this coercion to growth. Especially the latter question is still a largely blind spot of current research.

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