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Project Overview

1 Kurzfassung

Das aufkommende Konzept einer biobasierten Wirtschaft, d.h. die graduelle Substitution von fossilen Rohstoffen durch Biomasse (sowohl für Energie als auch Materialien), wird als wichtiger Schritt gesehen, um Klimawandelsmitigationsziele zu erreichen (European Commission, 2012). Ein zukünftiger signifikanter Anstieg der Biomassenachfrage wird jedoch große Auswirkungen auf Landnutzungsentscheidungen und damit einhergehende mögliche negative Nebeneffekte haben, wie z.B. Waldrodungen. Zusätzlich wird eine biobasierte Wirtschaft in verstärktem Ausmaß vom Klimawandel selbst betroffen sein (Rosenzweig et al., 2014).

Wir sind daran interessiert diese Thematik auf drei unterschiedlichen räumlichen Ebenen zu analysieren, d.h. auf globaler, europäischer und österreichischer, und die Anpassungskapazitäten entlang dieser räumlichen Ebenen zu identifizieren (z.B. Handel auf globaler Ebene, Politik auf nationaler/europäischer Ebene, sowie autonome Anpassung privater Akteure auf regionaler/lokaler Ebene). Unser Projekt basiert auf einem interdisziplinären Ansatz, um die Vielzahl an Faktoren zu berücksichtigen, die Landnutzungsentscheidungen und deren ökonomische und umweltrelevante Folgen beeinflussen. Dabei werden verschiedene disziplinäre Modelle miteinander verknüpft: das regionale Klimamodell für Österreich ACLiReM, das bio-physikalische Prozessmodell EPIC, das bottom-up Modell für den Land- und Forstwirtschaftssektor in Österreich PASMA[grid], das globale bottom-up Modell für Landwirtschaft, Forstwirtschaft und Bioenergie GLOBIOM, sowie das globale gesamtökonomische Input-Output Modell ADAGIO. Im Rahmen des Projekts wurden einige dieser Modelle weiterentwickelt sowie untereinander erstmalig verknüpft.

Im Zuge dieses Projekts wurden drei Biomassenachfrageszenarien entwickelt (Stagnation, Reference, Full Transition) in denen fortgeschrittene biobasierte (d.h. auf Grundlage von Biomasse produziert) Materialien, d.h. Polymere, Schmiermittel, Lösemittel, Tenside, und Bitumen, ihre traditionellen fossilen Gegenstücke zu einem festgelegten Teil ersetzen. Unserem Wissenstand zu Folge sind dies die ersten europaweiten Langzeitsubstitutionsszenarien. Zusätzlich schätzten wir auch die dafür erforderliche Menge an Biomasse für verschiedene land- und forstwirtschaftliche Erzeugnisse. Im Reference und Full Transition Szenario werden Polymere, Schmiermittel und Lösemittel zu einem Großteil aus Biomasse produziert. Im Jahr 2050 ist der Substitutionsgrad im Reference Szenario vergleichbar mit den 2030 Zielen für biobasierte Chemikalien des „Public Private Partnership on Bio-Based Industries“ (30% Substitution im Jahr 2030 (CEPI, 2015)).

Die Biomassenachfrageszenarien wurden im GLOBIOM Modell implementiert, gemeinsam mit einem größeren Set an Szenarien, das v.a. zwei weitere Dimensionen abbildet: Die grundsätzliche sozio-ökonomische Entwicklung auf globaler Ebene bis 2050 anhand der Socio-Economic Pathways (SSPs; 3 Szenarien), sowie den Einfluss des Klimawandels (10 Szenarien). Die sozio-ökonomische Szenarien spiegeln einen vorteilhaften Trend für den europäischen Landwirtschaftssektor bis 2050 wider, mit erhöhter Produktivität (+20-30%) und Wettbewerbsfähigkeit (niedrigere Nettoimporte), was zu einem langfristigen Preisrückgang auf global Ebene für landwirtschaftliche Produkte führt (-3%), mit einem schwachen Rückgang an Ackerfläche (-2%) und langfristigen strukturellen Anpassungen. In diesem Kontext kann die zusätzliche Nachfrage im Reference Szenario sehr einfach erfüllt werden,: die Hälfte der zusätzlichen Nachfrage wird importiert, der Preisrückgang in Europa ist nur wenig geringer als im Ausgangsszenario (-8% anstelle von -14%), die Ackerlandfläche steigt leicht (+4% anstelle von -2%) und die langfristige sektorale Anpassung ist geringfügig anders. Im Jahr 2050 betrifft die gesteigerte Nachfrage im Full Transition Szenario hauptsächlich forstwirtschaftliche Erzeugnisse. Hier würde es eine Erhöhung der europäischen forstwirtschaftlichen Biomasseproduktion im Jahr 2010 um 2/3 benötigen. Aber da der Forstwirtschaftssektor nicht im Fokus dieses Projektes stand, wurde diese Herausforderung nicht im Detail untersucht. Die Berücksichtigung von Klimawandelszenarien zeigt, dass Europa im Durchschnitt besser abschneidet als der Rest der Welt, mit positiven Auswirkungen auf Ernteerträge (+4%) und geringfügig besseren Möglichkeiten für Exporte. Der Klimawandel würde daher im Durchschnitt das Aufkommen einer biobasierten Wirtschaft in Europa unterstützen. Jedoch muss dabei berücksichtig werden, dass die Variation der Szenarien sehr stark ist und langfristige Trends damit sehr unsicher sind. Zusätzlich führt die Anpassung an den Klimawandel zu unerwünschten Umwelteffekten, wie z.B. erhöhten THG Emissionen (+13% zwischen 2010 und 2050 anstelle von +9% in der gleichen Periode ohne Klimawandel) und höheren Waldrodungsraten (+16% höher als die Ausgangsbasis zwischen 2010 und 2050).

Für Österreich zeigt PASMA[grid], dass die höhere Nachfrage nach Biomaterialien Landnutzungsentscheidungen und ausgewählte Umweltindikatoren nur im Full Transition Szenario und kurzfristig signifikant beeinflusst. Höhere Preise resultieren in höheren Deckungsbeiträgen für die Landwirte (ca. +5%). Auf nationaler Ebene gibt es zwar kaum Veränderungen in der Düngeranwendung, jedoch können wir lokale Hot-Spots identifizieren, in denen es zu starker Intensivierung kommt. Die regionalen Klimawandelauswirkungen sind stark, sowie räumlich sehr unterschiedlich und unsicher bis 2050. Die Produktivität steigt dabei im Durchschnitt. Landnutzungsintensivierung dominiert daher als Anpassungsmaßnahme in den meisten Regionen, wodurch die Düngeintensität (zwischen +1% und +8%) und die THG Emissionen (zwischen 0% und +3%) auf nationaler Ebene steigen. Die indirekten Klimawandelauswirkungen (d.h. Preisänderungen auf globaler Ebene) haben dabei nur minimal Auswirkungen auf Landnutzungsentscheidungen und auch kaum Einfluss auf die allgemeine Bandbreite an Unsicherheit bis 2050.

Gesamtökonomisch zeigt ADAGIO, dass sich die Biomassenachfrageszenarien positiv auf das BIP auswirken, die Effekte sind aber nur im Reference und Full Transition Szenario merklich spürbar (ca. +0.5% zum globalen BIP). Zudem dämpfen ökonomische Rebound-Effekte die Reduzierung im Rohölverbrauch in den die Biomassenachfrageszenarien. Die Auswirkungen des Klimawandels auf das BIP sind sehr szenarien-, regions- und zeitabhängig. So wird in manchen Szenarien ein positiver Effekt des Klimawandels auf das BIP in späteren Jahren wieder umgekehrt.

Unsere Ergebnisse zeigen auf, dass es Potentiale gibt, die Produktion von biobasierten Materialen in der EU zu erhöhen, ohne signifikante Auswirkungen auf Landnutzung oder Umweltindikatoren in der EU oder Österreich zu haben, obwohl Hot-Spots identifiziert werden können und die Reduktion im Rohölverbrauch durch Rebound-Effekte gedämpft wird. Das Produktionspotential in Europa wird durch den Klimawandel bis 2050 eher erhöht als verringert werden, jedoch ist die Unsicherheit sehr hoch. Zudem können autonome Anpassungsmaßnahmen an den Klimawandel negative Umweltauswirkungen mit sich ziehen, z.B. erhöhte THG Emissionen und Waldrodungen. Dementsprechend müssen Politikmaßnahmen getroffen werden, die den Anreiz umweltgefährdende Anpassungsmaßnahmen zu treffen verringern. Diese Politikmaßnahmen müssen auf allen Ebenen angesetzt werden: global (z.B. Leakage-Effekte), regional (z.B. GAP), national (z.B. Agrarumweltprogramme) und lokal (z.B. Schwerpunktgebiete). Anzumerken ist, dass die Aussagekraft unsere Resultate natürlich durch die Modellannahmen und den inhärenten Modellunsicherheiten, die im Modellverbund mit jeder Verknüpfung weitergegeben werden, eingeschränkt ist. Die identifizierten Trends können aber als robust angesehen werden, wenn auch noch zusätzliche Forschungsprojekte in Zukunft nötig sind, um die Unsicherheiten in den Modellen und Modellverknüpfungen zu identifizieren und diese zu verbessern.

2 Executive Summary

The emerging concept of a bio-based economy, i.e. the gradual substitution of fossil fuels with biomass (both for energy and materials), is seen as an important step towards meeting climate change mitigation targets (European Commission, 2012). However, substantial increases in biomass demand in the future will affect land use decisions and potentially also negative environmental impacts associated with increased land use intensity. In addition, a bio-based economy may be considerably affected by climate change itself (Rosenzweig et al., 2014).

We are interested in assessing these issues along three spatial scales, i.e. at global, European and Austrian level, and to capture the adaptive capacity along these spatial levels (e.g. trade at global level, policies at national/European level and autonomous adaptation by private actors at regional/local level). Our project relies on an interdisciplinary approach in order to cover a multitude of factors that affect land use decisions and associated economic and environmental impacts. We link various disciplinary models, the regional climate change model ACLiReM, the biophysical process model EPIC, the bottom-up agricultural and forestry model for Austria PASMA[grid], the global bottom-up partial equilibrium model for agriculture, bioenergy and forestry GLOBIOM, and the global Input-Output model (ADAGIO). The project is also used to enhance the development of some of these models and to address some of the challenges of interlinking them.

We developed three biomass demand scenarios (Stagnation, Reference, Full transition) in which advanced bio-based (i.e. produced from biomass) materials such as polymers, lubricants, solvents, surfactants and bitumen are replacing given shares of their traditionally fossil based counterparts. To our knowledge, these scenarios are the first European-wide long term substitution scenarios. In addition, we estimated the required amount of biomass for different types of crops and forestry products. In the reference and the full transition scenarios polymers, lubricants and solvents are produced from biomass to a large extent.

We then implemented these three scenarios of biomass demand for advanced biomaterials in GLOBIOM, among a larger set of scenarios. In addition to the biomaterial biomass demand, our scenarios depicted two main additional dimensions: the baseline development of these sectors at global scale to 2050 (through the socio-economic pathways SSPs, 3 scenarios), and the impacts of climate change (10 scenarios). We found a relatively favorable baseline trend common to all three SSPs for the European agricultural sector throughout 2050, with increased productivity (+20-30%) and competitiveness (decreased net imports) allowing a long-term decline in world agricultural prices (about -3%) with slightly declining cropland (-2%) and long-term adjustments in the structure of the sector. In this context, the additional biomass demand from the Reference scenario could be met relatively easily, and it only modulates the baseline trends: half of the additional demand is imported, the price decrease in Europe is slightly lower (-8% instead of -14%), cropland slightly increases (+4% instead of -2%) and long-term sectoral adjustment is slightly altered. By 2050, the additional biomass demand required to reach the Full transition scenario comes mostly from the forest sector. This would require a two-third increase of 2010 European forestry biomass supply: since we did not to focus on the forestry sector, we did not investigate how such a challenge could be met. When including climate change, Europe is on average better-off than the rest of the world with positive direct impacts on crop yields (+4%) and slightly higher opportunities for exports. Climate change would thus on average facilitate the emergence of the bio-economy in Europe. However, the variation across scenarios is very large, making long-term trends much more uncertain. In addition, adaptation to climate change could have undesirable environmental impacts such as increased GHG emissions (+13% between 2010 and 2050, instead of +9% without climate change in the same period) and higher deforestation rates (+16% higher than in the baseline between 2010 and 2050), although the latter is very uncertain across scenarios (-6% to +37%).

For Austria, results of PASMA[grid] indicate that higher demand for bio-based products impacts land use choices and indicators significantly only in the full transition scenario and in the short term. Higher prices for these crops result in higher gross margins for farmers (ca. 5%). Although overall fertilizer application does not change substantially at national level, local hot-spots with large increases in fertilizer intensity can be identified. Furthermore, regional climate change impacts in Austria are spatially heterogeneous and uncertain until 2050, but mostly increase plant productivity on average. Land use intensification as an adaptation measure to this increased productivity dominates in the most regions, which leads to higher fertilizer levels (between +1% and +8%) and GHG emissions (between 0% and +3%) at national level. Indirect climate change impacts (i.e. changes in commodity prices) only marginally affect land use choices and do not add much to the uncertainty of regional climate change scenarios until 2050.

According to simulations with ADAGIO, the biomaterial scenarios affect GPD positively in most regions, but impacts are significant only in the Reference and Full transition scenarios (adding around +0.5% to world GDP). Furthermore, the assumed reduction of crude oil consumption due to increased biomaterial substitution is thwarted by economic-wide rebound effects. Climate change impacts on GDP are scenario, region and time specific, e.g. in some regions and scenarios GDP increases initially but decreases in later periods.

According to our findings, there is potential to increase the supply of bio-based materials in the EU without significant impacts on land use and environmental indicators in the EU and Austria, although some local hot-spots are identified. Also, due to increases in agricultural production as well as rising incomes, global crude oil consumption may not decrease as much as would be expected from the original biomaterial-induced substitution of oil by bio-materials. This production potential in Europe will not be significantly lowered by direct or indirect climate change impacts until 2050 on average, although uncertainty is high. Climate change impacts are spatially very heterogeneous and quite uncertain. Autonomous adaptation measures to climate change pose some environmental threats, such as increased GHG emissions or increases in global net deforestation rates. Policies should be put in place to counteract incentives for environmentally damaging autonomous adaptation choices. These need to tackle impacts at global (e.g. leakage), regional (e.g. CAP), national (e.g. agri-environmental measures) and local level (e.g. focus areas). Notably, our results are limited by model assumptions and inherent uncertainties that propagate with each additional linkage. The trends identified are still seen as robust, but additional research is needed to elicit these uncertainties and shortcomings in models and model linkages better.

3 Research background and objectives

In order to achieve sustainable economic development and to meet climate change mitigation targets, such as those set in the recent Paris Agreement, i.e. “holding the increase in the global average temperature well below 2°C above pre-industrial levels” (UNFCCC, 2015, p. 2), there seems to be the need to move our currently mainly fossil based economic systems towards a bio-based economy, i.e. “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” (European Commission, 2012, p. 3). The transformation towards a bio-based economy thus necessitates the substitution of fossil based inputs with biomass based inputs – both for energy and materials. This transformation may still trigger unintended and unwanted side-effects, such as loss of biodiversity due to unsustainable land use intensification or deforestation caused by increased demand for biomass (Havlík et al., 2011; Lapola et al., 2010; Searchinger et al., 2008). Our project dedicates its analyses to the material aspect of a bio-based economy and its impact on land use and environment. This has so far not attracted much attention in the scientific community (one exception for Austria is Höltinger et al. (2014)), in strong contrast to the impact of increased biomass production for energy on land use and environment (e.g. Frank et al., 2013; Kirchner et al., 2015a; Macedo et al., 2008; Schmidt et al., 2012).

At the same time, an increasingly bio-based economy could face increased vulnerability by climate change itself. Climate change will significantly alter production potentials in agriculture and forestry in the upcoming decades. This will shape farmers’ management and land use choices in unprecedented ways (Alexandrov et al., 2002; Nardone et al., 2010; Olesen et al., 2011; Olesen and Bindi, 2002). The impacts of climate change will differ greatly among regions. With respect to global climate change, agricultural yields may increase in northern latitudes but substantially decrease in low-latitude regions (Hitz and Smith, 2004). Depending on the actual adaptive capacity, socio-economic development, environmental conditions, and trade opportunities, this could potentially be a threat for global food security, environmental deterioration or GHG emissions (Fischer et al., 2005; Iglesias et al., 2012, 2011; Parry et al., 2004; Reilly et al., 2007).

Moreover, in a globally connected world, it becomes important to not only consider direct regional and local impacts (Briner et al., 2012; Kirchner et al., 2015b; Mitter et al., 2015a; Schönhart et al., 2014) but also indirect impacts of both climate change and increased demand for biomass, i.e. changes in global production opportunities and thus adaptation with regard to trade opportunities and commodity prices. Ignoring the impact on global commodity markets could lead to misleading findings as this affects the comparative advantages of agricultural regions and production systems. This in turn can affect global agricultural commodity markets and thus prices, imports, and exports (Reilly et al., 2007; Ciscar et al., 2011; Iglesias et al., 2012). These changes will ultimately also be felt by Austrian farmers and influence their management choices, thereby amplifying or mitigating the impacts.

Important to our research context is how these global impacts feed back to the regional/local level via their impact on the global economy and how adaptation mechanisms such as trade or management choices at local level shape these impacts. Many analyses have shown that trade and resource allocation across regions and other sectors can play a substantial role for net economic impacts and may alleviate negative consequences of global climate change (e.g. Fischer et al., 2005; Iglesias et al., 2012; Reilly et al., 2007). Thus, scholars increasingly stress the importance of free(r) trade as an important adaptation tool to compensate for losses in regions where yields are predicted to decrease (Chen et al., 2012; Huang et al., 2011; Schmidhuber and Tubiello, 2007). Any study that does not take into account the interaction between global climate change and global markets therefore cannot accurately predict the impacts of climate change (Reilly et al., 2007).

We have identified two research gaps in the scientific literature. First, while the economic and environmental impacts of biomass production for energy has been thoroughly investigated in the past (e.g. Frank et al., 2013; Kirchner et al., 2015a; Macedo et al., 2008; Schmidt et al., 2012), the substitution potential of fossil based inputs with biomass for materials and their associated impact on land use and environment has so far been not adequately addressed by the scientific community. Second, while many studies have addressed the impact of global climate change at highly aggregated levels, focusing on economic impacts, food security and the role of trade (Fischer et al., 2005; Parry et al., 2004; Reilly et al., 2007), there seems to be a lack of consideration of the indirect feedbacks that global climate change has on global agricultural markets (i.e. comparative advantages, import and exports, and commodity prices) and other bio-based economies in regional and local studies with highly disaggregated spatial resolution (Wirsig, 2009). For example, the most recent climate change impact studies for Austrian agriculture lack the consideration of indirect climate change impacts (Kirchner et al., 2015b; Mitter et al., 2015a; Schönhart et al., 2014). And despite major improvements (e.g. Leclère et al., 2014), global impact studies still remain at a relatively coarse resolution, at least in comparison with regional or local case studies. And even though some modelling frameworks have explicitly been developed to cover different spatial scales, such as SEAMLESS-IF (van Ittersum et al., 2008) or the Thünen-Modelling-Network (Offermann et al., 2014), selected publications often only focus on specific parts or sections in these modelling frameworks (e.g. Henseler et al., 2015; Röder et al., 2015), with some recent exceptions (Wolf et al., 2015).

Therefore, we are interested in assessing the impacts of increased demand of biomass for biomaterials as well as climate change until 2050 and how adaptation measures at different spatial scales influence the magnitude of impacts. We apply a global to regional/local integrated assessment analysis with Austria as a country specific case study. Our interdisciplinary approach aims to cover a multitude of factors at play in a bio-based economy under climate change. To some extent, our methodological framework rests on and profits from our developments and experience in the previous ACRP project CAFEE. The regional climate change model ACLiReM (Strauss et al., 2013) provides daily climate data for Austria at a resolution of 1km² until 2040. Also, we use output of future scenarios of general circulation models (GCMs) to obtain global climate change data. Climate data is an important input to the bio-physical process model EPIC (Balkovič et al., 2013) which simulates plant growth, nutrient cycles and soil erosions at both global level at 5 arcmin and at 1km² for Austria. Plant growth data is essential input to the bottom-up agriculture and forestry models. At global level we employ the partial equilibrium model for agriculture, bioenergy and forestry GLOBIOM (Havlík et al., 2011) and for Austria the agricultural and forestry sector model PASMA[grid] (Kirchner et al., 2016). The economic wide impacts of changes in the agriculture and forestry sector are assessed with the global CGE model ADAGIO (a geographical extension of the model described in Kratena et al., 2013). This modelling framework will be used to investigate the following specific research questions:

- What is the impact of an increased demand of biomass for biomaterials on land use, environment and the economy?
- How does climate change affect land use, environment as well as biomass potentials for biomaterials?
- How significant is the impact of indirect climate change effects, i.e. changes in global commodity prices, compared to direct climate change effects, i.e. changes in agricultural and forestry productivity in the region?
- How efficient are adaptation mechanisms along different scales (global to regional/local) in mitigating or exploiting negative and positive impacts of higher demand of biomaterials and/or climate change?

4 Project content and results

The research background and project objectives have already been outlined in section 3. This section aims to provide information on project activities and results along the work packages in this project. We only provide brief information on methodology and methodological developments as these are addressed in detail in section 6.

WP1: Biomass Demand Scenarios for Bio-based Materials

Scenario development

For this project we focused on advanced biomaterials which just entered the market with relatively high growth rates or are expected to diffuse into it in the upcoming decades, and which are thus expected to hold a theoretical potential to change the current biomass demand distribution significantly. For the European Union four major product groups were identified at the beginning of this century (EC, 2002) between the Directory General (DG) Enterprise and the European Renewable Resources & Materials Association (ERRMA) to have a significant contribution in substituting products which were mainly fossil based in the past century. In the final report of the BIOCHEM project (EC, 2010) the same products were discussed again as promising product segments and the market potentials were analysed. The same list of products is used in this work. It contains 1) surfactants, 2) solvents, 3) lubricants and 4) polymers. Another product traditionally based on fossil carbon is 5) bitumen which was also included in the assessment since its traditional production processes are related to the other products in existing fossil fuel refineries.

Based on non-energy fossil fuel use projections by Capros et al. (2013), three substitution scenarios are calculated partly raising the low shares of advanced bio-based materials to substantial ones in the time frame of 2015 - 2050. However, bio-based surfactants have to be treated as an exception since historical data indicates a higher share of bio-based than of fossil based surfactants in the European market. The aim of the scenarios is to elaborate possible but not necessarily feasible targets:

1. A *“stagnation scenario”* where bio based materials grow similar to the growth rate of the fossil based materials. Casually speaking it represents a stagnation scenario for the time frame 2015 – 2050. Around 5% of all fossil based materials (excluding bitumen) are substituted by bio-based materials today and no expansion is considered in this scenario. It is used as a lower threshold of the range within which the advanced bio-based materials are expected to develop. Furthermore, it facilitates the comparative illustration of advanced bio-based materials as well as respective biomass demands derived from the next two scenarios.
2. A *“reference scenario”* discusses a 40% substitution of fossil based production quantities with bio-based production quantities for lubricants, biodegradable polymers, solvents and PET. Other durable polymers as well as bitumen are not considered in this scenario. For the case of bio-based surfactants a full substitution of fossil based surfactants with bio-based surfactants is calculated for this scenario in 2050, since this product already exhibits market domination in the historical data. No major breakthrough in drop-in biopolymers and bio-based bitumen research, i.e. assuming moderate progress, is a further characteristic of the reference scenario. Substitution shares are well below the biochemical target of 30% for 2030 from the public private partnership (PPP) on bio-based industries (CEPI, 2015). Therefore, this scenario illustrates a less optimistic and less technological world, even though it assumes significant market developments for some bio-based materials.
3. An *“full transition scenario”* illustrates a 70% substitution for all products in 2050 including other drop-in polymers and bitumen and outlines an ambitious development for advanced biomaterials production. Bio-based surfactants are again considered to reach full substitution in 2050. In the final report of the BREW-project (Patel et al., 2006), a poll including the consortium partners outlines an expected range of 10 - 50% substitution level in 2050 for all bio-based chemicals. This scenario discusses a world in which a higher focus is set on substitution of fossil based materials with biomaterials than any participants of the indicated study ten years ago expected. It serves as an upper threshold of the range within the advanced bio-based materials are expected to develop heading for a full transition to bio-based products within the current century.

The estimation of biomass demand related to advanced bio-based materials production is based on two assumptions: 1) factors to be assumed for the conversion of glucose, sucrose, oil and lignin based agricultural and forestry biomass into advanced biomaterials and 2) the share of different biomass types used in the discussed sector of the bio-based economy. Together these factors form the biomass type, scenario time step and advanced biomaterials specific demand factors which can be used to derive biomass demands. The assumptions used in this Work Package, as well as the presented results were discussed in the CC2BBE workshops, on conferences (Biomass conference Vienna, 2015) and during the Young Scientists Summer Program at IIASA.

Biomaterial potentials

Long term scenarios for different advanced biomaterials are illustrated for the EU28 aggregation in Figure 1. For the investigated product types (projection for 2015), bio surfactants currently hold the highest share. However, since surfactants based on biomass have already a higher market penetration than fossil based ones, their maximal growth potential (65% between 2015 and 2050) is expected to be the lowest compared to the other investigated biomaterials. For the substitution of fossil based solvents, the material utilisation of ethanol is considered. A maximum growth of about 400% from 0.6 Mt/a in 2015 to 3.3 Mt/a in 2050 is assumed for the full transition scenario. Compared to the use of ethanol for biofuel consumption (4.5 Mt/a) of the 28 MS in 2050 assumed in the reference scenario from Capros et al. (2013), production of materials and production of ethanol for biofuels could be of about the same magnitude. With an estimated fossil based production of about 10 Mt/a, lubricants exhibit an interesting theoretical substitution potential. Biolubricants production is assumed to grow from 0.2 Mt in 2015 to 3.9 Mt and 6.8 Mt for the reference and full transition scenario respectively. For this work, polymers were split into three types; 1) biodegradable polymers considered to substitute the application of fossil based PE and PP 2) bio-based PET considered to substitute fossil based PET and 3) other drop in biopolymers considered to substitute fossil based PVC, PUR and other resin types. It is important to outline that a sole effort in substituting fossil based PET exhibits a maximum substitution (for the full transition scenario) of about 2.3 Mt/a compared to a total biopolymer production of 35.3 MT/a in 2050 for the EU28. For biodegradable polymers (based on biomass[1]), a 28 fold and 50 fold increase between 2015 and 2050 is assumed for the reference and full transition scenario respectively. With a 103 fold increase for drop in biopolymers in the full transition scenario, an average annual growth rate of about 300% must be implemented to reach this target. No statement is made under which circumstances such a substitution potential may be realistic. Considerable substitution for drop in biopolymers is only assumed for the full transition scenario in which also a breakthrough for the utilization of bio-based bitumen is considered. Production levels are compared to theoretical potentials in literature (see Schipfer et al., submitted).

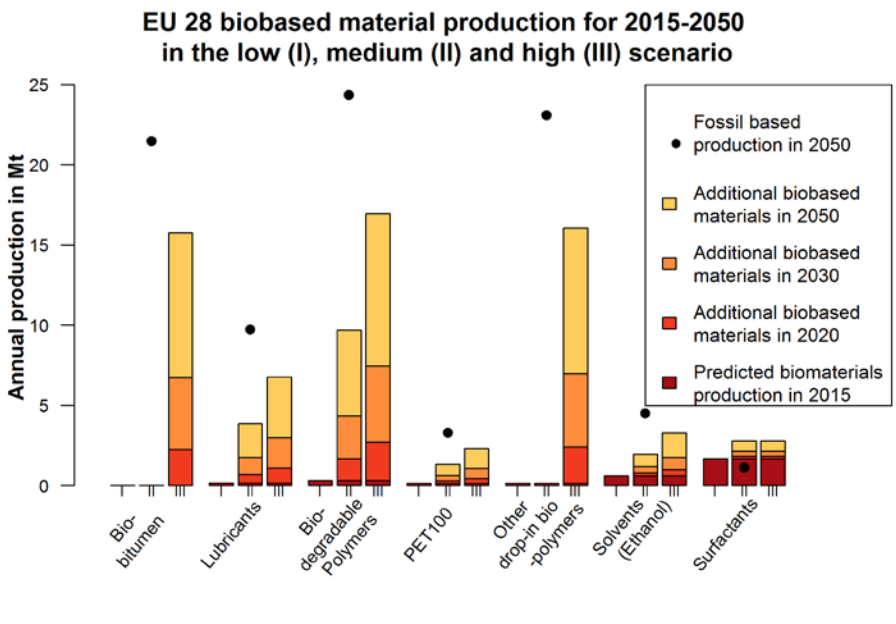

Figure 1: Projected advanced biomaterials production in 2015. For the years 2020, 2030 and 2050 the figure shows the advanced biomaterials scenarios for the stagnation, reference and full transition scenario denoted with I, II and III respectively in the x-axis. In contrast the expected fossil based material productions in 2050 are illustrated with black dots and serve as substitution bench marks for the scenarios.

Biomass demand

The respective biomass demand for the reference and the full transition scenario in 2050 on a member state level is illustrated in Figure 2. Due to the assumption of a functionalisation of lignin for biobitumen as well as the

[1] Fossil based biodegradable polymers are not considered in this work.

decomposition of hemicellulose and cellulose into sugars for the production of polymers and solvents, the demand for oil, sugar and starch plants in the reference and the full transition scenario are comparable. In contrast the utilisation of wood becomes the major source for advanced biomaterials production respectively biomass demand in all countries in 2050. No literature containing scenarios on biomass demand for advanced biomaterials could be found. However, domestic biomass production of the MS dedicated for bioenergy have been used based on the 2013 reference scenario from Capros et al. (2013). This comparison is useful, since country specific biomass production for bioenergy purposes and country specific biomass demand for advanced bio-based materials can give an indication which MS would probably rely on biomass imports in the scenarios and which countries could cover this additional biomass demand by e.g. rededication of the expected biomass production from bioenergy to advanced biomaterial uses. Since fossil based chemical production, and therefore the theoretical substitution potential, is comparable high in Belgium, Cyprus, Italy and the Netherlands, while expected biomass production for bioenergy application is comparably low in these countries, they are expected to become biomass importers in the full transition scenario. Maximal country specific demand for biomass for advanced biomaterials is expected to occur in Germany in 2050 with about 60 kt and 30 kt in the high and the reference scenario. In comparison domestic biomass production for bioenergy use is expected to account for 118 kt in the same year (8% increase compared to 2010).

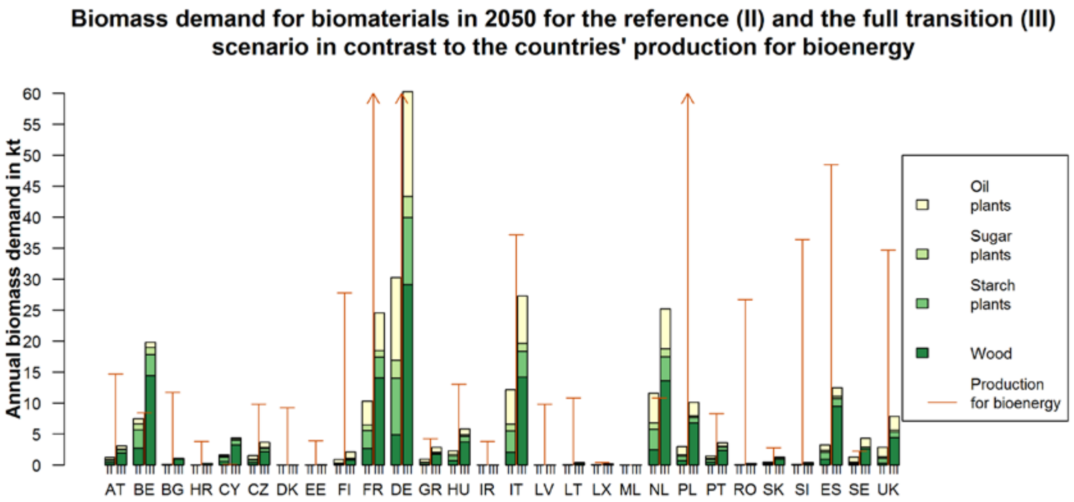

Figure 2: Biomass demand for the advanced bio-based materials production scenarios on a MS-level in 2050. The biomass demand is composed by different plant types, namely oil, sugar, starch plants and wood. Bars for reference and full transition scenarios are denoted with II and III in the x-axis. Furthermore the national production of biomass for bioenergy purposes based on Capros et al. (2013) is illustrated using a red line and in case of France, Germany and Poland where biomass production for bioenergy purposes exceeds the used scale (71 kt/a,118 kt/a and 66 kt/a resp.) by using a red arrow.

WP2: Socio-Economic Scenarios

In the project we aimed to parameterize the Shared Socioeconomic Pathways (SSPs). These scenarios describe the state of human and natural societies as it evolves over the 21st century at a macro scale (see O'Neill et al., 2012). They were developed in the frame of the IPCC to picture alternative futures with respect to the main challenges the society would face with respect to mitigation of and adaptation to climate change (Figure 3), and consist in qualitative and quantitative assumptions about broad global development patterns (including common inputs required by models such as GLOBIOM). SSP 1 (low adaptation and mitigation challenges), depicts a future with strong reduction of fossil fuel dependency and rapid technological changes directed towards reduced environmental impacts, more efficient institutions and reduced world-wide wealth inequalities. By contrast, SSP 3 (high challenges in both mitigation and adaptation) depicts a fragmented world with strongly growing population, growing wealth inequalities across world regions, high emissions and low adaptive capacity. As an intermediate, SSP2 is the continuation of current trends with medium effort to reduce inequalities and resource and energy intensity, a rapid population growth, and an intermediate success in addressing vulnerability to climate change.

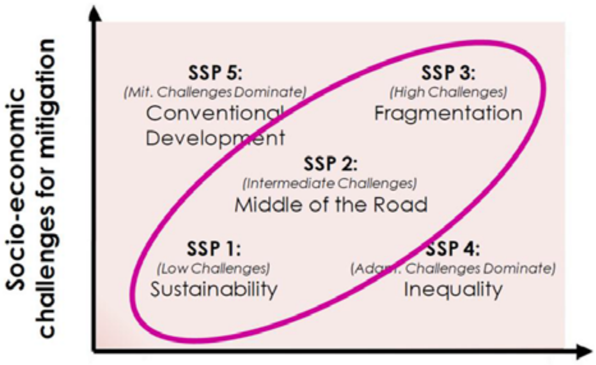

Figure 3: The scenario space to be spanned by Shared Socioeconomic Pathways, contrasting five SSPs differing in challenges for adaptation and for mitigation. In the frame of the CC2BBE project, we focus on SSP2 as the central assumption for future (O'Neill et al., 2011)

Within the CC2BBE project we decided to focus on SSP2, for three main reasons. Firstly, we focus on Europe and assume the world outside Europe keeps its current trajectory (the Middle Of the Road assumption). Secondly, we focus on the vulnerability of a bio-based economy under strong mitigation efforts: this can be viewed as Europe moving out of a SSP2 trajectory in a SSP2 world. Lastly, we do not consider a change in the adaptive capacity to climate change, and therefore assume intermediate challenges for adaptation.

We here briefly describe the parameterization of SSP2 into assumption for the GLOBIOM model, more details can be found in Havlík (2012). The main quantitative elements in the SSP framework are time series of changes in population and income per capita, generated by IIASA outside of this project[2]:

- **Population** increases to reach 9 billion by 2050, the increase being located mainly in Africa, Asia and Latin America while population in Europe remains stable (Figure 4a), assuming educational investments are not high enough to prevent fast population growth in low-income countries.
- **Global per capita income** increases at a medium pace to reach 16,000 USD 2005 per capita by 2050 (Figure 4b), with slowly converging income levels between developing and industrialized countries.

Qualitative elements of the SSPs were translated into quantitative scenarios:

- **Food consumption**: We complement the income projections with scenarios of future diets mainly based on FAO projections (Alexandratos et al., 2006), and then adapted to the different SSPs (Valin et al., 2014). While consumption is capped to 3600 kcal/c/d (4000 kcal/c/d for the USA), the elasticities follow GDP pathways at regional level, and are calibrated so that SSP2 follows FAO projection. For products categories (i.e., 'Oilseed and Pulses', and 'Milk' products), SSP specific projections were assumed based on per-capita-GDP trajectories.
- **Demand for bioenergy products** follows projections of the POLES model (Havlík et al., 2011) and corresponds to a 'continuing trend' philosophy (SSP2), with reductions in resource and energy intensity at historic rates. For t Europe, assumptions were updated upon the Reference scenario of the European Commission (Capros et al., 2010).
- **Trade**: In a world with continuing trends, agricultural sectors of most economies are assumed globally connected. In GLOBIOM, bilateral trade follows observations in the base year, and can evolve over time. Trade cost is split into a fixed part (assimilated to tariffs, decreasing over time with SSP-specific rates) and transport cost with increasing economies of scale, i.e. decreasing unit costs with increasing trade volume. We also consider a sectoral transport capacity adjustment over ten year periods: if in one period, trade increases, transport costs will be slightly reduced for the next period (and vice-versa).
- **Technological progress:** Assumptions about technological progress determine in GLOBIOM the changes in the productivity of various production activities (e.g., the yield of various crops) that is not related to switch between available production technologies (e.g., extension of irrigation). We assumed exogenous SSP specific effects of technological progress on crop yield as a function of changes in SSP-specific per capita income, and a relationship between GDP per capita and technological progress estimated upon historical data (Figure 5). In addition, the SSP specific technological progress effect on yield was translated into a change in fertilizer input requirement per unit of yield increase: 0.75 (increased fertilizer use efficiency), 1 (constant fertilizer use efficiency), and 1.25 (reduced fertilizer use efficiency) for respectively SSP1, SSP2 and SSP3. For the livestock sector, we considered the effect of exogenous technological change on animal productivity as an increase in feed conversion efficiency, estimated from Bouwman et al. (2005) for the continuing trends (SSP2), and modulated for the other SSPs following the effect on crop yields.

[2] These SSP dataset can be accessed publicly here: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=welcome

- **(a) Population** [Mio individuals] **(b) GDP per capita** [1000·USD2005 at MER]

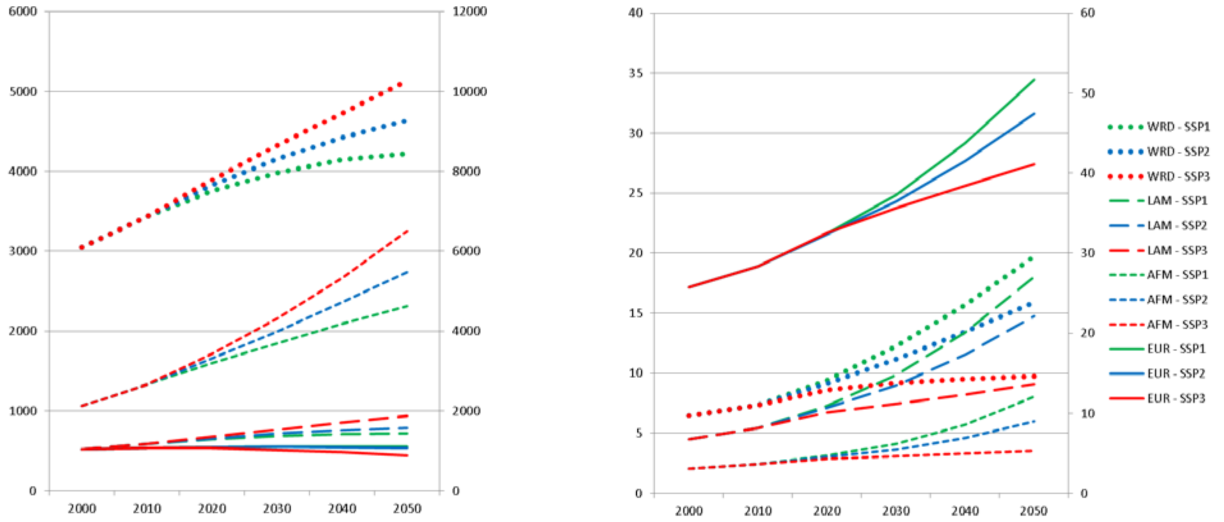

Figure 4: Main trends in SSP1 (green), SSP2 (blue) and SSP3 (red) in Europe (EUR), Latin and Central America (LAM), Africa and Middle East (AFM), and at World (WRD) level. (a) Population in million individuals (left axis for EUR, LAM, and AFM, right axis for WRD), and (b) GDP per capita in thousand 2005 US dollars at market exchange rate (all left axis except for EUR displayed on the right axis).

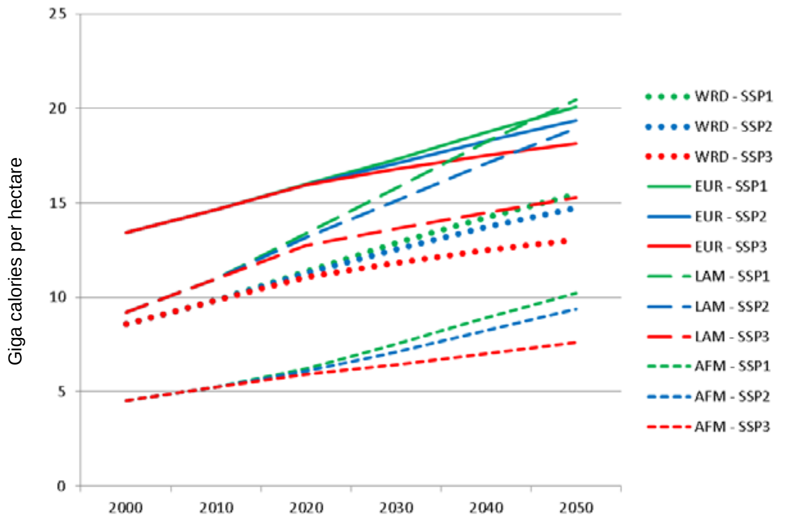

Figure 5: Aggregated measure of the effect of exogenous technological progress on crop yields (total production in giga calories per hectare of land summed over all crops).

WP3: Simulation of Bio-physical Impacts of Global and Regional Climate Change

At global scale we used the projections of climate change scenarios on individual crop production technologies combinations estimated at high resolution (pixels of maximum 0.5 ° x 0.5 ° lat-lon) by the EPIC model up to the year 2100. These projected impacts were performed in the frame of the ISI-MIP and AgMIP international projects for 5 different GCMs and four RCPs (spanning the main uncertainties in changes in temperature and precipitation - Warszawski et al., 2013) and main results are described in Rosenzweig et al. (2014). While for these 5 climate models the impacts were estimated for a relatively high level of anthropogenic perturbation of the climate system (RCP 8.5, i.e. a GHG emission trajectory leading to an additional radiative forcing of 8.5 W/m^2 by 2100), they were also estimated for lower perturbation levels (RCP 2.6, 4.5, and 6.0) for one climate model (HadGEM2-ES).The scenarios span the main uncertainties in climate change and of concomitant changes in the atmospheric carbon dioxide concentration, another main source of uncertainty for estimating the future yields but also their water requirements.

If aggregated over all crops in calorie content at global scale, climate change impacts would range between -18% and +3% of total vegetal calorie supply by 2050 if no adaptation occurs, other than marginal changes in crop management practices such as adjusting sowing and harvesting date (Leclère et al., 2014). By that time horizon, the demand for vegetal calories would increase by 77% under the SSP2 scenario and climate change could potentially significantly threaten food security. Noteworthy, the impacts are much more variable at continental to sub-continental scale (see Table 1) and Europe is always among the most favoured regions. This points to potentially significant changes in comparative advantages between regions, which forms a second layer of impacts (indirect impacts through trade) that could translate as an increased opportunity for trade for Europe, and cumulates to local climate change impacts.

Table 1: Climate change scenario specific aggregated impacts on crop yields aggregated in vegetal calories at global and regional level.

REGION	MEDIAN	**Climate change scenarios**									
		RCP	2.6	4.5	6.0	8.5	8.5	8.5			
		GCM	HadGEM2-ES			HadGEM2-ES	HadGEM2-ES	ISPL-CM5-LR	GFDL-ESM2M	MIROC-ESM-CHEM	NorESM1-M
		[CO2]	x	x	x	**x**	**-**	x	x	x	x
WORLD	**-4**		**-2**	**-5**	**-2**	**-8**	**-18**	**-6**	**3**	**-7**	**-2**
LAM	-4		-2	-4	-2	-4	-11	-11	-3	-7	-4
NAM	-14		-9	-18	3	-32	-42	-12	13	-25	-17
MNA	4		1	-2	5	4	-10	7	8	-2	17
SSA	-8		-6	-9	-10	-11	-18	-13	-6	-2	-4
EUR	10		6	7	9	11	-1	10	11	10	10
CIS	9		6	5	10	8	-11	11	36	16	2
EAS	-5		-2	-5	-5	-6	-17	-6	2	-12	-3
SAS	-4		3	-4	-1	-8	-18	-9	-4	-12	-3
SEA	-9		-9	-9	-9	-14	-24	-11	-5	-6	-2
OCE	8		8	5	8	6	-8	9	-4	19	16

Note: Values are computed by the EPIC crop model, in percentage change relative to no climate change scenario, by 2050. The first column of figures provides median values across all scenarios, the following columns provides values for individual scenarios. Each row corresponds to a global (*WORLD*) or large region aggregate (LAM – Latin America; NAM – North America; MNA – Middle East & North Africa; SSA – Sub-Saharan Africa; EUR – Europe; CIS – Former USSR; EAS – East Asia; SAS – South Asia; SEA – South-East Asia; OCE – Pacific Regions).

Many forms of adaptation could, however, buffer these impacts, and the structure of agricultural supply can adjust so that impacts on prices remain within a ±3% range. We found these adaptations to be largely sensitive to the choice of scenario. For the CC2BBE project, we can thus draw the following conclusions: impacts in Europe are not necessarily dramatic but are largely uncertain, while the uncertainty in impacts outside of Europe are equally important to properly characterize the adaptation challenge for the bio-based economy in Europe, with probably a significant role of trade. While this first exploration of climate change impacts allowed us to get a clear view on the main global patterns of estimated climate change impacts, this project could provide much better insight into intra-European impacts and adaptation.

At Austrian scale, we used the high resolution climate data of the Austrian Climate change Model using Linear Regression (ACLiReM) (Strauss et al., 2013). ACLiReM linearly extrapolates the measured temperature trend of the past period (1975-2005) to the future period (2010-2040), and re-allocates the past observations of precipitation, solar radiation, relative humidity and wind speed by applying regression and bootstrapping methods. Additionally, precipitation is manipulated according to the particular scenario assumption (e.g. increases, decreases or shifts in precipitation patterns as well as drought scenarios). The result is a variety of different climate change scenarios for Austria in form of daily time series of solar radiation, maximum and minimum temperatures, precipitation, relative humidity and wind speed in a 1km grid for Austria. Table 2 shows the scenarios considered in our analysis.

Table 2: The climate change scenarios considered in our analysis.

Scenario	Period	Temp.	Precipitation
Base	1990-2005	observed	observed
High	2025-2040	+1.5°C	+20% annual precipitation sums
Similar	2025-2040	+1.5°C	assuming similar distributions of precipitation sums compared to the past
Shift	2025-2040	+1.5°C	20% increase in winter precipitation sums and respective increase in summer
Low	2025-2040	+1.5°C	-20% annual precipitation sums

These climate data are input to the bio-physical process model EPIC (Environmental Policy Integrated Climate) (Balkovič et al., 2013; Izaurralde et al., 2006; Williams, 1995). EPIC provides information on the level and variability of crop yields and environmental outcomes (e.g. soil organic carbon stocks – SOC) of alternative crop management choices. It takes topography, soil characteristics, weather, and management choices (i.e. fertilization intensity, soil management, irrigation) into account. EPIC outputs are differentiated at a spatial resolution of 1km and used as an important input to $PASMA_{[grid]}$. Simulations for all possible regional climate change scenarios to be considered in this project have been carried in December 2013 and utilized in several publications (Kirchner et al., 2016, 2015b; Mitter et al., 2015a, 2015b).

WP4: Computation of Alternative Adaptation States in Austrian Agriculture and Integration with GLOBIOM (WP5)

This work package was dedicated to the adjustment of PASMA[grid] and the integration of GLOBIOM and PASMA[grid] outputs.

PASMA[grid] is a bottom-up economic land use model for the agriculture and forestry sector. It derives optimal management and production portfolios for agricultural and forestry land use by maximizing regional producer surplus (RPS) for each NUTS3 region subject to natural, structural and regional resource endowments, technical restrictions, and observed mixes for livestock, crops, and other land use types. The model represents the structural and environmental heterogeneity of the agricultural sector in Austria at a spatial resolution of 1km² for cropland, grassland, and permanent crops (e.g. wine, fruit orchards). During this project we have applied extensive validation as well as sensitivity and uncertainty analyses for the model (see Kirchner et al., 2016).

Initially, we aimed at integrating PASMA[grid] and GLOBIOM outputs in one reduced model, similar to an approach by Baldos and Hertel (2013, 2012). However, as the reduced model would have required a lot of input from the models, we lacked the resources to compute additional simulations. Therefore, we opted for a conventional linkage of global partial equilibrium models, such as GLOBIOM, and price exogenous agricultural sector models, such as PASMA[grid], i.e.: providing border price adjustment from GLOBIOM to $PASMA_{[grid]}$, similar to Wolf (2015). Simulations carried out in this WP have to a large extent been used to adjust linkage and consistency issues, and provided the basis for the scenario simulations in WP6.

WP5: Development of Input-Output Model ADAGIO/AEUIO and Coupling with GLOBIOM

This work package aimed to improve the I-O model ADAGIO, as well as to develop a consistent integration of GLOBIOM outputs into the model. More details are provided in section 6.

Model improvements

The ADAGIO (**A** **D**yn**a**mic **G**lobal **I**nput-**O**utput Model) family of models builds on Supply-Use tables: these tables describe the economy in term of commodity flows: which sectors of the economy produce which commodities (Supply) resp. who consumes these commodities (If the consumers are sectors, then this is called *intermediate use*: sectors need products from other sectors in their own production processes. *Final consumption*, on the other hand, is what might be called the “raison d’etre” of economic activity: it consists of consumption by private households and government, investment by sectors, changes in inventory, and exports. Supply-Use tables (SUTs for short) are the basis for Input-Output tables (IOTs): whereas SUTs distinguish between producers and consumers on the one hand and commodities on the other, IOTs show directly the flow between sectors and users (with only implicit distinction between commodities: in SUTs, a sector can (and usually will) produce more than one commodity, which can be "traded" separately. In IOTs, it is only total flows between economic agents, without distinction by type of commodity. IOTs are usually calculated from SUTs; however, going from SUTs to IOTs involves a loss of information – therefore, it is not possible to reverse this process).

While providing detailed information at the sectoral and commodity level, these SUTs convey only coarse geographic information: by recording "imports" separately, they allow for a rough distinction between commodities produced at home and abroad. The whereabouts of imports, however, are usually not recorded in SUTs. These are provided by trade matrices: they record flows of commodities between all model regions, possibly even distinguishing between different users of a commodity (conceivably, vehicles used as investment goods exhibit different trade patterns from vehicles used as consumption goods)[3].

The original ADAGIO was based on the WIOD Data Base[4] (see www.wiod.org). This data base encompassed Supply and Use tables as well as multi-regional Input-Output Tables (MRIOT) for 40 countries: EU27 plus AUS, BRA, CAN, CHN, IDN, IND, JPN, KOR, MEX, RUS, TUR, TWN, USA (plus Rest-of-the-World, ROW), thus covering about 85% of World GDP. Though impressive, the geographical distribution of these 40 countries is very Eurocentric: apart from 29 European and 3 North-American countries, there are only 5 Asian countries (6 if we include Australia), and a single South-American country (Brazil). As for Africa, WIOD does not include a single region or country. Thus, the geographical congruence with GLOBIOM's geographical pattern was less-than-satisfactory. To improve matters in this respect, an adapted version of ADAGIO was developed, which now covers 67 countries and regions (see Figure 7), resulting in a satisfactory congruence with GLOBIOM's regions (see Figure 7a).

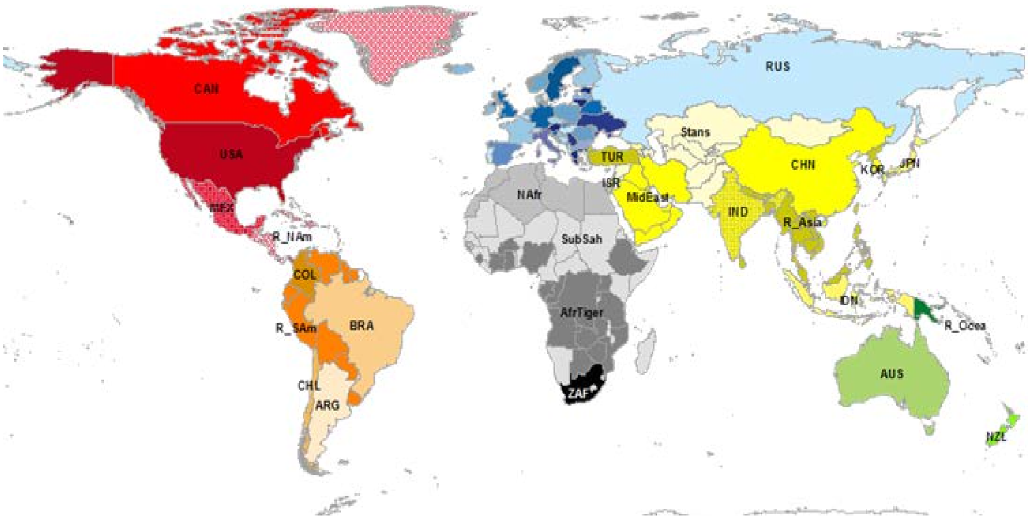

Figure 6: The World as it is represented in ADAGIO.

The extension of ADAGIO draws on three major sources: United Nations Statistic Division (UNSD, which provides National Accounts data for almost all countries of the world[5]); OECD (which provides IO tables for some countries)[6]; and GTAP (the Global Trade Analysis Project)[7], which in its version 8 provides IO tables (albeit based on a different principle than ADAGIO'S) and trade flows for 120 countries. The UNSD data provided the boundary values for the additional 27 countries and regions: Output, Value added and employment for 13 different sectors, as well as the main aggregates of final consumption. The other data sources, OECD (for ISR, CHE, CHL, and ARG) and GTAP (all other countries and regions) provided the structural commodity information to disaggregate UNSD's boundary values. A balancing algorithm (RAS) ensured commodity balance (total demand ≡ total supply) for each country or region. The SUTs are compiled for the base year of 2007. The tables for all countries distinguish between 58 commodities. On the user side, all have 6 categories of final demand:

[3] of course, the pieces of information contained in SUTs and trade matrices can be combined, leading to so-called multi-regional SUTs.
[4] The WIOD project was funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities. Grant Agreement no: 225 281
[5] see http://unstats.un.org/unsd/snaama/introduction.asp
[6] http://www.oecd.org/trade/input-outputtables.htm
[7] www.gtap.org

private consumption (CP, plus “non-profit institutions serving households” – NPISH[8]), government consumption (CG), investment (I), Changes in Inventory (Inventories) and exports (X). The sectoral level of detail, however, is varying: whereas the EU27 (which are based on EUROSTAT data) distinguish between 50 sectors, the WIOD countries offer only 35 (or, rather, 37: the original WIOD had a combined agricultural/forestry/fishery sector. For CC2BBE, we split this aggregate into its three constituent sectors agriculture, forestry and fishery. The basis for this disaggregation was provided by GTAP). The sectoral resolution of the 27 “new” countries and regions, at 43, is in-between EUROSTAT and WIOD). Contrary to WIOD, which covers “only” around 85% of world GDP, the 67 ADAGIO regions encompass the whole world – so, in principle, there is no “Rest-of-the-World”. In practice, however, a (very small) RoW serves as a repository for “statistical differences” –inconsistencies arising from the quite diverse sources of information on which the 67 SUTs are based.

Integrating GLOBIOM data

The simulation strategy splits the task of estimating the economic consequences of the bio-based economy (as well as its climate-change-induced risks) between GLOBIOM and ADAGIO: GLOBIOM determines the effects on the agricultural part of the economy, whereas ADAGIO aims at estimating the impacts on the rest of the economy. These impacts have backward and forward aspects: backward linkages of the agricultural sector to the rest of the economy include intermediate consumption. If agricultural output changes, so will the quantity and composition of products that the agricultural sector buys from other sectors, bot for intermediate inputs (like fertilizer or fuel) as well as capital goods (like tractors or buildings). Forward linkages, on the other hand, mainly act through prices: changes in output (both from changes in demand through the bio-based economy and induced by climate change) lead to changes in the price level of agricultural products. In turn, this influences the production environment for sectors that use agricultural products, first and foremost the sector “food & beverages” (but also, of course, other sectors that use agricultural inputs) – and in the economic cycle, such price changes will reach all actors, both on the production and the consumption side of the economy, at home and abroad.

The second main adaptation (after the expansion of the data base to cover 67 countries and regions instead of 40) of ADAGIO in this project aimed at improving the sectoral link with GLOBIOM: ADAGIO has one agricultural sector (as well separate sectors for forestry and fisheries) and one sector “Food and Beverages”. GLOBIOM has 23 agricultural products and 8 different kinds of food. Structural changes in the composition of these detailed product mix have to be translated into changes in ADAGIO’s single “agricultural sector”. The main aspects that have to be dealt with include gross output and production technology. Of these two aspects, gross output is quite straightforward: the aggregate change in GLOBIOM’s output of its agricultural products is directly transferred to ADAGIO’s agricultural sector (as a percentage change). This cannot, however, be simply repeated for the production technology, i.e. intermediate inputs and investment: a 1% increase of output need not (in fact, most likely will not) be accompanied by a 1% increase in inputs. Rather, the “commodity mix” of old and new output will determine the changes in the necessary production technology and, hence, input requirement (ceteris paribus, if the new mix involves more intensive cultivation, then it will likely require a more-than-proportional increase in inputs, and vice versa).

This discrepancy, between 23 GLOBIOM products and 1 ADAGIO sector, is mediated using GTAP data: GTAP distinguishes 12 agricultural products and 8 products of “processed food”. Based on this data, ADAGIO’s agricultural and food sectors are disaggregated (see Figure 7b), resulting in a much improved interface with GLOBIOM; additionally, GTAP provides information on the disaggregated agricultural sectors which GLOBIOM lacks (specifically, intermediate inputs).

Effects on the aggregate production technology are brought about not only by changes in the product mix, but also by changes in the production intensity: GLOBIOM distinguishes between high, medium and low–intensity production technology (high encompasses different irrigation techniques; low tech is mainly subsistence farming); for European countries (which all practice some form or other of “high-intensity farming”), different fertilizer regimes are distinguished (conventional farming, reduced fertilizer input). When GLOBIOM simulates the move from one production regime to another, ADAGIO needs to modify the technology of its agricultural sectors accordingly. The “elasticity of inputs with respect to farming intensity” is again derived using GTAP information:

[8] “Non-profit institutions serving households (NPISHs) consist of NPIs which are not predominantly financed and controlled by government and which provide goods or services to households free or at prices that are not economically significant”. (OECD, http://stats.oecd.org/glossary/detail.asp?ID=1827). Examples for NPISH are religious associations, labour unions, or associations (e.g. sports clubs)

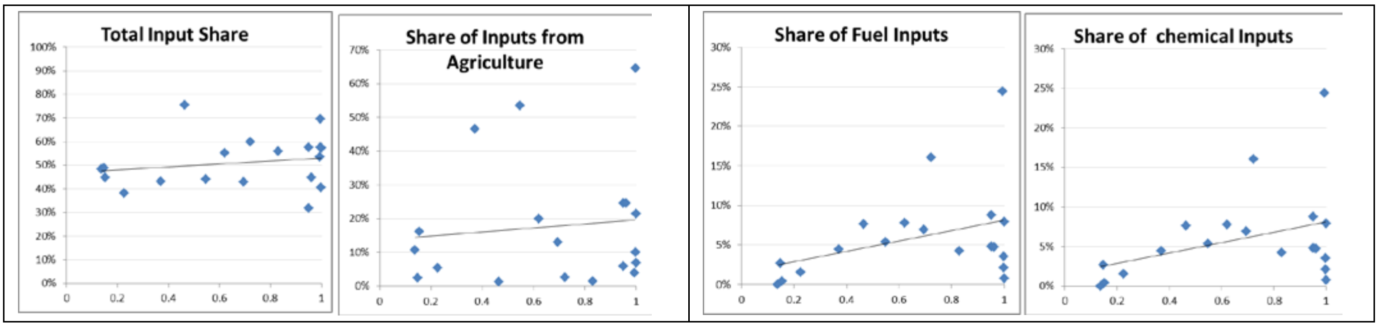

Figure 7: The diagrams show the respective parameters (total inputs plus several selected inputs) against "net share of area under high-intensity cultivation": this is the percentage of agricultural area under high- or medium-intensity cultivation minus the percentage under low-intensity cultivation. The diagrams exhibit the expected relationship: the higher the intensity level, the higher the input share, the higher the input of fuel and chemicals, and the higher the inputs from the agricultural sector itself (which might be interpreted as "division of labour" within the agricultural sector). From these relationships, we extract "elasticities" which link changes in input use to changes in the farming intensities.

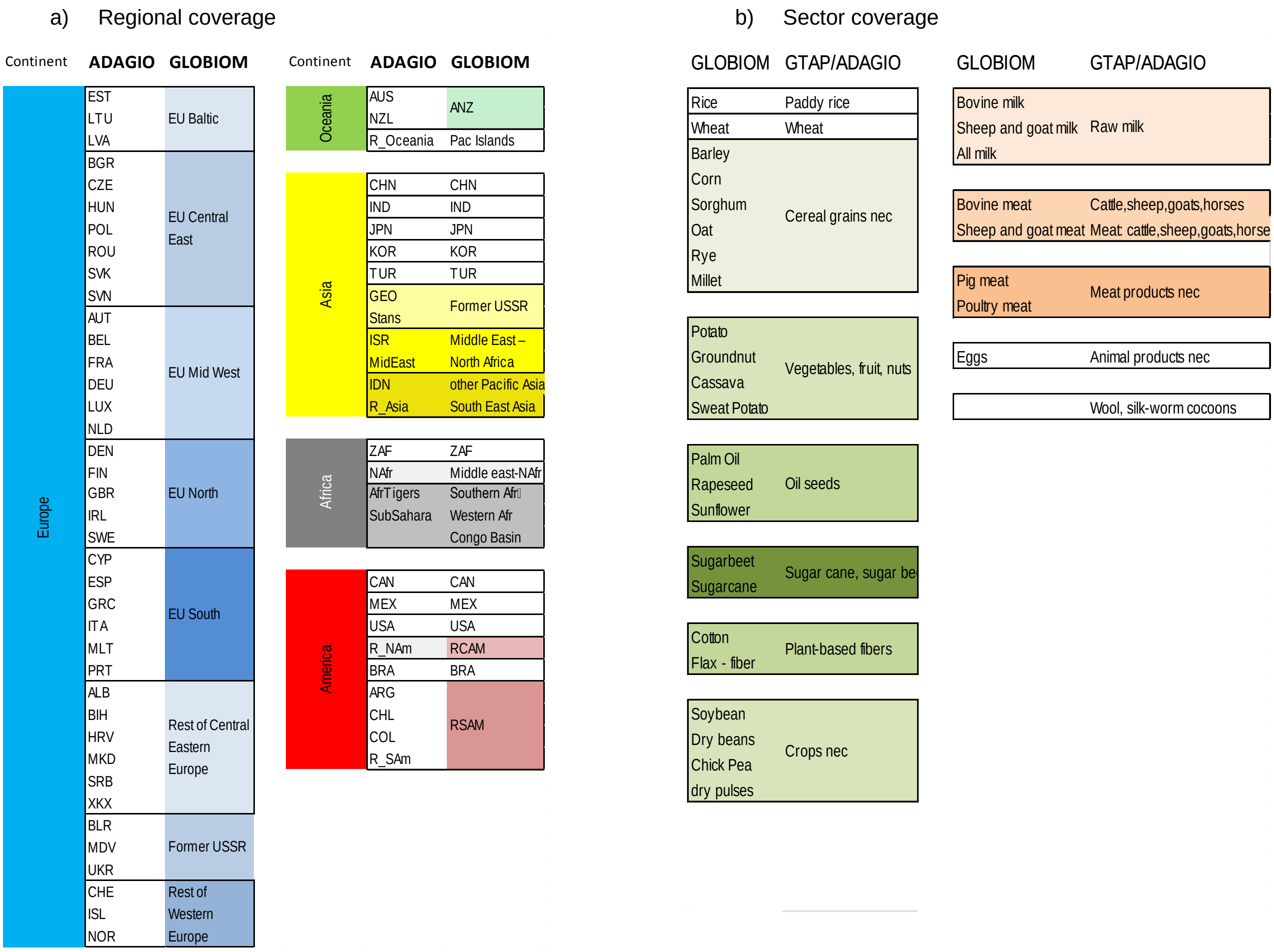

Figure 8: Congruence of ADAGIO with GLOBIOM (a) as well as GTAP (b).

WP6: Scenario Impact Analysis

GLOBIOM Results at Global and European Level

The various scenarios considered affect the level of demand, trade, production and price for agricultural goods (aggregated here in terms of total calories from cropland) at global and European level, as well as some adjustments in the agricultural sector within Europe. While the 120 scenarios (3 SSP scenarios x 4 biomaterial scenarios x 10 climate change scenarios) can be analysed in different directions, we here restrict to a few selected results highlighting i) the baseline trends of the sector (while focusing on SSP2 as a core assumption), ii) the effect of an additional biomass demand for advanced biomaterial (while focusing on the Reference scenario as a core assumption) and the effect of climate change (while focusing on the average over the 10 scenarios).

The baseline depicts a world in which the European agricultural sector sees its competitiveness slightly increasing, and its productivity increasing faster than demand. This follows SSP assumptions, by which demand for food products rise sharply at global level (+63%, +68% and +60% for respectively SSP1, SSP2 and SSP3) but not at European level (+14%, +12% and -9% for respectively SSP1, SSP2 and SSP3), while technological progress on crop yields remains significant in Europe. If looking at SSP2 the price of agricultural goods would continue its long-term decline (-3% and -14% at respectively World and European levels, Figure 8a) while Europe would become more competitive: production level increases faster than domestic demand (respectively +20% and +12%) while net imports decrease (-8%) and Europe would become a small net exporter. There is no qualitative difference in SSP1 & SSP3 for production, but for SSP3 the demand decreases by 9% and Europe becomes a large net exporter (almost 20% of its production exported). The price of agricultural products would decrease by 9% (resp. increase by 3%) for SSP1 (resp. SSP3) at global level, but SSPs are not differentiated with respect to price evolution in Europe. The production increase in the agricultural sector relies mostly on gains from technological progress (see Figure 9a), while cropland slightly decrease at the EU level (-2% for all SSPs). Changes in cropland are more variable across EU-MS: it decreases in Romania, Poland, Hungary, Bulgaria but also in UK, Belgium and the Netherlands, while it increases Finland, Spain, Sweden, Germany, Ireland and Baltic countries. These patterns are robust across SSPs, and cropland increases by 9% in Austria (see Figure 9a). Another facet of this structural evolution is the trend toward slightly less intensive cropland (see Figure 9a), as allocations of cropland to different crops and locations induce a negative effect on total cropland productivity.

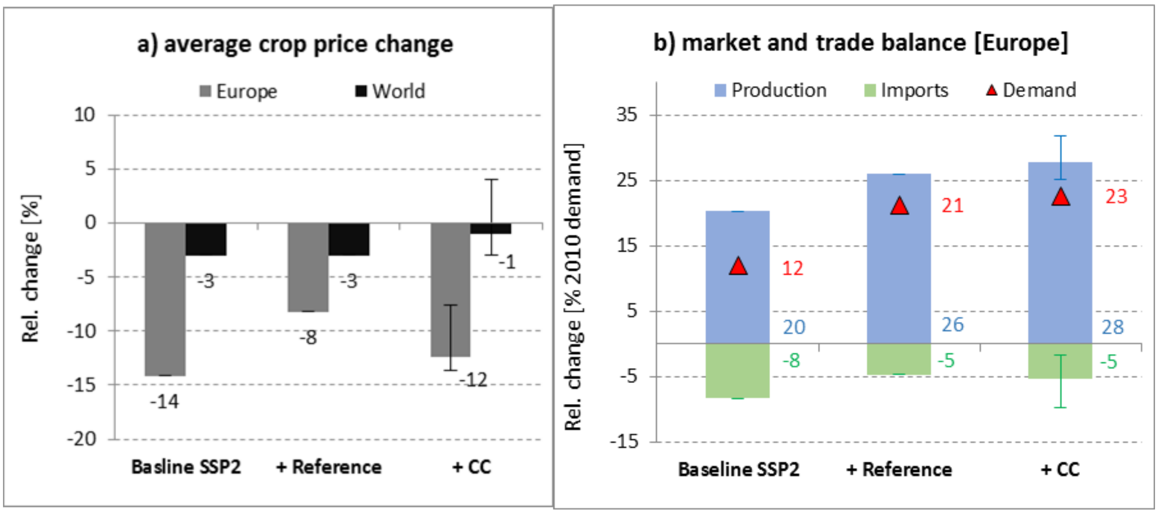

Figure 9: Overview of scenario effects on the agricultural sector between 2050 and 2010. The figure displays the relative change between 2010 and 2050 (in percentage) of a) the average crop products index (at world and European level), and b) the level of production, demand and net imports for Europe (all three expressed in percentage of 2010 demand of calories from cropland). Error bars denote the range across climate change scenarios.

The Reference scenario of additional biomass demand for advanced biomaterials seems feasible at European level at a relatively low cost. Although it represents almost a doubling of the demand for agricultural products between 2010 and 2050 (see Figure 8b, for SSP2 baseline), from +12% to +21%, about two thirds of the Reference-specific additional demand is produced domestically (+26%, instead of +20% with no biomaterial demand), while the remaining is imported (net imports reduction is only -5%, instead of -8% without) and the price of agricultural products still decreases (-8%, instead of -14% with no biomaterial demand) at European level and is not affected at global level. The additional domestic production is met with slightly more additional cropland (see Figure 9a), +2% instead of -2%, and small structural adjustments in the European agricultural sector (see Figure 9a, 'Yd-ALLO' effect is -3% instead of -5%), such as reallocation of production across countries, crops, and crop management systems permitted by a slightly higher value of production output in Europe. For example, in Austria, the production increases slightly less (+28% instead of +33%, see Figure 9a) and the allocation effect is stronger (-7% instead of -2%, reflecting a change in crop mix towards less calorific crops). The share of the imported vs. domestically produced share of this additional demand however reflects the fact that even though Europe increases its competitiveness, in a world of relatively well connected markets, this additional adjustment cost compensates relatively quickly the baseline increase in comparative advantage of the European agricultural sector. The Full transition scenario does not differ qualitatively from this picture by 2050, as most of the additional biomass is sourced from forest resources. It has a strong price impact in Europe by 2020 (+7% instead of -9%), but this owes to a very fast booming of the bio-economy processing chains that was judged as not realistic by the stakeholders. Compared to 2010 levels, the European supply of forest biomass would increase moderately in the baseline (+21% by 2050, not shown) and slightly more (+29%) under the Reference biomaterial scenario. We assumed these increases to be met with entirely increased management intensity of existing forests in Europe. However, the Full transition scenario implies a much larger increase (+67%) by 2050 that might not easily be met with sole increases in management intensity. However, since our various models represent the forestry sector with limited detail, do not incorporate climate change effects on forestry, and since furthermore the Full transition scenario has been evaluated as relatively unlikely, we decided not to investigate this question further.

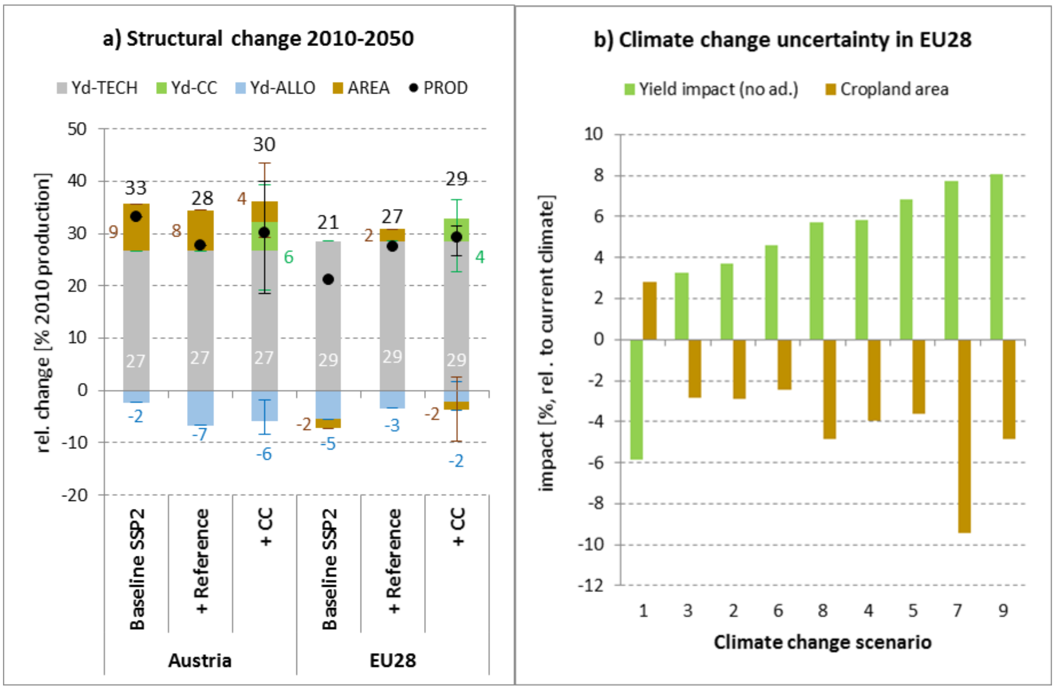

Figure 10: a) Overview of structural changes in the agricultural sector between 2050 and 2010 for the various scenarios for Austria and Europe, and b) uncertainty across climate change scenarios in their impact over EU28 countries. Panel a) displays the relative change between 2010 and 2050 (in percentage of 2010 total calorie production from cropland) in production due to: technological progress on cropland productivity (grey bars/white text), climate change effect on cropland productivity (green bars, error bars and text), effect on cropland productivity of changes in cropland allocation to crops/countries/pixels (blue bars, text and error bars), change in total cropland (brown bars, error bars and text) and net change in production (black dots, text and error bars). Panel b) gives for the individual scenarios (summarized with in error bars in panel a)) the impact in 2050 (i.e., percentage change in 2050 compared to the no climate change scenario) of pure climate change on crop yields (without allocation adjustments, green) and adjustments in cropland area (brown bars).

On average, climate change is relatively favourable to Europe and even helps to satisfy the additional demand for advanced biomaterial products, although there are large disparities within European countries. Without adaptation, total cropland productivity increases on average over Europe (+4%, see Figure 6a)) and is always positive for the various scenarios considered (except when the CO2 fertilization is not accounted for, -6%). There is however large disparities across crops and countries: while corn and sunflower are generally negatively affected, crops such as winter wheat or barley are having positive impact (not shown here). Similarly, Mediterranean countries such as Greece or Italy are on average negatively affected while Northern and Mid-Western European countries are positively affected (not shown here). Impacts in Austria are close to the EU28 average (+6%). Although the demand slightly increases in Europe (+23% instead of +21%, see Figure 8b), on average the production level and trade balance (see Figure 8b) are not much affected. The price of agricultural goods is reduced at European level (-12% from 2010 to 2050, instead of -8%, see Figure 8a) but increases at global level (-1% instead of -3%). The main adjustment is the European agricultural sector is a reduction in total cropland (-2% instead of +2%, see Figure 9a) following the positive effects on yields. This is also the case for Austria (see Figure 9a).

Uncertainty across climate scenarios is large and an average climate scenario might provide inadequate guidance on possible outcomes. This becomes more visible when looking at the individual scenarios: they are displayed by error bars in Figure 8 & Figure 9, and as individual bars in Figure 9b. The spread across scenarios in the effect of climate change on yields, cropland, production and trade balance in Europe, as well as on European and global prices, is at least as large as the average impact. As illustrated, uncertainty concerns **direct climate change impacts on yields** in Europe (green bars Figure 9b), from -6% to +8%, but also **the indirect impacts through differences in opportunities for trade**, and adaptations. For example, in scenarios 7 & 9 the direct effect of climate change is similarly beneficial, but the cropland decrease after adaptation is twice as large in scenario 7: this is due to the fact in this scenario the impacts are beneficial at global scale and Europe cannot export this additional production potential, while in scenario 9 the impacts are negative at global scale which create much more export opportunities to Europe. Finally, as suggested during the exchange with stakeholders, more uncertainty on indirect impacts would emerge if drivers like conflicts would be accounted for.

The benefits of adaptation to climate change, leading to overall positive (for Europe) or small negative (at global scale) might come with undesired environmental impacts. For example, GHG emissions from the land use sector (agriculture, forestry and land use change AFOLU) would increase by 9% between 2010 and 2050 for the baseline in Europe, would not be affected by the Reference scenario (also +9%), but would further increase after adaptation (+13% on average, see Figure 10a). The same result holds for global GHG emissions from the AFOLU sector, and deforestation would be similarly increased by adaptation to climate change (7 million additional hectares deforested compared the baseline, i.e. +16%, see Figure 10b). Deforestation in general remains significant already in the baseline, and European efforts to halt its contribution to deforestation should be strengthened. Similarly, the effects of adaptation on European AFOLU GHG emissions should be further investigated. In addition, we were not able to evaluate the net GHG emission savings generated by the biomaterial scenarios and associated economic rebound effects, and this should be further investigated.

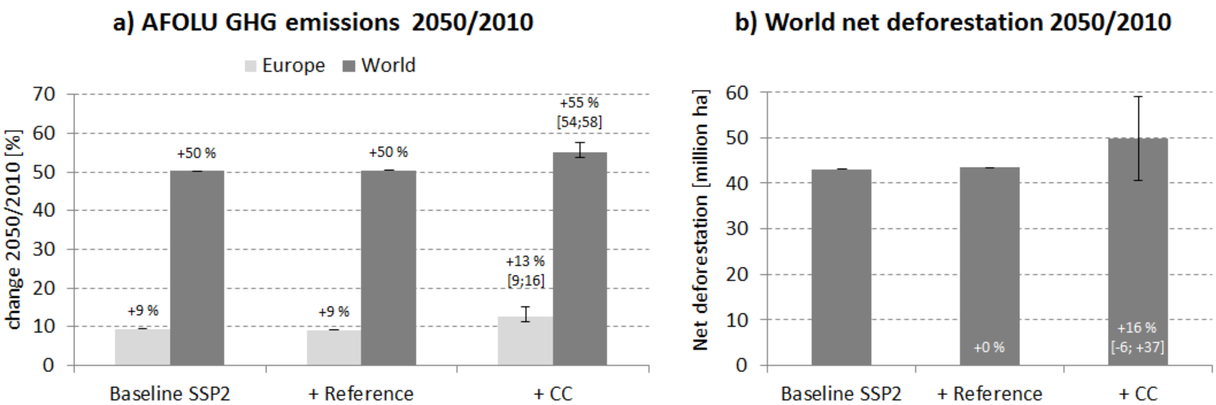

Figure 11: a) Net greenhouse gas (GHG) emissions from the agricultural, forestry and land use change (AFOLU) relative change from 2010 to 2050 (%) at European and global levels. b) Net loss of primary forest at global level between 2010 and 2050. For each panel, results are presented for the baseline (SSP2) scenario: without biomaterial scenarios nor climate change (first bar(s)), with the Reference biomaterial scenario without climate change (second bar(s)) and with the Reference scenario including climate change & adaptation (average over scenarios for the third bar(s), with range across scenarios indicated by the error bars).

PASMA[grid] Results for Austria

In PASMA[grid] we assumed a business as usual (BAU) scenario for all relevant socio-economic parameters, such as policy payments and technologies, which corresponds to the SSP2 in GLOBIOM. For the scenario analysis we accounted for the impact in GLOBIOM on commodity prices for both the 3 biomaterial scenarios as well as the 10 global climate change scenarios. In addition, we also ran the model for four different regional climate change scenarios (High, Similar, Shift and Low; see WP3).

The biomaterial scenarios have only limited impact on land use and selected land use development indicators in Austria, although local hot-spots can be identified in the short-term (i.e. 2020). The biomaterial scenario results from GLOBIOM only show high price increases for potatoes, sugar beets, field peas and moderate increases for many other crops in the short term (i.e. 2020) and in the full transition scenario. In the long term (i.e. 2050) and in the other biomaterial scenarios, price changes on crops produced in Austria are small and thus do not have much impact on model results. The substantial price changes in the full transition scenario in 2020 do affect land use and production choices in PASMA[grid]. Due to crop rotational constraints not all price increases results in an corresponding increase of the respective crop (e.g. sugar beets), but we see large increases in production volumes for potatoes (+28%), field peas (+13%) and winter rape seeds (+4%) at the cost of durum (-15%), sunflowers (-14%) and triticale (-6%). Livestock production is not affected.

Although these changes have only small impacts on relevant land use development indicators at national level (e.g. regional producer surplus, biomass production, fertilizer applications, GHG emissions), we identified some strong regional and local impacts as can be seen in Figure 12. Production regions with favorable conditions for potatoes, field peas and winter rape seed intensify production which can lead to high nitrogen emissions, e.g. Danube flatlands in Upper Austria, the North-West of Lower Austria ("Waldviertel") and the South-East in Styria.

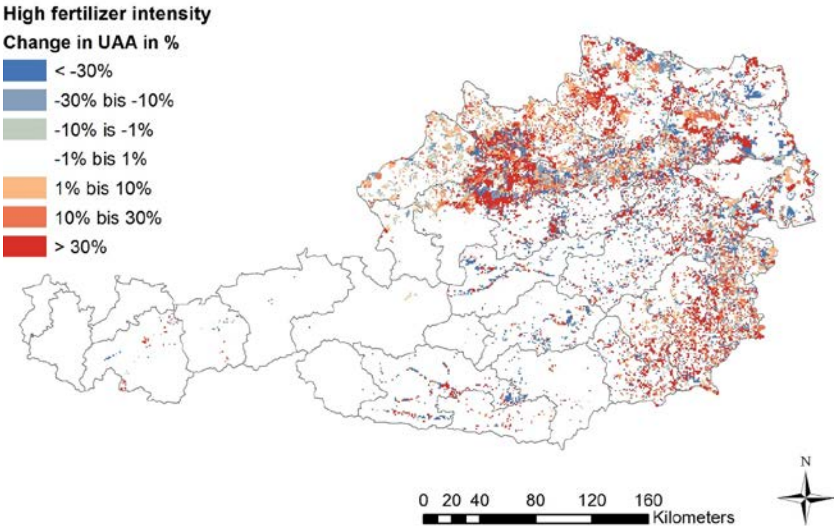

Figure 12: Change in utilized agricultural area (UAA) with high fertilizer intensity management in the full transition scenario in the year 2020. The reference scenario assumes business-as-usual policies and no climate change in the year 2020.

Regional climate change scenarios have a very pronounced impact on land use and land use development indicators in Austria, even when autonomous adaptation measures are accounted for. These impacts are also quite heterogeneous and differ especially among the cool and humid areas in the West (mostly alpine grassland regions) – which may utilize increases in plant growth productivity – and the relatively warmer and drier croplands in the East and South-East of Austria – which may suffer from production losses. Generally speaking, the model adapts to positive changes in productivity by increasing land use intensity (e.g. higher fertilization intensity) and to negative changes in productivity by either extensifying or by applying irrigation schemes (especially in the croplands in the East of Austria). Figure 13 illustrates these impacts by looking at changes in fertilizer application rates. Changes in fertilizer intensity thereby correlate with changes in plant productivity. Only in regions where water becomes a limiting factor (East and South-East) do farmers adapt to climate change by lowering fertilizer intensity levels (blue color).

At national level (see Figure 14) we find a small but positive impacts on agricultural producer surplus for all (between +0.3% in *Shift* and +1.2% in *High*), but the *Low* climate change scenarios (-1%). Biomass production increases in all regional climate change scenarios (between +3.2% in *Low* to +10.3% in *High*), most of which is attributed to large increases in grassland productivity. Biomass from cropland actually decreases in all (between -8.0% in Low and -2.3% in *Similar*) but the High scenario (+0.1%). Nitrogen application increases at national level in all scenarios (between +0.7% in *Low* and +8.3% in *High*). Similar results are also observed for phosphor application as well as GHG emissions. **This indicates that regional climate change may increase trade-offs between agricultural production and environmental indicators**.

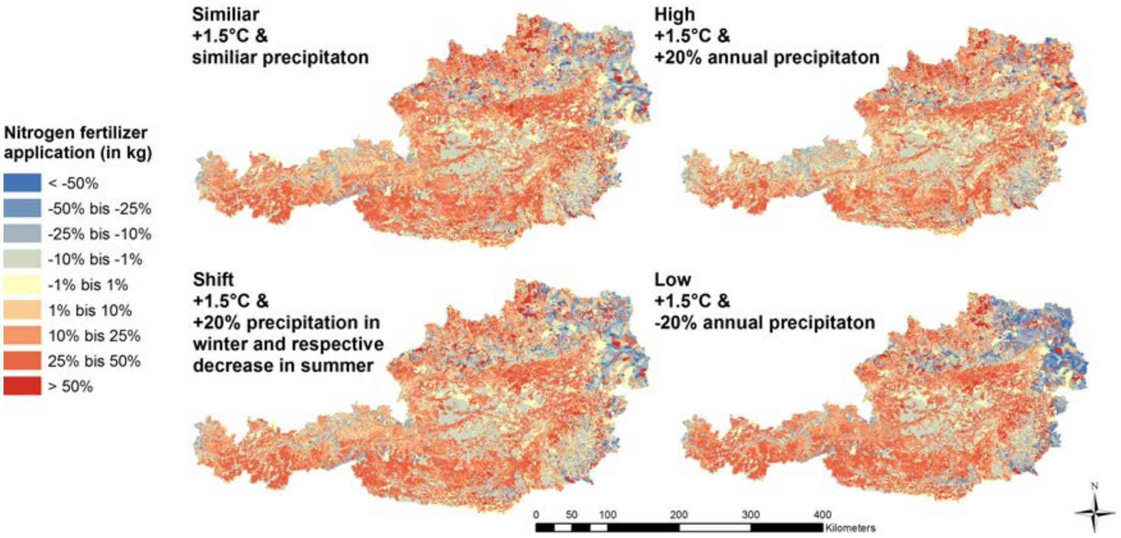

Figure 13: The impact of regional climate change scenarios on nitrogen fertilizer application rates in the year 2040 at 1km² resolution. The reference scenario assumes BAU and no climate change in the year 2040.

Indirect climate change impacts have only marginal impacts on land use and selected land use development indicators in Austria and add only little to overall climate change uncertainty. Indirect climate change impacts affect land use choices and indicators through changes in commodity prices. These remain quite low due to the buffering effects of trade at global level (see GLOBIOM results). Nonetheless, as illustrated in Figure 10 indirect climate change can increases the range of impacts, especially with respect to agricultural producer surplus. The global climate change scenario GFDL-ESM2M + RCP8p5 amplifies the differences between East and West in Austria the most, whereas the global climate change scenario HadGEM2-ES + RCP8p5 + No CO2 fert, is the most beneficial in economic terms, as it shows the highest price increases at global level and in Austria. Figure 14 also includes the impact of indirect global climate change on selected land use development indicators at national level in Austria. It clearly shows that the major bandwidth of climate change impacts is largely determined by the impacts of the regional climate change scenarios. Price changes induced due to climate change impacts at global level increase the uncertainty within each regional climate change scenarios, but do not considerable affect the total range of uncertainty.

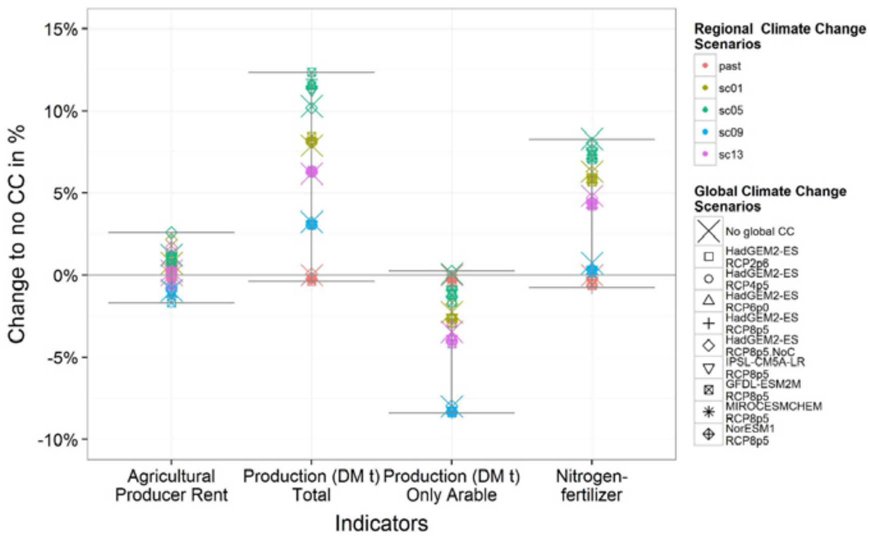

Figure 14: Direct and indirect climate change impacts on selected land use development indicators in Austria in 2040. The reference scenario assume BAU and no climate change in the year 2040.

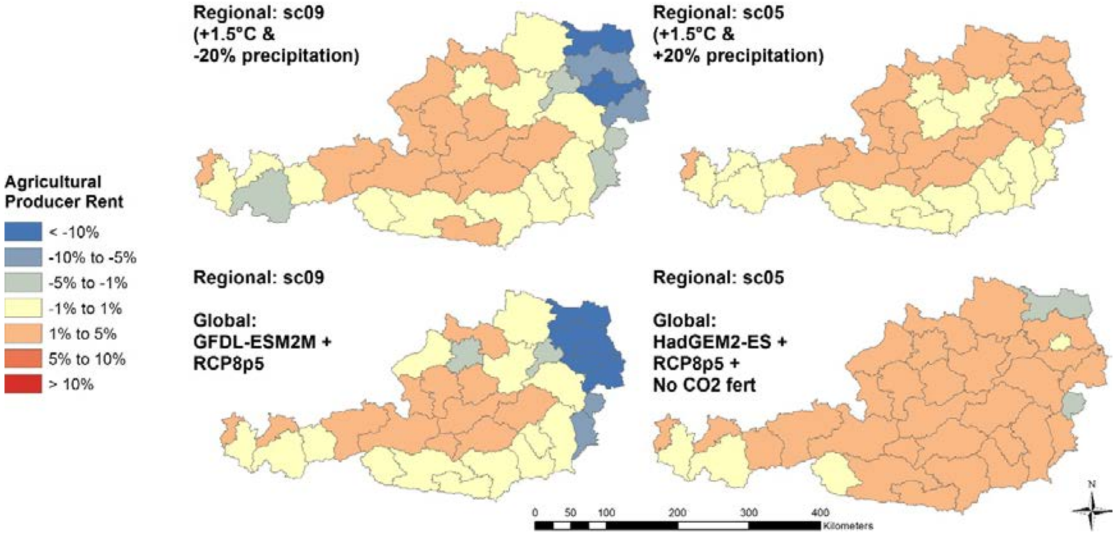

Figure 15: Range of impact for direct climate change (above) and direct + indirect climate change (below) in Austria the period 2025-2040. The reference scenario assume BAU and no climate change in the period 2025-2040.

ADAGIO Results

The biomaterial scenarios as developed before focus on the European economies: it is here that the transition towards a more bio-based economy is assumed. Through globalization and trade, however, the effects of this transition might be felt around the world. As a world model, ADAGIO is well suited to capture these knock-on effects on the world outside Europe. In the following, we will present the results for three (aggregate) regions: AUT, the EU27, and "Rest-of-the-World" (as well as the world total).

Biomaterial scenarios

Of course, with only a small number of countries affected (and only a low level of substitution), the economic effects of the Stagnation scenario are rather subdued, barely perceptibly raising the level of GDP in all three regions (see Figure 16). The Reference scenario, however, shows an increasing trend until 2030, when the expansion levels off, some +0.1% (EU) to +0.4% (AUT) above the base run solution. In the case of the Full Transition scenario, the expansionary effect in 2020-2030 is quite steep, although at a peak of around 0.25-0.55%, it again is not enormous. In this scenario, the expansionary phase is followed by a reduction of the effects' size to what seems to be a lower, but permanent level. Through most of the simulation period, the knock-on effects imply that the impact on the Rest-of-the-World is actually the largest across all three regions.

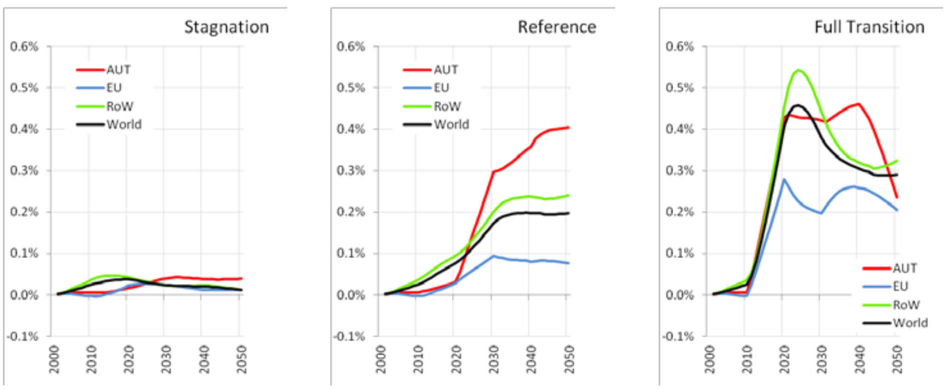

Figure 16: Total economic effects of three biomaterial scenarios. Source: own calculations.

The decomposition of the total effect shows very diverse specific time paths. We disaggregate the total effect into three specific routes of influence, whose relative importance will be determined using ADAGIO:

1. Output (and production technology) changes lead to UPSTREAM effects: changes in the level of agricultural output as well as changes in the production technology of the agricultural sector lead to changes in the level

and structure of demand for intermediate (and investment) goods. This leads to new flow patterns from upstream sectors.

2. Price changes in the agricultural sector lead to DOWNSTREAM effects on other sectors of the economy. Directly, this affects users of agricultural products. Indirectly, these price changes affects virtually all sectors of the economy – agricultural prices feed into food prices, which themselves feed into prices of restaurants and so on. Ultimately, the general price level will be affected, which in many countries has a quite immediate effect on wages (wage bargaining is usually conducted with an eye on the general price level).
3. Third, the premises of the Biomaterial scenarios involve a reduction in crude oil consumption (which is substituted for by agricultural products). This has an immediate bearing on the oil sector. Of course, the largest effect is on those countries whose economy is most dependent on the European oil market (Russia, Norway, UK, Northern Africa, Middle East). There are, however, feedback effects on oil consumers as well – if oil exporting countries become poorer, they will import less goods and services, to the disadvantage also of oil importing countries.

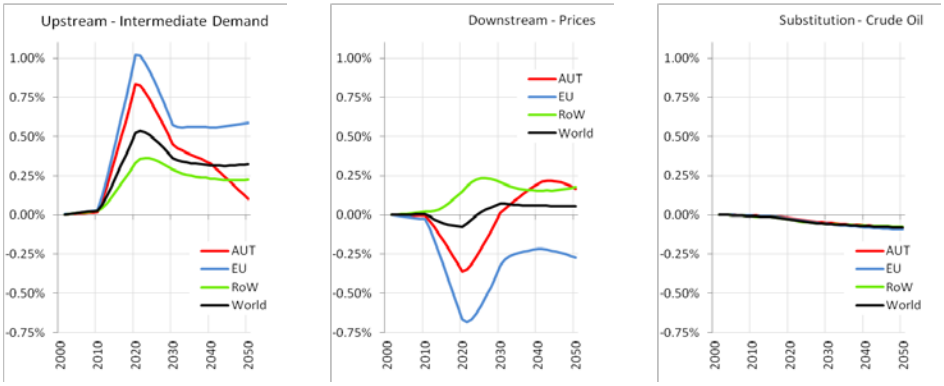

Figure 17: Decomposition of effects (Full Transition biomaterial scenario). Source: own calculations.

Figure 18 shows that upstream effects are positive in all regions, and right from the beginning. This comes as no surprise: the bio-based economy involves a sizable increase in agricultural production, which has a positive effect on the suppliers of intermediate inputs. This increase is to a very small degree only offset by a reduction in crude-oil consumption (Substitution scenario). Again, this should not be surprising: the volume of crude oil replaced by biomaterials, when compared with total oil consumption, is rather small. When total effects are considered, the immediate reduction in crude oil consumption through substitution by agricultural products, ironically, is partially compensated for by the necessary rise in farm output and intensification of farming practices, as both these effects will lead to higher energy demand in the agricultural sector - and, barring a complete de-fossilization of farming (which is not considered here) - this will lead to an increase in fossil fuel consumption, thereby dampening the initial reduction in crude oil demand.

As for the second route of influence, in the countries affected by the transition to the bio-based economy, via the EU27, the accompanying increase in demand for agricultural products leads to a price rise – even if agricultural prices rise everywhere in response to the demand increase, it is the European countries that face the highest price increases. This, then, produces negative downstream effects: users of agricultural products are confronted with higher prices for their (agricultural) inputs, and react with price increases themselves, leading to deteriorating terms-of-trade. Over time, however, the negative impact is mitigated when users learn to "live with" higher prices for agricultural products (at least partly this is brought about by substitution effects). RoW is a double beneficiary of the price increases: not only are accompanying price increases much smaller than in the EU countries, the now relatively lower prices vis a vis the EU countries lead to trade diversion away from the EU, to the advantage of the Rest-of-the-World.

Figure 18 shows the impact of the Full Transition scenario on the GDP of the 67 model countries (average GDP effect for 2010-2050).

Sectoral effects are quite diverse – not only between sectors in the same region, but also between the same sector in different regions. In Austria, agriculture and forestry exhibit developments characterized by substitution: while agriculture expands markedly until 2050, forestry contracts. The reason for this is that the reduction in cultivated area, which would have happened were it not for the biomaterial scenarios, is actually reversed. The area which would have gone out of agricultural production, however, would have been converted to forestry usage – as this does not happen in the biomaterial scenarios, forestry loses relative to the non-biomaterial base run. At the level of the EU27, an initial expansion of agricultural value added is followed by a contraction towards the end of the simulation period. At that time, negative price effects begin to dominate the expansionary drive of the bio-economy. In the EU, however, forestry and agriculture do not play the substitutional role as in Austria; as a result, forestry follows an expansionary path until 2050. Outside Europe, impacts in the primary sector are more subdued, with agriculture gaining only around 0.2-0.3% on average; forestry follows a more sinuous path, small gains earlier in the simulation period followed by small losses later on. Toward 2050, forestry again witnesses a positive shock in the rest of the world.

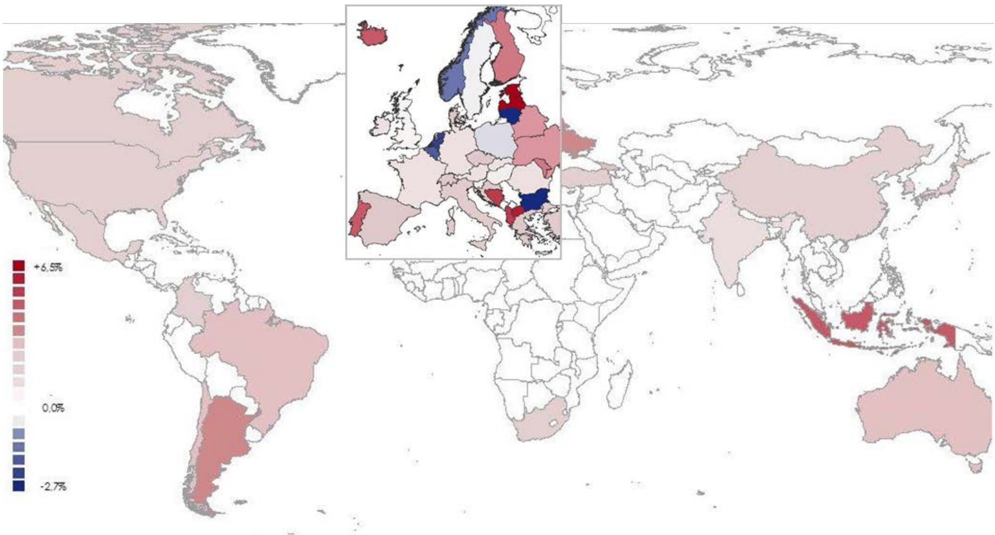

Figure 18: Impact of the Full Transition scenario on regional GDP. Source: own calculations.

As for the production of food and beverages, the main sector influenced by donwstream (i.e. price) effects, this sector faces a positive shock in Austria after around 2030 (as well as in the Rest-of-the-World, though to a smaller extent) and a negative effect in the EU27. Here, actually two effects combine to give this result: first, the price effect, with a negative impact on demand for food and beverages, which is counteracted by a positive demand shock induced by a positive development in regional GDP (although unelastic - the elasticity is less than 1 – an increase in income produces c.p. an increase in food demand). Other sectors for which agricultural prices are important are clothes, textiles and leather products; here, the effects are regionally quite diverse, implying a complex pattern of domestic output price, import prices (these sectors are characterised by globally organised supply chains), and changes in demand following increases in income.

An interesting case, of course, is sector 23, the production of refined petroleum products: in all regions and over the course of the whole simulation period, this sectors exhibits positive development (which in the case of Austria and the EU in general, is also among the sectors with the highest impact). Given that the bio-based economy started from the premise of substituting fossil fuels, this clearly warrants an explanation. Actually, it is two sets of reasons, one the consequence of a "technology assumption", the other one of the general economic development. The "technology assumption" means that in the simulations, we assumed that the production of the bio-based materials is organized in the same sector as the replaced fossil-based materials, as this substitution is one of degree more than one of kind: whether bio-derived or fossil-based, quite similar chemical processes are needed to convert the raw materials into usable forms like polymers and plastics. As a consequence, sector 23 does not lose out in the biobased economy, but only replaces fossil inputs by bio-derived inputs (it is only sector 11 – extraction of crude oil – which is hurt by the direct consequences of the bio-based economy, as duly happens in all regions).

So, the technology assumptions ensures that sector 23 does not face negative impact in the bio-based economy. The reason for its actual expansion lies elsewhere and is very similar to the rationale pertaining to the service sectors: economic expansion increases demand for the products of most sectors (demand for virtually all products rises with a rise in income). In the case of fuels, however, the effect is augmented by the demand (and consequent supply) shock for agricultural products: agriculture is an important user of fuel, chemicals and fertilizer, all of which pertain to sector 23 – fuel is a direct product of sector 23, while chemicals and fertilzers are produced by sector 24, which, however, is an important user of output of sector 23.

Service sectors ("genuine service sectors" start from the trade sectors 50-52, but also include sectors 40-45, electrity supply, water supply, and construction), in general exhibit developments which resemble the regional

GDP paths. This can be explained by the nature of demand for and supply of services: as for demand, services play a greater role in final demand than they do in intermediate demand. Shocks in final demand, therefore, exert a relatively large impact on the service sectors. However, final demand (especially its most important components, private and public consumption, are closely linked to the general economic development, which faces a positive shock in the biomaterial scenarios). Supply, on the other hand, is primarily regional: international trade in services is of secondary importance. This predominance of local supply, combined with the importance of local economic conditions for service demand, implies a close correlation between the developments of the general economy and the service sectors (which, in the course of the economic circle, acquires a strong feedback flavor, when additional demand for services creates additional demand derived from income).

Vulnerability of the Biobased Economy – Global Change scenarios

To assess the risks posed by climate change (the "vulnerability of the bio-based economy"), we combine the Full Transition biomaterial scenario with different assumptions about climate change (see Figure 18).

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Figure 19: Climate change impacts in ADAGIO. Source: own calculations.

The overlay of climate change scenarios on top of the Full Transition biomaterial scenarios tilts the economic pathways until the end of the simulation period in 2050. The regional pattern is similar in most scenarios and – of course – reflects the basic effects of climate change on the agricultural sector: for Europe, this effect is small and even positive; (partly substantial) negative effects are to be expected in non-European regions.

In all CC scenarios, the Biobased Economy (pictured are the effects from the High Biomat-scenario) leads to an increase in GDP in all regions, with a peak in this development in the early 2020s. This expansionary effect wears off afterwards, but remains positive in most of the simulated CC scenarios, at least in Europe (in the Rest-of-the-World, CC induced contraction starts to gain the upper hand sometime in the 2030s or 2040s). In most CC scenarios, however, the trend at the end of the simulation period faces downward, so that after 2050, contractionary might be expected in all regions

WP7: Dissemination and Stakeholder Process

The first stakeholder workshop on 2013-11-24 was attended by seven stakeholders from private industries (Papierholz Austria), extension services (WKO, Ecoplus Kunsstoff-Cluster), administrative agencies (Wiener Umweltanwaltschaft), environmental NGOs (Platform Footprint), as well as private (Austrian Institute of Ecology) and public research institutes (Institute of Applied Synthetic Chemistry, TU Vienna).

The project team provided an overview of the project, detailed information on the models involved, presented illustrative results of predecessor studies, as well as the bio-economy concept and respective demand scenarios. This was followed by an open discussion at the end. However, stakeholders were encouraged to already ask questions and to comment during the presentation. This ensured a good and continuous exchange between researches and stakeholders during the meeting. Many questions regarding model understanding and research focus could be clarified. Important issues that were raised by stakeholders were, among many others: consideration of climate extremes; the importance of global aspects for climate change analyses; limitations with regard to the use of biomass for synthetic materials; consideration of biodiversity in the bio-economic demand scenarios; be aware of the competition between paper and biomass industry; impact of change in diets; include worst-case scenario. The overall feedback from the stakeholders was good and the meeting itself successful. Due to time, budget and modelling constraints not all issues can be addressed by the project team (e.g. impact of change on diets, biodiversity, or footprint calculations). However, it was very helpful to see what matters most to the stakeholders in order to take these issues into account to the best extent possible in our analyses (e.g. global linkages, drought, price scenarios and competition of biomass resources). The meeting showed that our project addresses issues relevant to all stakeholders and to the institutions they represent.

Due to delays in model and scenario development, the second stakeholder workshop took place on 2015-09-04, i.e. half a year later as expected. Although six stakeholders confirmed their participation, most cancelled shortly before the meeting and it was thus only attended by two. Nevertheless, these two stakeholder were very engaged and provided us with ample feedback. For the biomaterial scenarios stakeholders see (i) a substitution potential at 30% (= reference scenario); (ii) that new players, specialized and diverse sectors will emerge; and (iii) that the assumptions made are reasonable. With respect to climate change stakeholders noted that (i) impacts on calorie production are interesting, (ii) impacts on different crops are interesting (oil plants in particular); and (iii) positive impact is doubted because of the emergence of extreme events. The Stakeholders also wished that we should focus more on externalities and leakage effects, e.g. GHG emissions or deforestation. The protocol of the meeting was later send out to all stakeholders. We also received an additional e-mail by one of the stakeholders, which laid out, in detail, that there may be serious flaws in our theoretical assumptions taken in our modelling approach. In particular, the role of out-of-equilibrium dynamics was discussed, with respect to how the changing productivity in agriculture and forestry are mitigated by trade in our modelling approach.

A final stakeholder workshop took place on 2015-12-14 in which our final scenario results were presented. Again, similar to the second workshop, only two stakeholders participated (different ones than in the second workshop) although we had six confirmations. Nonetheless, the discussions were fruitful and helpful for a final framing of the results. The discussions centred about details in the biomaterial assumptions, the buffering effect of adaptation measures with respect to scenario impacts, leakage effects, and competition for biomass in the industries (e.g. tall oil). The protocol of the meeting was again send out to all stakeholders.

5 Conclusions and Recommendations

Summary of major results

Biomass demand scenarios for materials

We developed three different biomass substitution scenarios for fossil-based materials for the following products: surfactants, solvents, lubricants, polymers and bitumen. The "Stagnation scenario" assumes that 5% of all fossil based materials (excluding bitumen) are substituted by bio-based materials today and no expansion is considered in this scenario. The "reference scenario" discusses a 40% substitution of fossil based production quantities with bio-based production quantities for lubricants, biodegradable polymers, solvents and PET. This scenario illustrates a less optimistic and less technological world that still shows significant market developments for some bio-based materials. The "full transition scenario" illustrates a 70% substitution for all products in 2050 including other drop-in polymers and bitumen and outlines an ambitious development of advanced biomaterials production. This scenario discusses a world in which a higher focus is set on substitution of fossil based materials with biomaterials.

GLOBIOM – Global and Europe

If leaving climate change aside, the simulations with the global model GLOBIOM indicates a relatively favourable future in the decades to come for European agriculture with a capacity to increase production levels faster than in other regions of the world, and faster than the European demand. Europe would reduce its imports and become a small exporter (or large in the case of SSP3, in which the population drops in Europe). Different trends are expected across Member States of the European Union, but Austria would see its production and cropland slightly increasing.

In this context, the need for additional biomass associated to a realistic development of the bio-economy (Reference scenario) would induce only a small increase in the price of agricultural goods by 2050. More specifically, such a development of the bio-economy would not reverse the projected long-term decline in prices, a trend consistent with the last decades if excluding the 2008 food crisis. The later provides an interesting perspective to our results: it owes to factors similar to what can be found in our scenarios (fast development of biofuel production, comparable to the Full transition scenario), but also to factors that we do not model, such as short-term export restrictions, speculative trading of agricultural goods, dramatic weather on a few breadbaskets. We found that a fast development as pictured in the Full transition scenario could have large price effects in the short-term. A fast transition to the bio-economy could thus carry risks similar to the 2008 food crisis - however, our models are not adequate to tackle these questions accurately, and this scenario is not seen as very realistic by the stakeholders.

Including climate change translates into more uncertainty on top of the above picture. On average, climate change would be beneficial to Europe with positive direct local impacts on crop yields and positive indirect impacts via increased competitiveness. This would facilitate the contribution to the bio-economy, lower its effects on prices and save cropland. Although this remains true for Austria, Mediterranean countries such as Greece or Italy would however be negatively affected. More importantly, both indirect and direct impacts are highly uncertain, leading to more uncertain outcomes with respect to prices, trade balance, cropland extent and production levels, as well as long-term structural adjustments across EU Member States. While this uncertainty is more a modulation of baseline trends than a strong deviation from trends at the Austrian and EU28 levels, this means climate change will make long-term projections more uncertain, and make both the transition to a bio-economy and adaptation to climate change an increased source of risk for European producers. Another important aspect to consider is that adaptation to climate change comes at the cost of increased pressure on the environment in other parts of the world (e.g., deforestation) but also in Europe (increased greenhouse gas emissions).

PASMA[grid] - Austria

For Austria, the biomaterial scenarios only show substantial impact in the short term and for the full transition scenario, which is consistent with the GLOBIOM results. In the long term, price changes are too marginal to significantly affect model outputs. The short term impacts in the full transition scenario see an increase in potatoes, field peas and winter rape seeds. While impacts on relevant land use development indicators at national level (e.g. regional producer surplus, biomass production, fertilizer applications, GHG emissions) remain small at national level even in the short term, we can identify some strong regional and local impacts such as land use intensification in productions regions with favorable conditions for the crops mentioned above (e.g. Danube flatlands in Upper Austria, the North-West of Lower Austria ("Waldviertel") and the South-East in Styria).

Regional climate change scenarios have a very pronounced impact on crop productivity and thus land use and land use development indicators in Austria, even when autonomous adaptation measures are accounted for. These impacts are quite heterogeneous and differ especially among the cool and humid areas in the West (mostly alpine grassland regions) – which may utilize increases in plant growth productivity – and the relatively warmer and drier croplands in the East and South-East of Austria – which may suffer from production losses. Farmers adapt to these changes in productivity mainly by intensifying land use (e.g. fertilizer application rates), where increased crop productivity can be utilized, and by extensifying land use where crop productivity decreases. As the former dominates, we see a deterioration of environmental land use development indicators at national level, such as increased fertilizer application rates and GHG emissions, but also an increase in economic output.

Indirect climate change impacts affect land use choices and indicators through changes in commodity prices (simulated in GLOBIOM). These remain quite low due to the buffering effects of trade at global level. Therefore we only see small impacts of indirect climate change on land use and land use development indicators in Austria. Within our modelling framework much more uncertainty can be attributed to direct regional climate change impacts than to indirect ones for Austria.

ADAGIO - Economic wide results

The Stagnation scenarios only affects a small number of countries (and only a low level of substitution). Hence, the economic effects are rather subdued, barely raising the level of GDP in all three regions. In contrast, in the Full Transition scenario the level of GDP is perceptibly higher (though still not in an overwhelming way), peaking at an increase of around 0.5% in the early 2020s. The impact is highest for the Rest-of-the-World and Austria; for the EU28, the impact is about half.

The main reason for this heterogeneous result is the relative importance of the three main paths of influence: the rest of the economy is linked to the agricultural sector via upstream and downstream effects[9], leading to a loss of competitiveness. The Rest-of-the-World experiences the least price increases; accordingly, the positive upstream impacts of increased agricultural production are only to a small extent crowded out by rising prices for downstream sectors. This also means that in relative terms, agricultural prices in RoW actually drop in comparison to the EU prices, where price increases are much more substantial. This diverts trade away from the EU and towards the RoW. Austria faces a special situation: here, price increases are smaller than in the rest of the EU, because the expansion in farming output is brought about by a re-cultivation of land which in the base run would have been converted to forest usage. As a result, agricultural prices remain lower, but at the expense of the forestry sector's output.

The third venue by which the rise of bio-based materials influences the wider economy is via a reduction of crude oil consumption. This directly affects oil producers; indirectly, however, it affects virtually all sectors in all countries (although of course to varying degrees), as a drop in oil producers' income will lead to a drop in their consumption. The effect from this factor is of lesser importance, however, as the volumes of crude oil conserved by the biobased economy are only a small part of total oil consumption. Moreover, the overall expansionary effect of the bio-based economy leads to an increase in the demand for crude oil, both from higher final demand as well as from higher demand from a marked increase (and intensification) in agricultural production (the farming sector being an above-average user of oil-based products, either as fuel or in the form of chemicals and fertilizers). This might be viewed as an "income-induced rebound effect".

The expansionary effect peaks in the early 2020s; towards the end of the simulation period, the effect is around half of this earlier peak. The effect of climate change is quite regional-specific: whereas in Europe, climate change seems to have no overwhelming impact on the time path of the expansionary effect (the impact remains positive throughout the simulation period for all CC scenarios), the economic development of the RoW is quite dependent on different CC scenarios. In some scenarios, the initially positive effect is completely wiped out in the second half of the simulation period; in some scenarios, CC exerts even a contractionary influence, despite the bio-economy's positive stimulus.

[9] Upstream effects capture changes in the input requirement of the farming sector; this directly impacts the demand for other sectors' products. Downstream effects are of a more indirect quality: changes in the price of agricultural products affect those sectors which use farming products in their own production process; the most important (but not exclusive) user of agricultural products being the food sector. If agricultural prices rise, so will the input prices (and, consequently, output prices) of those sectors.

Conclusions

Our project provides first European-wide long term biomass substitution scenarios for fossil based materials and assesses their impact on land use, selected environmental indicators and the economy. In addition, we include the impacts of direct and indirect climate change on the bio-economy at global and European level, as well as for Austria specifically.

The model simulations show that there is potential to increase the supply of bio-based materials in the EU without significant impacts on land use and environmental indicators in the EU and Austria, although some local hot-spots are identified. Moreover, the ADAGIO model indicates that, due to economic wide rebound effects, crude oil consumption may actually increase. Climate change will, on average, affect the production potential only moderately until 2050. However, climate change impacts are spatially very heterogeneous and add a lot of uncertainty to the analyses. The impacts on GDP are small but positive for the biomaterial scenarios as well as scenario, region and time dependent for the climate change scenarios (e.g. initial increases in GDP are reversed later in some scenarios).

At European level, GLOBIOM simulates that the main adjustment pathways to either an additional demand of biomass for biomaterials or to climate change will occur continuously over time via market-driven changes in the trade balance and in the structure of the European agricultural sector. This will contribute relatively smoothly over time to changes in the extent and distribution of various types of production across Member States, which could be rather deep at local scale. For Austria, PASMA[grid] simulates that land users may adapt autonomously to higher productivity by intensifying land use, thereby utilizing new opportunities, or to adapt to lower productivity by extensifying land use or by applying irrigation schemes, thereby mitigating potential production losses. The overall gains in production potentials expected in Europe may lead to environmental deterioration due to private adaptation measures, as exemplified in the model results for Austria. Moreover, reshuffling of production potentials across world regions may increase global net deforestation rates and GHG emissions.

Given the large uncertainty of climate change impacts policies should try to buffer the risks associated with this increased uncertainty concerning the state of world markets, and the increased exposure of European producers to these markets. Furthermore, policies may need to be put in place to counteract incentives for environmentally damaging autonomous adaptation choices. These need to tackle impacts at global (e.g. leakage), regional (e.g. CAP), national (e.g. agri-environmental measures) and local level (e.g. focus areas). How to align different policy measures at different levels will remain a challenge.

Further Steps

We plan to submit a full paper to an SCI journal based on the results and conclusions drawn here in the final report. We would also like to quantify the GHG emissions savings by biomaterials in a next step. Currently, the biomaterial scenarios are also used in the ACRP project BioTransform.at, which focuses on transformation scenarios to a low-carbon society in Austria. Moreover, another ACRP project aims to assess mitigation options in the livestock sector for Austrian agriculture (CAT-MILK). Furthermore, a project proposal will be submitted with focus on uncertainty propagation in integrated modelling frameworks. This issue has so far been not sufficiently addressed by the scientific community.

Dissemination to other target groups

The results have been discussed vividly with stakeholders and found to be of importance to them (see section 2.2.3.8). We were able to reach out to many different institutions, i.e. chemical industry, technology clusters, environmental agencies, NGOs, energy providers, and academia.

B) Project Details

6 Method

In section 3 we have already outlined the reasons for our methodological approach. First, we fill a research gap in the scientific community by providing first of its kind European biomaterial scenarios for the future. These are translated to specific biomass demands and integrated into GLOBIOM, a global partial equilibrium model for agriculture, forestry and bioenergy. Second, we want to address impacts of increased demand for biomass for bio-materials as well as climate change from global to local levels. Interlinkages at different spatial scales for global change studies are receiving more and more attention among scholars, but not many applications currently exist that really tackle the issue from global to very local levels (e.g. Wolf (2015)), and certainly not for Austria.

We have already provided detailed information on the bio-material scenarios in WP1 (section 4). Therefore, this section will concentrate on our integrated modelling framework and its individual models.

The integrated modelling framework

Figure 12 displays the integrated modelling framework (IMF) for our project. In aims to capture the multitude of factors that affect the bio-economy, land use and associated environmental impacts, as well as overall economic effects. We therefore link various stand-alone disciplinary models to better capture interlinkages between climate, the bio-economy, and the environment. Furthermore, we apply different scenarios that aim to capture the main driving forces of this system, i.e.: climate change, biomass demand, and socio-economic scenarios (these scenarios are described in section 4 in the respective WPs). The IMF comprises of the bio-physical process model EPIC (Balkovič et al., 2013), the global partial equilibrium model for agriculture, bioenergy and forestry GLOBIOM (Havlík et al., 2011), the Austrian agricultural and forestry sector model PASMA[grid] (Kirchner et al., 2016) and the global Input-Output model ADAGIO (a geographical extension of the model described in Kratena et al., 2013).

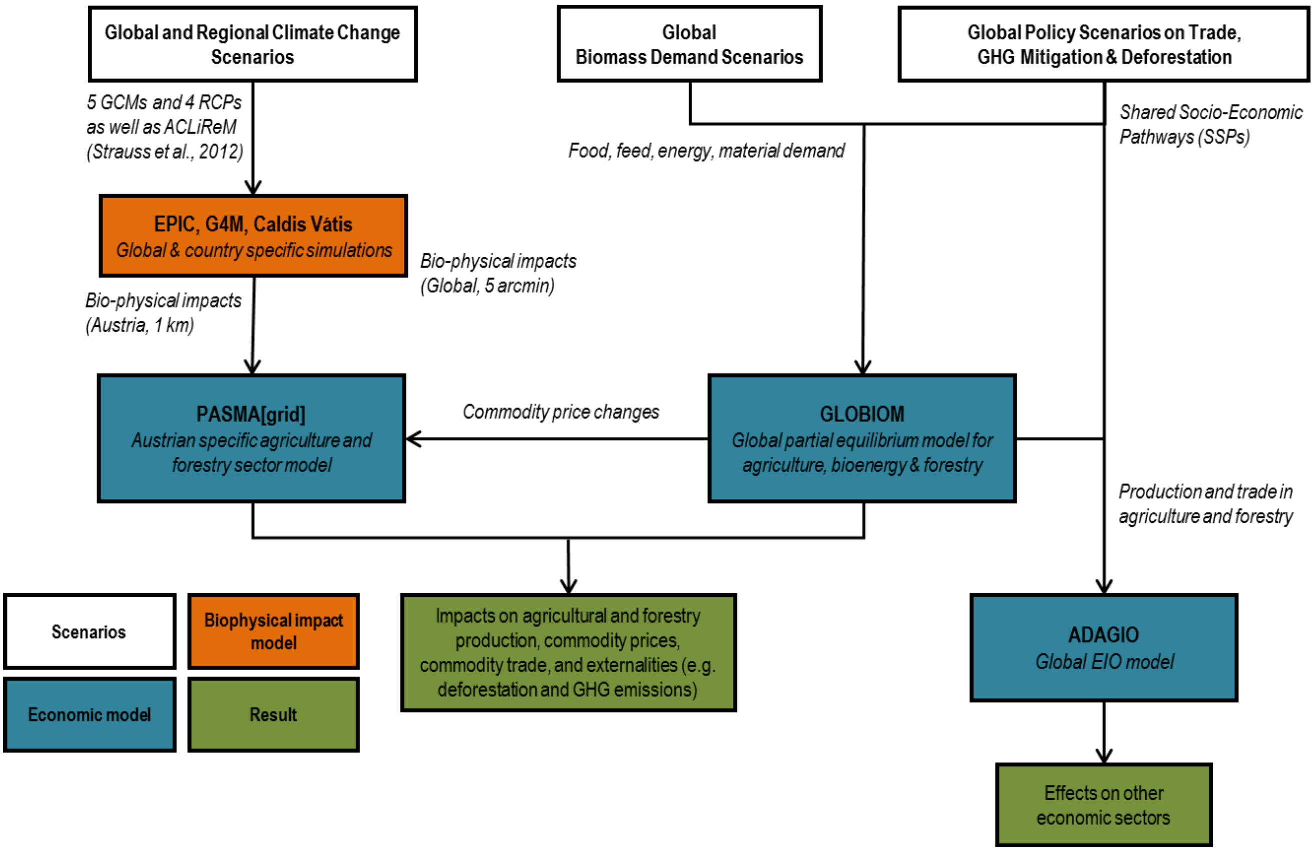

Figure 20: The integrated modelling framework for the CC2BBE project.

Model linkages

Climate Data and EPIC

Climate data for EPIC is provided by the regional climate change model ACLiReM (Strauss et al., 2013) for Austria (daily climate data for Austria at a resolution of 1km² until 2040) as well as from general circulation models (GCMs) at global level (30 arcmin until 2050). This affects the outputs of EPIC, i.e. plant growth, nutrient cycles and soil erosions at both global level at 5 arcmin arc and at 1km² for Austria.

EPIC and PASMA[grid]/GLOBIOM

Plant growth data from EPIC is provided for both PASMA[grid] and GLOBIOM for the various climate change scenarios. Changes in plant growth can significantly affect land use and production decisions in these models. The interface between the spatially stratified biophysical simulation data from EPIC and the bottom-up economic land use models applies the concept of homogeneous response units (HRUs) (Schmid, 2007; Stürmer et al., 2013). An HRU shares the same natural characteristics such as elevation, slope and soil type and allows consistent aggregation of impacts in bottom-up economic land use optimization models. Thus, economic land use models can integrate heterogeneous biophysical impact data at the intersection of HRU and a given spatial boundary (e.g. municipality) which results in unique geo-referenced spatial units (1km² for PASMA[grid] and 5 arcmin for GLOBIOM). This approach allows better representation of heterogeneities in farming responses and localisation of hot-spots.

PASMA[grid] and GLOBIOM

Further driving forces considered in GLOBIOM are biomass demand scenarios as well as the shared socio-economic pathways (SSPs). The later affect technological progress, food demand and trade opportunities. Both these scenarios as well as climate change affect global commodity prices which can be transmitted to PASMA[grid] via border price changes in the respective scenarios.

GLOBIOM and ADAGIO

GLOBIOM output data, such as production and intermediate inputs, are transmitted to ADAGIO, which can thus simulate the overall economic impacts induced by production changes in the agriculture and forestry sector. The variables taken from GLOBIOM include gross output of agriculture and forestry as well as output prices of the agricultural sector. The variables are introduced into ADAGIO as percentage changes vis a vis the base run. In this way, differences in the definition of, e.g., the "agricultural sector" can be overcome (there are some differences between ADAGIO and GLOBIOM in some definitions, especially a somewhat different boundary between "agricultural products" and "processed food", which ADAGIO attributes to a different sector). The differences are rather small, but existent). The changes are calculated for the 67 ADAGIO regions individually, based on regional correspondence to the 30 GLOBIOM regions. A second correspondence matrix aggregates GLOBIOM's 18 crops into ADAGIO's single agricultural sector, taking into account the impact of changes in the crop structure as well as farming intensities on the aggregate agricultural technology (which in ADAGIO determines the upstream effects – i.e. which products are provided by other sectors of the economy as inputs for the farming sector).

EPIC

The biophysical process model *EPIC* (Balkovič et al., 2013; Izaurralde et al., 2006; Williams, 1995) provides information on the level and variability of crop yields and environmental outcomes (e.g. soil organic carbon stocks – SOC) of alternative crop management practices. It takes topography, soil characteristics, weather, and crop management (e.g. fertilization intensity) into account. *EPIC* outputs are differentiated at a spatial resolution of 1km.

PASMA[grid]

$\text{PASMA}_{[\text{grid}]}$ builds on the Austrian agricultural and forestry sector model PASMA (Schmid et al., 2007; Schmid and Sinabell, 2007), but represents in more detail the structural and environmental heterogeneity of agricultural production. Agricultural land comprises cropland, grassland, Alpine meadows, permanent crops (i.e. wine, fruit orchards and short rotation coppice) and managed forests at 1 km resolution. Livestock production is modeled at NUTS3 level including feed and fertilizer balances. Within this project we have applied extensive validation, sensitivity and uncertainty analysis, as well as documentation of the model (see Kirchner et al., 2016).

Figure 2 gives an overview of the model structure. The objective function of the model maximizes producer surplus for each NUTS3 region subject to natural, structural and regional farm resource endowments (e.g. amount of agricultural land or livestock housing capacity available in a region) as well as technical restrictions (e.g. feed and fertilizer balances). To avoid over-specialization, observed land use and livestock activities provide boundaries and compositions from which the model chooses optimal convex combinations (McCarl, 1982), i.e. the solution space of the model is limited to what has been observed in the past (albeit relaxations are possible in particular scenario applications). $PASMA_{[grid]}$ is a bottom-up agricultural and forestry production model operating under the small country assumption, i.e. commodity prices are exogenously given and market feedbacks are not accounted for endogenously. It optimizes agricultural and forestry land use and livestock management for independent points in time (i.e. usually a specific year) which is typical for comparative static analysis.

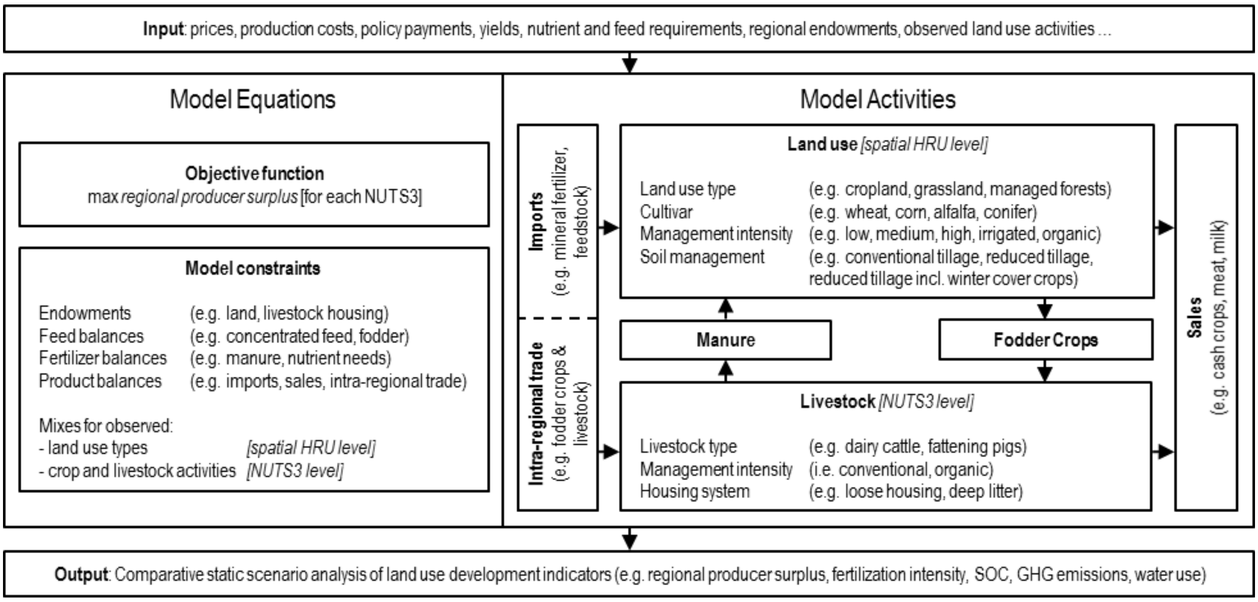

Figure 21: The model structure of $PASMA_{[grid]}$

Choices on agricultural and forestry land uses as well as crop and livestock management variants depend on factors such as commodity prices, production costs, subsidies, spatially-explicit yields, nutrient needs for crops and nutritional value for livestock activities. In this project, the model can choose among four mutually exclusive fertilizer management variants: rainfed agriculture with (1) high, (2) moderate, and (3) low fertilization intensities on cropland and permanent grassland, and (4) irrigated agriculture with high fertilization intensity on cropland. Due to resource constraints we only included one soil management option, i.e. conventional tillage (i.e. mouldboard plough with 15% crop residues left on soil surface before planting). The share of organic farming remains fixed (ca. 20%) as we currently do not account for the costs of conversion from conventional to organic farming and vice versa. The model currently allows for the conversion of agricultural land to managed forests and the cultivation of short rotation coppice plantations on cropland, but no conversion between cropland and grassland.

GLOBIOM

The GLobal BIOsphere Management model (GLOBIOM, http://globiom.org) is a global partial equilibrium model of the agricultural, forestry and bioenergy sectors. It simulates a ten-year time-step the evolution of the production, consumption, trade and price of major agricultural commodities, as well as the underlying use of land and water resources. It has a detailed spatially explicit representation of the producers of these sectors at resolution in space (5 to 30 arcmin pixels) and across activities (25 crop species & 4 crop systems, 7 animal species & 8 animal production systems). The high level of detail for the producers relies on specific models, such as EPIC. The behavior of producer is linked to an endogenous representation of the supply, consumption, price and bilateral trade of related commodities across 50 regions covering the globe. The model is also driven by assumptions about the evolution over time of population, its preferences, technological progress on crop and livestock yields, trade costs and policies, as well as conservation and environmental policies.

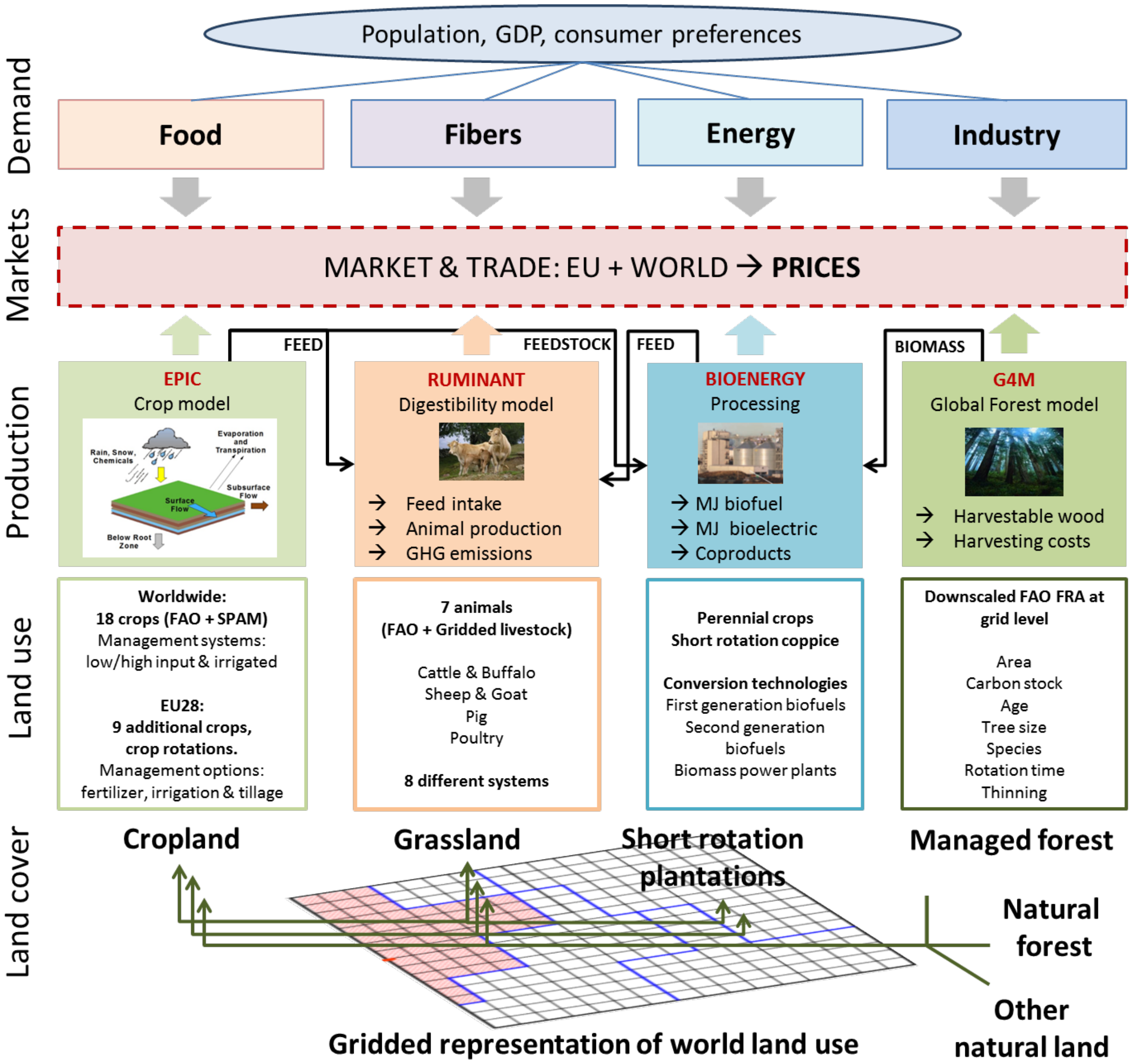

Figure 22: The model structure of GLOBIOM

ADAGIO

ADAGIO (A Dynamic Global Input-Output Model) consists of three main modules:

1. Supply and Use tables (SUTs) for 67 countries and regions, describing the commodity flows between producers and users. The SUTs differentiate between 58 commodities (goods and services), 35-58 sectors (depending on which sources of information the respective SUTs are based), and 6 categories of final demand (private and public consumption, non-profit institutions, investment, inventory changes, and exports).
2. Trade matrices for 58 commodities. These describe the geographical aspects of world production and consumption. The trade matrix is endogenous and reacts to changes in relative prices.
3. Econometric estimation of behavioural assumptions for production and consumption.
    a. The production technology: for all sectors, we assume a $KLEM_mM_d$-technology, that is, we distinguish between 5 factors of production: Capital, labour, energy, domestically produced intermediates, and

imported intermediates. These factor shares, together with the Output Price (on which all other prices are based in the model, taking into account trade and transport costs as well as commodity taxes), are modelled within a TRANSLOG framework.

b. Wages are set under a Wage bargaining assumption, taking into account sectoral productivity, the general price level, and the unemployment rate. In the wage and employment block, three skill levels – low, medium, high – are distinguished.

c. Consumption by households distinguishes between 15 consumption goods; 2 of them are treated as "durable consumption goods" (housing and vehicles) and modelled in a stock-flow-model. The rest are "non-durables", modelled in an AIDS framework (Almost Ideal Demand System). Current consumption is determined by current income as well as the stock of wealth. Accumulation of wealth is modelled in an intertemporal framework.

For an account of the modeling philosophy, see Kratena and Streicher (2009). For an extensive and in-depth treatment of all parts of the model, see Kratena et al. (2013).

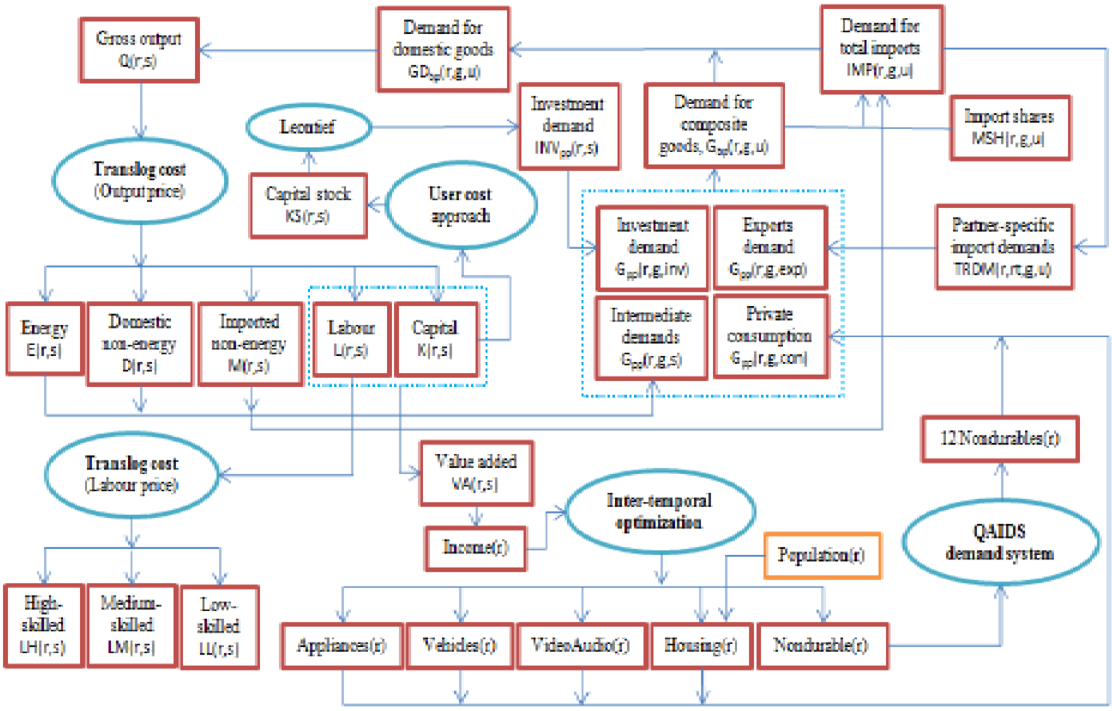

Figure 23: ADAGIO's model structure. Source: Kratena et al. (2013).

7 Arbeits- und Zeitplan

The Gantt diagram in Figure 1 shows the final work and time schedules of work packages (WP). WP 2 (Parameterization of socioeconomic pathways) and WP 3 (Simulation of bio-physical impacts) have all been completed as initially planned. The development of biomaterial scenarios (WP1 – Identification of relevant sectors and trade flows) took longer than initially planned as well as WP 4 (Computation of alternative adaptation states in Austrian agriculture and forestry with PASMA[grid] and integration into GLOBIOM/miniGalaxy) and WP 5 (development of ADAGIO and coupling). As a result we extended the project for another 6 month and accordingly also WP6 (Scenario impact analysis) and WP7 (Dissemination & stakeholder process).

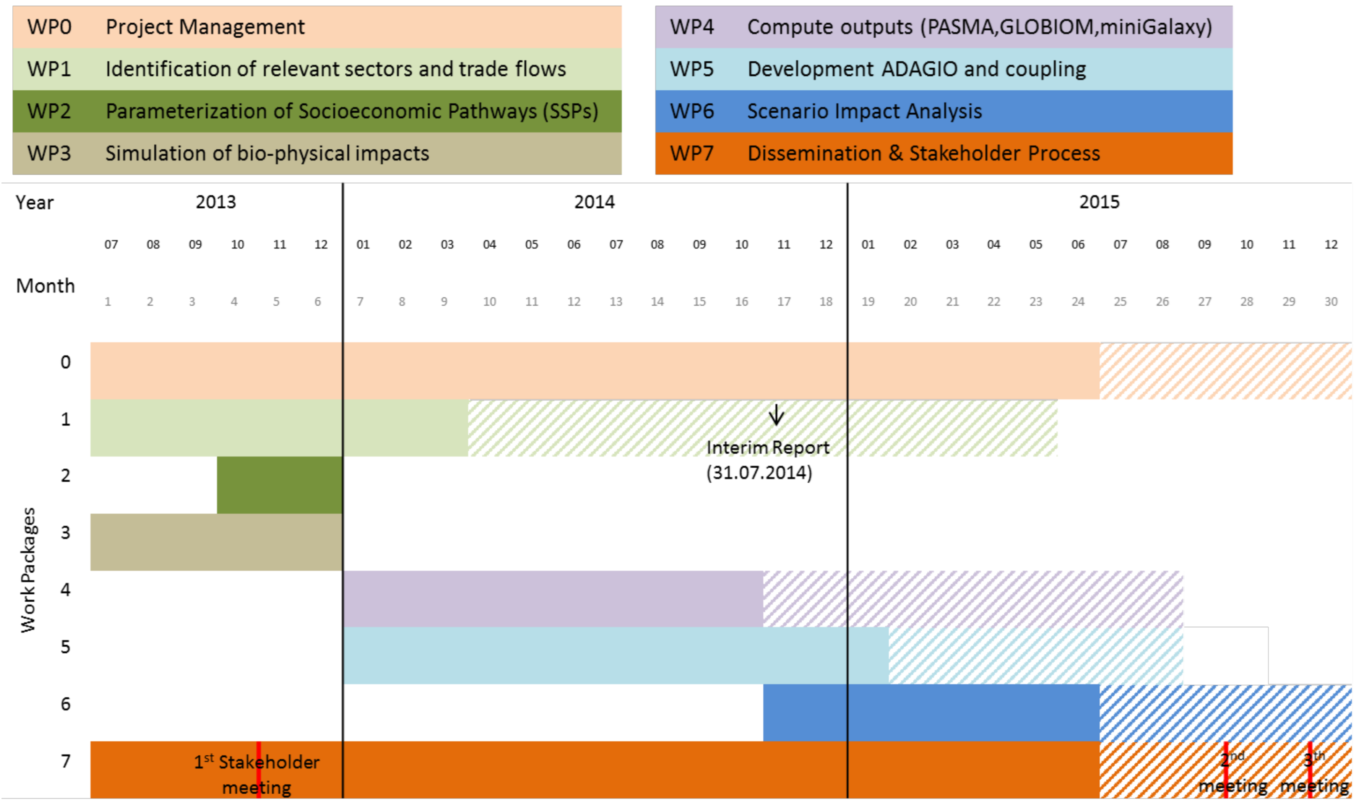

Figure 24: Gantt diagram for the specific work packages

8 Publications

Table 7 includes all publication that have been published within this project. Information on other dissemination activities are provided in the WP7 description in section 4.

Table 3: Publications within the project

Articles in peer reviewed journals
Schipfer,F., Kranzl, L., Leclère, D., Leduc, S., Forsell, N., Valin, H., unpublished. Advanced biomaterials scenarios for the EU28 up to 2050 and their respective biomass demand. Submitted to “Biomass and Bioenergy” in July 2015.
Kirchner, M., Schönhart, M., Schmid, E., 2016. Spatial impacts of the CAP post-2013 and climate change scenarios on agricultural intensification and environment in Austria. Ecological Economics 123, 35–56. doi:10.1016/j.ecolecon.2015.12.009
Kirchner, M., Schmidt, J., Kindermann, G., Kulmer, V., Mitter, H., Prettenthaler, F., Rüdisser, J., Schauppenlehner, T., Schönhart, M., Strauss, F., Tappeiner, U., Tasser, E., Schmid, E., 2015. Ecosystem services and economic development in Austrian agricultural landscapes — The impact of policy and climate change scenarios on trade-offs and synergies. Ecological Economics 109, 161–174. doi:10.1016/j.ecolecon.2014.11.005
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Mitter, H., Schmid, E., Sinabell, F., 2015. Integrated modelling of protein crop production responses to climate change and agricultural policy scenarios in Austria. Clim Res 65, 205–220. doi:10.3354/cr01335
Mitter, H., Heumesser, C., Schmid, E., 2015. Spatial modeling of robust crop production portfolios to assess agricultural vulnerability and adaptation to climate change. Land Use Policy 46, 75–90. doi:10.1016/j.landusepol.2015.01.010
Höltinger, S., Schmidt, J., Schönhart, M., Schmid, E. 2014. A spatially explicit techno-economic assessment of green biorefinery concepts. Biofuels Bioproducts and Biorefining. 2014; 8(3): 325-341.
Mitter, H., Heumesser, C., Schmid, E., 2014. Crop production portfolio optimization in managing climate-induced risks in Austria. Journal of the Austrian Society of Agricultural Economics 23, 121–130.
Conference publications
Kirchner, M., Schönhart, M., Schmid, E., 2015. The impacts of CAP post-2013 and regional climate change on agricultural land use intensity and the environment in Austria, in: Agriculture in an Interconnected World. Presented at the 29th International Conference of Agricultural Economists, Milan.
Kirchner, M., Schönhart, M., Mitter, H., Schmid, E., 2014. How does climate change adaptation impact GHG emissions – The case of Austrian agriculture, in: Grohsebner, C., Grötzer, M., Hambrusch, J., Heinschink, K., Kantelhardt, J., Kirchweger, S., Morawetz, U., Oedl-Wieser, T., Schermer, M., Schönhart, M., Sinabell, F., Stern, T. (Eds.), Food Security, Safety and Sovereignty. Presented at the 24th Annual Conference of the Austrian Society of Agricultural Economics, Vienna, 25th to 26th September.
Kirchner, M., Mitter, H., Schönhart, M., Schmid, E., 2014. Integrated Land Use Modelling to Analyse Climate Change Adaptation in Austrian Agriculture, in: Agri-Food and Rural Innovations for Healthier Societies. Presented at the 14th EAAE Congress, Ljubljana, August 26th to 29th 2014.
Reports
Kirchner, M; Schmid, E; Mitter, H; Schönhart, M (2014): Modeling Impacts of Climate Change and Market Integration on Agricultural Production and Land Use in Austria. YSSP Interim Report. IIASA, Laxenburg. Austria. *Unpublished*

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