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A) Projektdaten

Kurztitel:	CAFEE
Langtitel:	Climate change in agriculture and forestry: an integrated assessment of mitigation and adaptation measures in Austria
Programm:	Austrian Climate Research Program
Dauer:	29.6.2011 – 31.12.2013
KoordinatorIn / ProjekteinreicherIn:	Erwin Schmidt Institut für Nachhaltige Wirtschaftsentwicklung Universität für Bodenkultur, Wien
Kontaktperson Name:	Erwin Schmid
Kontaktperson Adresse:	Feistmantelstraße 4, 1180 Wien
Kontaktperson Telefon:	(+43) 1 / 47654-3653
Kontaktperson E-Mail:	Erwin.schmid@boku.ac.at
Projekt- und KooperationspartnerIn (inkl. Bundesland):	Institute of Landscape Development, Recreation and Conservation Planning, University of Natural Resources and Life Sciences (ILEN, Vienna) Federal Research and Training Centre for Forests, Natural Hazards and Landscape – Department of Forest Growth and Silviculture (BFW, Vienna) Institute of Ecology, Leopold-Franzens University Innsbruck (IBK, Tyrol) Institute for Alpine Environment, European Academy of Bozen (EURAC, South Tyrol)
Schlagwörter:	Integrated assessment, climate change, adaptation, mitigation, ecosystem services, regional economy, land use, agriculture, forestry
Projektgesamtkosten:	342.768 €
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1 Executive Summary

We have developed an integrated interdisciplinary modelling framework (IMF) to assess a broad range of ecosystem services (ES) in agricultural landscapes (*provisioning*, *regulation and maintenance*, and *cultural* services) as well as economic indicators (EI) important to regional development (e.g. regional added-value, employment). The framework has been designed to explore the interfaces between climate, biophysical, and economic factors in agricultural and forestry land use management at a high spatial resolution (ranging from national scale to a 1km grid resolution). The integrated framework links climate change impacts, bio-physical processes, forestry growth, land use management, energy production, and economic behaviour. In addition, spatially explicit land use outputs from the IMF are analysed to identify impacts on biodiversity, naturalness and landscape diversity. Our final assessment comprises different policy and regional climate change scenarios which have been facilitated by a stakeholder process.

Results of our scenarios reveal, on the one hand, prevalent trade-offs between different ES and EI. A focus on policy measures that ensure a more balanced supply of ES (e.g. agri-environmental payments) increases most *regulation and maintenance* ES (e.g. greenhouse gas emissions, naturalness) but comes at the cost of *provisioning* ES (e.g. biomass production) and regional economic output (and vice versa). Regional climate change scenarios amplify these trade-offs by stimulating land use intensification due to positive impacts on overall agricultural yields. However, on the other hand, forcing the cultivation of plants for renewable energy production can result in some synergies as high prices for fuel wood would lead to large afforestation measures in the Alps and to substantial increases in short rotation coppice plantations on croplands. Afforestation and short rotation coppice can increase biomass production while at the same time contributing positively to naturalness and climate regulation. Short rotation coppice is further expected to increase biodiversity (compared to conventional cropland) and to add more structure to agricultural landscapes (in adequate size and if cultural landscape features are not destroyed), whereas large-scale afforestation leads to more monotonous landscape (and thus decreases in landscape structures and biodiversity). Finally, the results show that magnitude, sign and variability of impacts on ES and EI in agricultural landscapes are highly diverse along geographical and topographical trajectories as well as land use sectors and farm production. Hence, in future studies it would be worthwhile to investigate trade-offs and synergies at farm to global scales to better represent the direct and indirect impact chains of climate change as well as the potential of regionalised programs that aim at a more sustainable supply of ES. Further research should focus on (i) automatizing interfaces between the models to allow for a larger range of model runs and thus the possibility of extensive sensitivity analysis, and (ii) on the development of tools for multi-criteria analysis, thus enabling stakeholders and policy-makers to better evaluate the trade-offs and synergies between different ecosystem services and economic indicators with respect to their strategies.

The project was accompanied by a stakeholder process. In three workshops, stakeholders from public administration and from research institutions active in the field, contributed to the project by evaluating scenario assumptions and by fine-tuning parameters, mainly with respect to the reform of the common agricultural policy and with respect to climate change scenario selection. The final results of the project were positively evaluated by stakeholders, pointing out that the spatially explicit approach allows distinguishing between regional impacts.

Executive Summary - Deutsch

Um eine möglichst umfassende Analyse von Ökosystemdienstleistungen (ÖSD; z.B.: bereitstellende, regulierende, unterstützende und kulturelle ÖSD) und ökonomischen Indikatoren (z.B.: regionale Wertschöpfung und Beschäftigung) in der österreichischen Land- und Forstwirtschaft durchzuführen, wurde ein integrativer und interdisziplinärer Modellverbund entwickelt. Dieser Modellverbund zielt darauf ab, die Einflüsse klimatischer, biophysikalischer und ökonomischer Faktoren auf land- und forstwirtschaftliche Landnutzungen räumlich explizit darzustellen (von nationaler Ebene bis hin zu einem 1km Raster). Dazu werden Modelle für regionale Klimaentwicklung, Waldwachstum, biophysikalische Prozesse, Landnutzung, Energieversorgung und regionale Wirtschaft miteinander verlinkt. Räumlich explizite Landnutzungsdaten aus diesem Modellverbund, bezogen auf einen 1km Raster, werden für die Analyse von Biodiversität, Natürlichkeit und Landschaftsdiversität herangezogen. Für die integrative Analyse werden in den Modellen verschiedene Politik- und regionale Klimaszenarien simuliert, die mit Unterstützung von Stakeholdern erstellt worden sind.

Die Ergebnisse der Szenarien zeigen zum einen auf, dass es zu großen Diskrepanzen zwischen den verschieden Indikatoren kommt. Ein Fokus auf Politikmaßnahmen (z.B. Agrarumweltmaßnahmen), die auf eine ausgewogenere Balance zwischen den verschiedenen ÖSD abzielen, erhöht zwar einen Großteil der regulierenden und unterstützenden ÖSD (z.B. Treibhausgasemissionen, Natürlichkeit), führt aber zu einer Reduktion von bereitstellenden ÖSD (z.B. Biomasseproduktion) sowie der regionalen Wertschöpfung (und umgekehrt). Die regionalen Klimawandelszenarien verstärken diese Diskrepanz, da sie durch einen generell positiven Einfluss auf die Pflanzenerträge in der Landwirtschaft zu einer Intensivierung der Landnutzung führen. Zum anderen kann aber ein Fokus auf Biomasseproduktion für die Energieversorgung zu Synergien zwischen vielen Indikatoren führen, da hohe Preise für Brennholz und Kurzumtrieb großflächigen Aufforstungen in den Alpen und zahlreiche Bestandesgründungen von Kurzumtriebsplantagen (z.B. Pappel) auf Ackerflächen zur Folge haben. Aufforstungen wie auch Kurzumtriebsplantagen wirken sich sowohl auf die Biomasseproduktion als auch auf die Natürlichkeit und Treibhausgasreduktionen positiv aus. Zusätzlich weisen Kurzumtriebsplantagen eine höhere Gefäßpflanzenvielfalt als übliche Ackerkulturen auf und können die Landschaftsdiversität vor allen in strukturarmen landwirtschaftlich geprägten Regionen verbessern. Ein übermäßiges Auftreten von Kurzumtriebsplantagen in wertvollen Kulturlandschaften hat jedoch negative Effekte auf das Landschaftsbild, da sie typische Elemente einer Kulturlandschaft zerstören und extensive Strukturen auflösen. Auch großflächige Aufforstungen bewirken eine Strukturbereinigung und das Verschwinden von aus Landschaftssicht sehr wertvollen Flächen wie Almen sowie geringerer Gefäßpflanzenvielfalt. Die räumlich expliziten Resultate zeigen auf, dass Höhe, Richtung und Variabilität der Ergebnisse in Agrar- und Forstlandschaften entlang von geographischen und topographischen Breiten als auch verschiedenen Landnutzungssektoren und Bewirtschaftungsformen stark variieren kann. In zukünftigen Studien ist es deshalb zielführend, Unterschiede und Synergien auf Betriebs- bis hin zur globalen Ebene zu untersuchen, um die direkten wie auch indirekten Wirkungsketten des Klimawandels, als auch das Potential regionalisierter politischer Programme für eine nachhaltige Bereitstellung von ÖDS besser darstellen zu können. Der nächste methodische Schritt wäre die Schaffung von automatisierten Schnittstellen zwischen den verschiedenen Klassen von Modellen. Dies würde eine höhere Anzahl an Modellläufen und somit die Durchführung extensiver Sensitivitätsanalysen erlauben. Die Entwicklung von Multikriterienanalysen wäre ein weiterer erstrebenswerter Forschungsschwerpunkt. Damit könnten Stakeholder oder EntscheidungsträgerInnen Diskrepanzen und Synergien zwischen den verschieden ÖSD und ökonomischen Indikatoren besser evaluieren.

Stakeholder aus der öffentlichen Verwaltung und Forschungsinstituten begleiteten das gesamte Projekt. In insgesamt drei Workshops wurden gemeinsam mit den Stakeholdern die Annahmen für die Szenarien und wichtige Politikparameter besprochen, insbesondere die Reform der Gemeinsamen Agrarpolitik und die Auswahl der Klimaszenarien. Zudem wurden die Endergebnisse von den StakeholderInnen einem „Reality-Check“ unterzogen, wobei sie vor allem die räumliche Analyse positiv hervorhoben, da mit dieser regional unterschiedliche Auswirkungen gut dargestellt werden können.

2 Background and objectives

Land use choices in agriculture and forestry usually focus on the supply of food, fodder, fibre as well as biomass for paper, pulp, and renewable energy production, which can be viewed as ecosystem services (ES) from agricultural and forestry ecosystems. Agricultural and forestry ecosystems both rely on (e.g. pollination, pest control, nutrient cycling) and contribute to the supply of many ES (e.g. food, climate regulation, aesthetic landscapes). Agriculture and forestry are thus at the same time beneficiaries as well as a facilitators of ES (Swinton et al., 2007; Zhang et al., 2007; Power, 2010). These services, by definition, contribute directly and indirectly to human well-being (MEA, 2003; TEEB, 2010) and are commonly categorized into *provisioning* (e.g. food, fodder, timber), *regulation and maintenance* (e.g. local and global climate regulation, water supply, nutrient cycling, soil formation and fertility), and *cultural* (e.g. landscape aesthetics, spiritual values, recreation) services (Haines-Young and Potschin, 2013).

The ES concept does not necessarily point to previously unknown environmental, social, economic or cultural impacts of the human-environment nexus (Tallis et al., 2008) but it recognizes complex interlinked (both in space and time) ecosystems, which are providing direct and indirect contributions to human well-being (MEA, 2003; TEEB, 2010). Although the concept may be prone to oversimplification (Hauck et al., 2013), it provides an anthropocentric justification for the use of ES (Lamarque et al., 2011) and seems therefore to be helpful in communicating the benefits of providing a whole bundle of non-market ES (Reid et al., 2006).

The findings of the Millennium Ecosystem Assessment (MEA, 2005) have sparked a plethora of research on ES, such as, among many others, a sponsored MEA feature in the journal Ecology and Society ('Scenarios of Global ES', May 2007), The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010), special sections in the journal Ecological Economics (e.g. 2007, Vol. 64, Issue 2; and 2010, Vol. 69, Issue 6) and the creation of the journal Ecosystem Services in 2012 (Braat, 2012). It resonated in policy initiatives, such as the EU Biodiversity Strategies for 2010 and 2020 (European Commission, 2011), or the recent undertaking of the Austrian Environmental Agency to provide an inventory of ES from and to agriculture in order to allow for a better accounting of environmental impacts (Umweltbundesamt, 2011).

An important finding from these studies is that, because ES often represent characteristics of a public good (TEEB, 2010), they have, among many other reasons (e.g. lack of policies, institutions or knowledge), experienced degradation and under-provisioning at a rate of change that has never been greater than in the past 50 years (MEA, 2005). Some ES (i.e. climate regulation, nutrient cycling) as well as biodiversity are likely to have already moved beyond certain global biophysical threshold levels (Rockström et al., 2009). ES are interdependent and their relationship is often non-linear (Rodriguez et al., 2006). Hence, the supply of one ES very often, although not necessarily, comes at the cost of others at both spatial and temporal scales (MEA, 2005; TEEB, 2010). For instance, the increase in agricultural production has been a dominant driving force in diminishing the potential of ecosystems to provide ES related to *regulation and maintenance* as well as *cultural* services (Tilman et al., 2002; Bennett and Balvanera, 2007; Power, 2010; Bryan, 2013; Schirpke et al., 2014).

Trade-offs are thus often inevitable, yet sometimes unintended, consequences of public policies. Prominent examples are agri-environmental programs (AEPs). AEPs aim at a more balanced supply of ES from agriculture (Power, 2010; Pirard, 2012) by compensating farmers for switching to more extensive (and usually less profitable) forms of production (BMLFUW, 2009). This can be roughly translated as a trade-off from less *provisioning* ES (e.g. food production) to increasing the supply of *regulation and maintenance* ES (e.g. fewer emissions through decreased fertilizer use, increased biodiversity through ecological focus areas), and *cultural* ES (e.g. maintaining permanent grasslands or traditional structures and elements like hedges or orchards) (Barraquand and Martinet, 2011). Nevertheless, studies show that synergies between ES can be achieved if adequate management measures are applied, e.g. organic agriculture, conservation tillage or cover crops (Schmid et al., 2004; Badgley et al., 2007; Pretty et al., 2006). The selection of adequate management measures usually depends heavily on regional circumstances.

ES supply in agricultural landscapes is also highly challenged by climate change (Schröter et al., 2005). On the one hand, ES supply is directly affected via the impact on the ecosystem functions and processes that provide ES

(e.g. sediment loss, see Mitter et al. 2014) and on the other hand through land use and management adaptations by farmers to a changing climate (Briner et al., 2012; Leclère et al., 2013; Schönhart et al., 2014). Climate change impacts on ES in agricultural landscapes in Europe and Austria (e.g. biomass, water use, soil organic carbon) are expected to strongly depend on regional and local characteristics (e.g. altitude, climate, resource endowments) (Olesen and Bindi, 2002; Eitzinger et al., 2009; Schönhart et al., 2014), thereby making it paramount to account for spatial heterogeneity.

When assessing trade-offs and synergies, it remains crucial to link changes in the supply of ES to the benefits and costs they have on human well-being (TEEB, 2010). Most of the benefits and costs are difficult to assess and many limitations exist for a monetary valuation of non-market ES (Turner et al., 2003; Zhang et al., 2007; Pirard, 2012). Therefore, studies usually refrain from an economic valuation of non-market ES (Helming et al., 2011a) and quantify the impacts on non-market ES in biophysical terms and provide an assessment of the benefits of marketed *provisioning* ES, e.g. the economic value of production of crop, forage and fibre (c.f. Swallow et al., 2009; Schönhart et al., 2011a; Goldstein et al., 2012; Briner et al., 2012). Our integrated assessment follows this approach.

Lack of knowledge about the causal relationships between ES supply and (1) drivers such as policy and climate (Carpenter et al., 2009), (2) agricultural land use and management measures (Swift et al., 2004; Horrocks et al., 2014), and (3) biophysical processes (Swinton et al., 2007) have so far made it difficult to implement policies that diminish trade-offs or support synergies (TEEB, 2010). This study aims to close the gap in research by revealing and assessing these interlinkages in a multidimensional framework to provide sound advice for policy interventions. We explore the impact of different agricultural policy pathways on ES supply, trade-offs and synergies, as well as economic impacts (EI) taking into account regional climate change. We apply a multi-model approach, as recommended by Rounsevell et al. (2012). This refers to the coupling of already existing individual models in order to combine their strength and utilize valuable resources in an efficient manner. Our spatially explicit integrated modelling framework (IMF) features climate, agronomic, biophysical process, forest growth, agricultural sector, energy sector and economic input-output models. In addition, spatially explicit outputs are assessed with regard to biodiversity and landscape effects using a broad set of indicators.

3 Project content and results

We have developed a spatially explicit integrated modelling framework to assess our research questions. Seven models, ranging from a climate model over a bio-physical process model to an economic input-output model were linked together. Also, a set of indicators for assessing ecosystem services and economic impacts was developed and used to evaluate scenario outcomes. The main focus of the work was therefore put on defining policy and climate scenarios, designing interfaces between the models, and adapting our models to allow scenario simulation. Additionally, we organized a stakeholder process to gather input from public administration and related research institutions with respect to the assumptions taken in our scenarios and to check the feasibility of our project results. The set of models used in our project, as well as the respective interfaces between these models and the indicators used for evaluation of model outcomes are presented in more detail in section 5 of this document. An in-depth description of the methodology and project activities can be found in the appendix of this document. The work of the 5 partner institutions was organized along 11 work packages. Those are outlined in section 6. In this section, we present the scenarios used in our model runs and the final results of our modelling exercise.

Scenario development

Our analysis considers two major drivers, namely climate change and agricultural policy pathways up to the year 2040 (see Figure 1). Scenario development has been facilitated by stakeholders from the Austrian Ministry of Agriculture, Forestry, Environment and Water management (BMLFUW), the Austrian Environmental Agency (UBA), the Austrian Agency for Health and Food Safety (AGES) and the Austrian Institute of Technology (AIT).

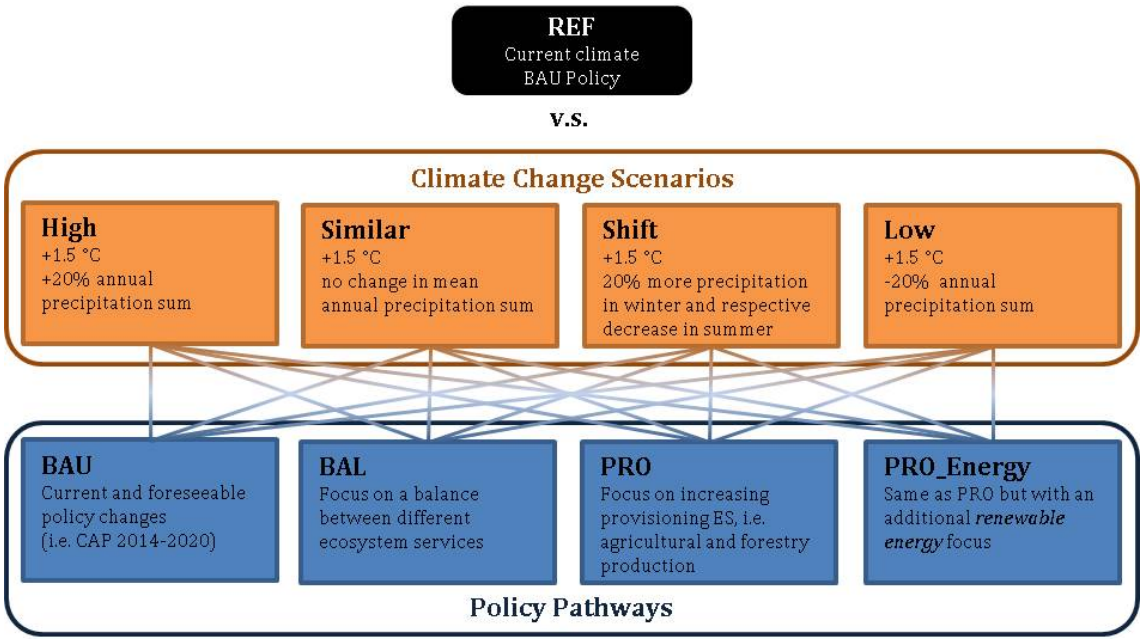

Figure 1: Climate change scenarios and policy pathways until 2040 (own source)

Furthermore, stakeholders from the BMLFUW have informed us on the most likely outcome of the CAP post-2013 reform[1].

In total, 16 possible scenario combinations are compared to a reference scenario (*REF*), which encompasses a future BAU policy pathway for the period 2025-2040 (i.e. the new CAP reform 2014) and current climate data. The historical analysis of biophysical data for this reference scenario is 1981-2009 for Caldis vâtis and 1996-2005 for EPIC simulations. Using such a reference scenario allows us to disentangle policy and climate impacts from market and other socio-economic developments (e.g. technological progress).

In general, uncertainties in future developments of precipitation patterns are much larger than in temperature trends (Auer et al., 2007; Formayer et al., 2009; Gobiet et al., 2013). This is also valid for shorter target periods (like 2040) compared to the typical target periods of GCMs and RCMs (e.g. 2100). The climate change scenarios of ACLiReM differ with respect to changes in precipitation but not in temperature. They have all in common a temperature trend of ca. 1.5 °C from 2008 until 2040 which has been estimated by using a homogenized climate dataset for Austria. Uncertainties in future precipitation developments are captured by the bootstrapping method taking into account different conditions, i.e. (i) *High*: assuming an increase of 20% in mean annual precipitation sums, (ii) *Similar*: assuming similar distributions of precipitation sums compared to the past, (iii) *Shift*: assuming that seasonal precipitation sums are re-allocated between winter and summer seasons, and (iv) *Low*: assuming a decrease of 20% in mean annual precipitation sums. The ACLiReM scenarios thus provide a plausible range of possible future climates and meet the specific data demands of typical biophysical impact simulation models such as EPIC.

[1] More information on the workshops and meetings are available in the activity report.

Table 1: Future policy pathways and their changes with respect to the year 2008

	Model Parameter	BAU	BAL	PRO	PRO_Energy
Market measures & direct payments	Price & cost development	OECD-FAO forecast to 2022[1]			
	Sealing of cropland	3% in 2040 (same for each grid)			
	Milk quota	Abolished			
	Suckler cow premium	Abolished			
	Payments for less favored areas	- 15%			
Agri-environmental program	Environmentally friendly management	Abolished	-50%		Abolished
	Renunciation of agro-chemical inputs	No change	+100%		Abolished
	Extensive grassland (one cut)	No change	+25%		Abolished
Renewable energy focus	Forcing the utilization of fuel wood and short rotation coppice for energy uses by implementing high oil prices in BeWhere. Demand for final energy is forecasted according to the Austrian Renewable Energy Action Plan (Karner et al., 2010).	No	No	No	Yes

[1] Prices and costs are kept constant from 2022 to 2040.

Table 1 provides details on policy measures. Some measures and time related economic parameters are kept constant across the scenarios, i.e. price and cost developments, sealing of cropland, the abolishment of the milk quota and the suckler cow premium, and the reduction of payments to less favored areas. The business as usual scenario (*BAU*) depicts the most likely outcome of the current CAP post-2013 reform and has been developed in extensive exchange with stakeholders from BMLFUW. It is anticipated that less funding will be devoted to the current agri-environmental program and that the measure "environmentally friendly management of agricultural land" is most likely going to be abolished. Reductions for further measures are expected (e.g. cover crops), but these measure are currently not incorporated in our IMF. We also take into account new requirements for direct payments (i.e. the greening measures) by requiring farmers to set-aside at least 3% of their arable land as Ecological Focus Areas (e.g. fallow and buffer strips that increase biodiversity). In the stakeholder process we decided on a percentage for EFAs of 3% instead of the current 5% (European Commission, 2013), as it was a more likely and politically feasible assumption at the time of the stakeholder meeting (March 2013). In addition to *BAU*, we developed, together with stakeholders, three alternative pathways that both differ with respect on their focus on ES supply. The provisioning scenario (*PRO*) assumes that policy makers aim at increasing the supply of *provisioning* ES, i.e. agricultural and forestry production. Hence, no funding is given to agri-environmental schemes as they facilitate more extensive production methods with low output. Furthermore, farmers are not required to set aside agricultural land for EFAs. We also implement a provisioning scenario that focuses on the additional utilization of fuel wood and short rotation coppice for renewable energy production (*PRO_Energy*). This scenario is driven by assuming high fossil oil prices in the energy system model BeWhere. Finally, a balanced ecosystem scenario (*BAL*) is introduced. It aims at increasing the level of ecosystem services other than *provisioning*. Hence, it increases funding devoted to certain agri-environmental schemes and increases the requirement for EFAs to 10%.

Results – Country Level

First in order to provide an overview, Table 2 shows the impacts for all indicators at country level compared to REF, Table 3 further depicts specific policy impacts (comparing the alternative policy scenarios to BAU). Selected indicators are illustrated in Figure 2 and impacts on sectoral production for selected scenarios in Figure 3. As time

related price and cost developments remain constant between all scenarios (see Table 1) the changes indicate climate change impacts only (BAU), climate change and policy impacts (Table 2, Figure 2, Figure 3), or policy impacts only (Table 3).

Table 2: Impacts at country level in 2040 (changes in percentage compared to *REF*)

Policy	Climate	Provisioning		Regulation and Maintenance				Cultural	Economic			
		Bio-mass	Water use	SOC	GHG em.	Bio-diversity	Natur-alness[1]	Shannon Diversity	RPS[2]	Sector value[3]	GDP	Employ-ment
BAU (Climate only)	High	9.4	-68.6	-3.7	6.1	-1.4	0.6	0.0	2.1	4.1	0.1	0.3
	Similar	7.6	305.0	0.6	4.7	-1.5	0.9	0.0	1.7	3.3	0.1	0.2
	Shift	6.2	404.4	1.6	3.8	-1.1	0.3	0.0	1.2	2.6	0.1	0.2
	Low	3.3	2158.6	4.8	0.9	-1.4	0.6	0.0	0.1	0.9	0.1	0.1
BAL	High	3.1	-71.2	-4.6	1.1	1.0	-0.7	0.0	3.7	1.0	0.1	0.1
	Similar	1.9	55.1	-0.1	0.2	0.9	-0.6	0.0	3.4	0.4	0.1	0.1
	Shift	0.5	155.4	0.9	-0.8	1.6	-1.0	0.0	3.0	-0.2	0.0	0.0
	Low	-2.0	1711.1	4.1	-3.2	1.1	-0.7	0.0	2.0	-1.7	0.0	0.0
PRO	High	25.8	48.4	5.0	10.7	-4.4	2.1	0.2	-3.1	9.8	0.2	0.6
	Similar	19.9	720.7	5.7	9.5	-4.3	2.1	0.0	-3.7	8.7	0.2	0.5
	Shift	22.8	1017.6	8.8	8.5	-4.4	1.6	0.3	-4.2	8.3	0.2	0.5
	Low	18.8	2600.3	11.0	5.0	-4.3	1.9	0.2	-5.6	6.1	0.2	0.4
PRO Energy	High	51.2	48.5	10.1	4.2	-2.1	0.2	-1.2	-2.1	11.6	0.3	0.7
	Similar	44.5	722.3	11.1	2.8	-1.9	0.2	0.1	-2.9	10.2	0.3	0.6
	Shift	49.2	1000.1	13.0	0.8	-1.5	-0.7	-1.6	-3.1	10.0	0.3	0.6
	Low	43.9	2452.8	14.7	-2.8	-1.5	-0.3	-1.4	-4.4	7.9	0.2	0.5

[1] Degree of naturalness is higher the lower the indicator. Hence, negative changes indicate an increase in naturalness and vice versa.

[2] RPS = Regional Producer Surplus (i.e. revenue minus costs plus subsidies).

[3] Relates only to the agriculture and forestry sector.

Table 3: Policy impacts at country level (changes in percentage compared to the respective BAU scenario, e.g. *BAL_High* vs. *BAU_High*)

Policy	Climate	Provisioning		Regulation and Maintenance				Cultural	Economic			
		Bio-mass	Water use	SOC	GHG em.	Bio-diversity	Natur-alness[1]	Shannon Diversity	RPS[2]	Sector value[3]	GDP	Employ ment
BAL	High	-6.2	-2.5	-0.9	-5.0	2.4	-1.3	0.0	1.6	-3.2	-0.1	-0.2
	Similar	-5.7	-249.9	-0.7	-4.5	2.4	-1.5	0.0	1.8	-2.9	-0.1	-0.2
	Shift	-5.7	-249.0	-0.7	-4.5	2.6	-1.3	0.0	1.8	-2.9	-0.1	-0.2
	Low	-5.3	-447.5	-0.7	-4.1	2.5	-1.3	0.0	1.9	-2.6	-0.1	-0.1
PRO	High	16.5	117.0	8.7	4.5	-3.0	1.5	0.2	-5.2	5.7	0.1	0.3
	Similar	12.3	415.7	5.1	4.8	-2.8	1.1	0.0	-5.4	5.5	0.1	0.3
	Shift	16.6	613.2	7.2	4.7	-3.3	1.3	0.3	-5.4	5.7	0.1	0.3
	Low	15.5	441.7	6.2	4.1	-3.0	1.3	0.2	-5.7	5.2	0.1	0.3
PRO Energy	High	41.9	117.1	13.8	-1.9	-0.7	-0.4	-1.2	-4.2	7.5	0.2	0.4
	Similar	36.9	417.3	10.5	-1.9	-0.4	-0.7	0.1	-4.6	6.9	0.1	0.4
	Shift	43.0	595.7	11.4	-3.0	-0.4	-0.9	-1.6	-4.3	7.4	0.2	0.4
	Low	40.6	294.2	9.9	-3.7	-0.1	-0.9	-1.4	-4.5	7.0	0.1	0.4

[1] Degree of naturalness is higher the lower the indicator. Hence, negative changes indicate an increase in naturalness and vice versa.

[2] RPS = Regional Producer Surplus (i.e. revenue minus costs plus subsidies).

[3] Relates only to the agriculture and forestry sector.

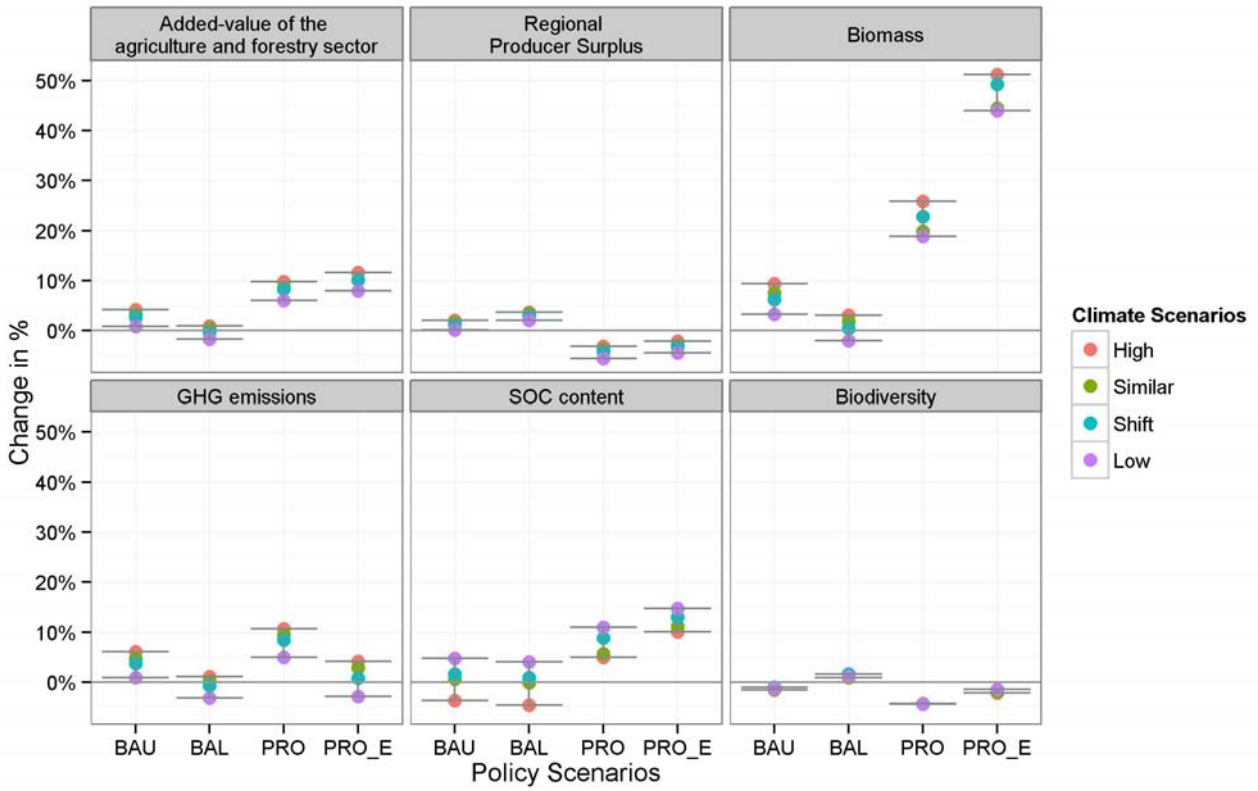

Figure 2: Selected policy results under regional climate change uncertainty at country level (changes in percentage compared to *REF*).

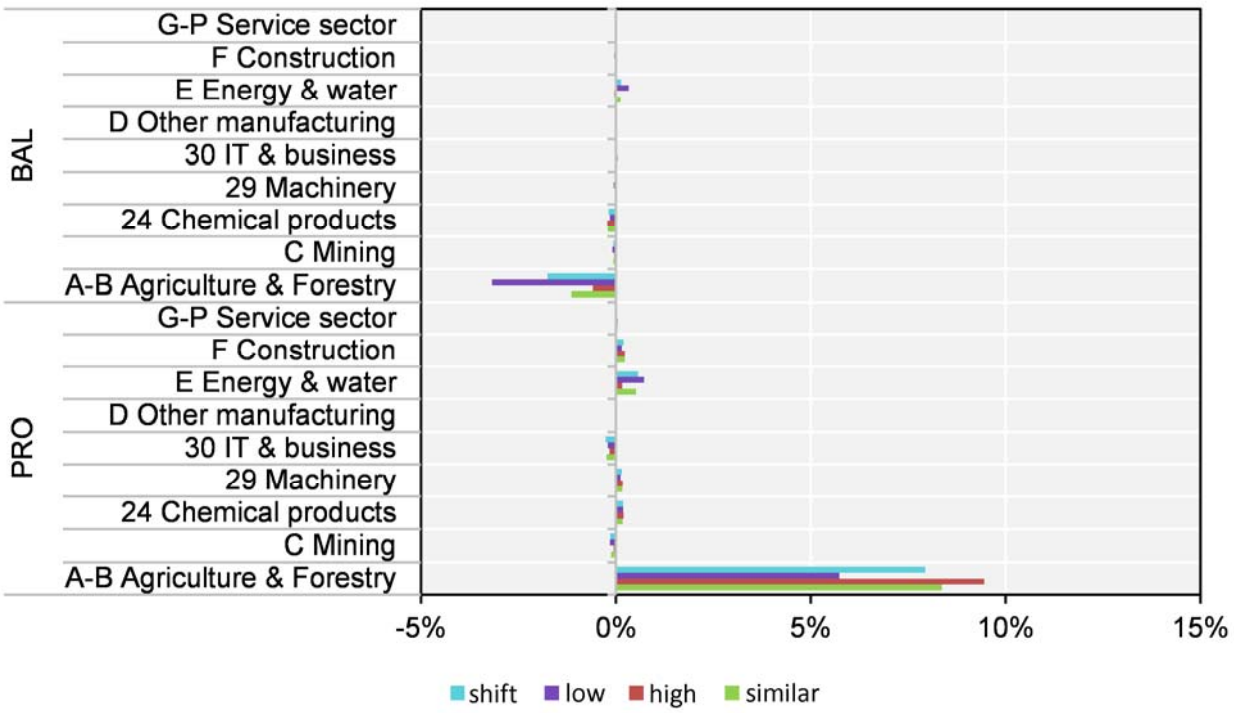

Figure 3: Impacts on sectoral production for selected scenarios (BAL and PRO + climate) (changes in percentage compared to *REF*)

BAU Scenario (Climate Change)

Changes in the *BAU* scenario depict changes in regional climate only (as *REF* has the same policy assumptions but uses current climate data). The climate change scenarios have positive impacts on overall agricultural yields. Farmers autonomously adapt to these impacts by increasing fertilizer application rates due to higher value of marginal product of fertilizer input. Positive climate change impacts, amplified by land use intensification, increase total biomass production in all climate change scenarios (between +3% and +9% in *Low* and *High*, respectively). Most of these gains come from large increases in forage yields on grassland and alpine meadows (+24% in *Low* to +27% in *High*). In contrast, crop production seems to be somewhat vulnerable to our climate change scenarios with decreases in most scenarios (-2% in *Similar* to -8% in *Low*) and a small increase in *High* (+1%). The indicator most sensitive to our climate change scenarios is water use for irrigation. Here, we find 3-fold, 4-foldfold and almost 22-fold increases in *Similar*, *Shift*, and *Low*, respectively, as well as a substantial decrease of 69% in *High*. However, the level of water use for irrigation in *REF* is very low (ca. 2000ha irrigated area with 4.6 million m³ water use). Irrigation is almost exclusively applied in eastern semi-arid crop production regions, where it could severely affect groundwater levels.

The intensification of land use leads to a decrease of the *mean species richness of vascular plants* (from -1.1% to -1.5%) and in the *degree of naturalness* (+0.3% to +0.9%). As the *degree of naturalness* values range from 1 (natural) to 7 (artificial) an increasing indicator value means a decreased *degree of naturalness.* More fertilizer use causes higher direct and indirect soil emissions from agricultural land use. Changes in other GHG relevant activities in the agricultural sector remain negligible (i.e. changes in livestock and crop choices). The net increases in GHG emissions are quite substantial in *High* (+6%) but remain marginal in *Low* (+1%). SOC increases in all but the *High* scenario. The additional C input due to higher biomass and thus residue production dominates the effect of higher mineralization from increasing temperatures in *Similar* (+5%), *Shift* (+2%) and *Low* (+1%). The positive net impact declines with more precipitation as this leads to both (i) higher soil moisture which further amplifies mineralization rates and (ii) more soil erosion. Ultimately, the negative impacts prevail in the *High* scenario (-4%). No impact has been observed for landscape diversity (i.e. Shannon Diversity), as changes in land use remain too small to have significant impacts on landscape structures.

The increase in productivity in all climate change scenarios positively affects the economic indicators, whereby *High* has the most positive impact and *Low* the lowest. The rising revenues of the agriculture sector boost RPS slightly (+0% to +2%) and even more so the production value of the agricultural sector (direct impact; between +1% and +4%). Due to linkages in the economy this positively affects the production value of most other sectors in the economy (indirect effect; e.g. sectors such as energy and water, chemical, machinery; see Figure 3), and thus GDP (+0.1%) and employment (+0.1% to +0.3%). The latter two indicators are inclined to small changes as the agricultural sector only contributes about 1.4% to national GDP.

BAL Scenario

Higher agri-environmental subsidies in *BAL* lead to the adoption of more extensive production measures compared to *REF*. In addition, ecological focus areas increase by about 57,000ha (ca. +70%) in all climate scenarios. Total biomass production still increases slightly in *High* (+3%) and *Similar* (+2%), stagnates in *Shift* and declines in *Low* by 2%. This indicates that climate change induced yield increases and land use intensification outweigh the extensification measures of *BAL*. Nonetheless, changes in total biomass production as well as water use for irrigation are the lowest compared to the other policy scenarios.

As intended by implementing *BAL* policy measures, less intensive land use in the *BAL* scenario increases the *mean species richness of vascular plants* (+0.9% to +1.1%) as well as the *degree of naturalness* (-0.6% to -1.0%). Further, changes in GHG emissions are the lowest for all policy scenarios. They decrease slightly in *Low* (-3%) and *Shift* (-1%), remain constant in *Similar* and marginally increase in *High* (+1%). SOC increases in *Low* (+4%) and *Shift* (+1%), is not affected in *Similar* and reduces significantly in *High* (-5%). Lower (and partly negative) SOC values in *BAL* can be explained by less C input as a result of the (relatively) lower biomass and

thus residue production in *BAL*. Landscape diversity is not affected at country level, although increases in ecological focus areas could lead to local improvements.

The economic impacts of *BAL* are mixed. On the one hand, the RPS increases by +2% to +4% due to higher agri-environmental subsidies that farmers receive. On the other hand, less intensive land use decreases productivity and hence the production value falls. *BAL* thus shows the lowest and, depending on the climate change scenario, also the only negative changes in the production value of the agricultural sector. While the positive climate change impacts on yields can offset policy induced decreases in productivity in *High* (+1.0%) and *Similar* (+0.4%), the production value declines in Shift (-0.2%) and *Low* (-1.7%). GDP increases due to positive indirect effects (e.g. energy and water, construction and service sectors), but these impacts are negligible (between +0.01% and+0.06%). Changes in employment are marginally positive for all climate change scenarios (+0.04% to +0.10%), but *Low* (-0.02%).

PRO Scenario

The decline of agri-environmental subsidies in *PRO* leads to intensification of agricultural land use (e.g. higher fertilizer use and almost no ecological focus areas) as well as large scale afforestation (between 184,000ha in *Similar* and 274,000ha in *High*), which mainly take place in marginal alpine areas. This markedly increases total biomass production (+19% to +26%) and irrigation water use (+48% to 26-fold).

Intensive production and high fertilizer use lead to higher pressures on ecosystems as indicated by changes of *mean species richness of vascular plants* (-4.3% to -4.4%) and *degree of naturalness* (+1.6% to +2.1%). GHG emissions also increase between +5% (*Low*) and +11% (*High*). Only SOC increases under *PRO* due to higher C input from biomass production and afforestation. Changes in landscape diversity at country level are insignificant, but regionally impacts can be substantial (e.g. afforestation on alpine meadows leads to substantial reduced structural richness in the landscape).

Economically, regional producer surplus declines significantly due the decline of agri-environmental subsidies (-3% to -6%), but *PRO* positively affects the other economic indicators, as intensification of land use increases the output of the agricultural sector. Hence, the direct production value of the agricultural sector increases between +6% (*Low*) and +10% (*High*). Moreover, the rise in the output of the agricultural sector also implies a rise in intermediate and factor demand. This boosts GDP increases (about +0.2%), as well as raises employment rates by +0.4% (*Low*) to +0.6% (*High*).

PRO_Energy Scenario

The expansion of bioenergy production in *PRO_Energy* leads to large increases in both short rotation coppice plantations (between 177,000ha in *High* and 219,000ha in *Low*) as well as afforestation (between 376,000ha in *Similar* and 429,000ha in *Low*). This results in the highest total biomass output (+44% to +51%) across all policy scenarios. Changes in water use for irrigation are similar to *PRO* (+49% to 25fold).

In adequate size, the increase in short rotation coppice plantations on cropland could be beneficial with respect to increasing landscape heterogeneity and biodiversity. Hence, changes in the *degree of naturalness* can improve at country level in some climate changes scenarios (-0.3% and -0.7% in *Low* and *Shift*, respectively). The *mean species richness of vascular plants* is still negatively affected (-1.5% to -2.1%) but much lower compared to *PRO*. Afforestation and short rotation coppice plantations require less fertilization than most other crops such that *PRO_Energy* has fewer GHG emissions than *BAU* and *PRO*, but still increase in all (+1% to +4%) but the *Low* scenario (-3%). The large increases in biomass production lead to higher SOC (+10% to +15%). The impacts on landscape diversity are negative at country level in most scenarios (-1.2%, -1.6% and 1.4% in *High*, *Shift* and *Low*, respectively, as well as +0.1% in *Similar*), although large regional differences exist. While afforestation leads to a more monotonous landscape structure in the alpine areas, short rotation coppice plantations may improve landscape diversity, albeit only if they do not dominate the landscape picture. In some regions in the North-Eastern part of Austria as well as along the alpine foothills a very high amount of short rotation coppice

plantations leads to a significant change of the landscape with presumable negative effects on the existing structures and typical landscape elements (e.g. hedgerows, orchards).

The economic impacts are comparable to *PRO*, although *PRO_Energy* results in lower decline of RPS (-2% to -4%) and higher increase in the direct production value of the agricultural sector (+8% to +12%), GDP (+0.2% to +0.3%), and employment (+0.5% to +0.7%). This is due to regional price increases for fuel wood and short rotation coppice products, which are the results of meeting policy induced regional bioenergy demands.

Results - Regional and Spatial Impacts

Biomass Production

Spatial impacts of climate change on total biomass production (dry matter from crops, forage, short rotation coppice and afforestation) are shown in Figure 4 and Figure 5. The Alpine grassland areas experience strong production increases as forage yields can gain from temperature increases in all precipitation scenarios until 2040. In contrast, crop yields are more exposed to changes in temperatures and precipitation as major cropland areas are located in warmer and drier flatlands in the North-East of Austria. This is most evident in the *Low* scenario, where decreases in mean annual precipitation sums lead to considerable yield losses in the North-East across all policy scenarios (see Figure 5). Figure 5 further indicates strong biomass production increases in the Alps and cropland areas due to afforestation and the adoption of short rotation coppice plantations.

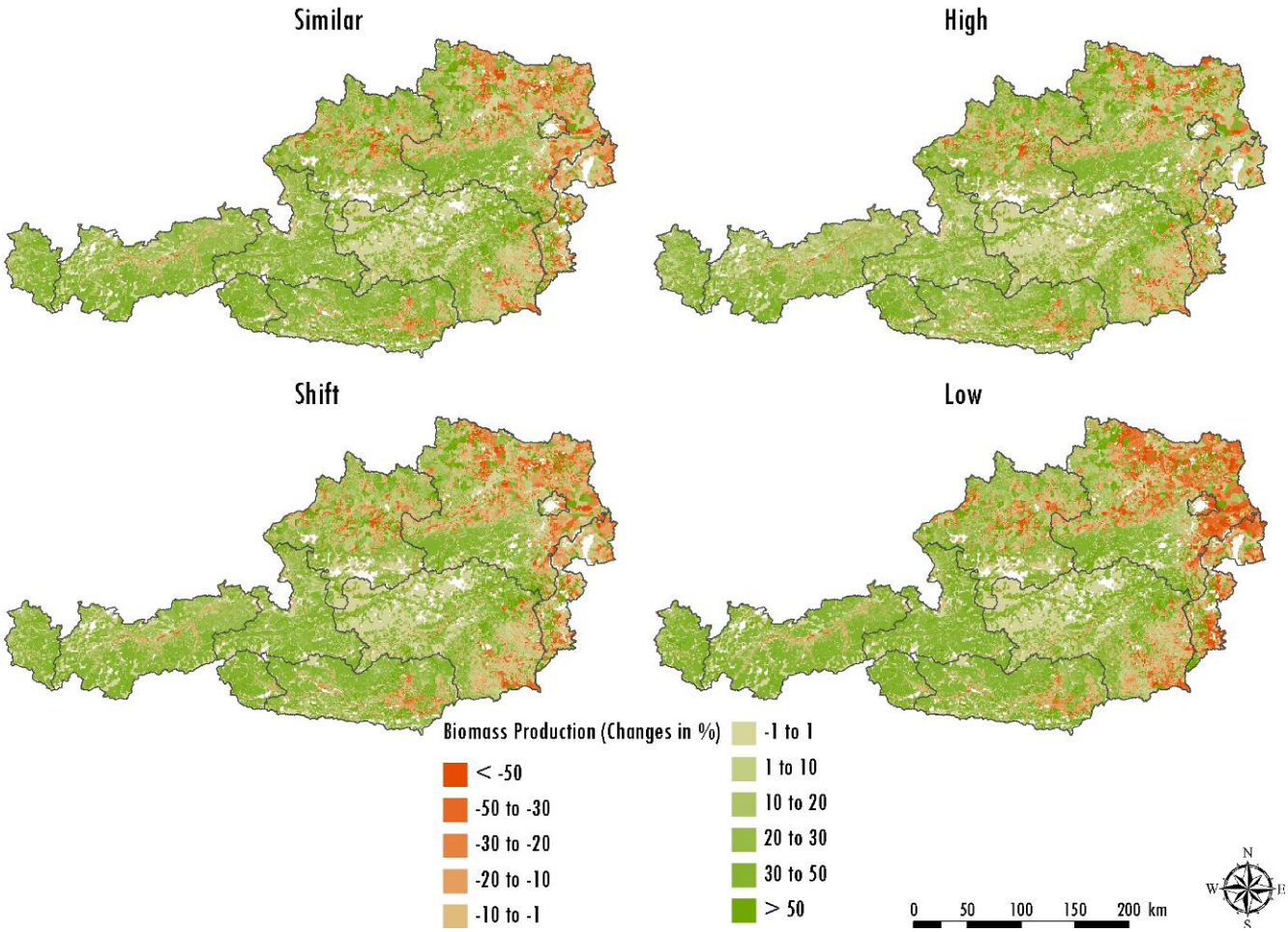

Figure 4: Percent changes in total biomass production on agricultural land (including afforestation) in the *BAU* scenarios at 1km grid resolution (compared to *REF*)

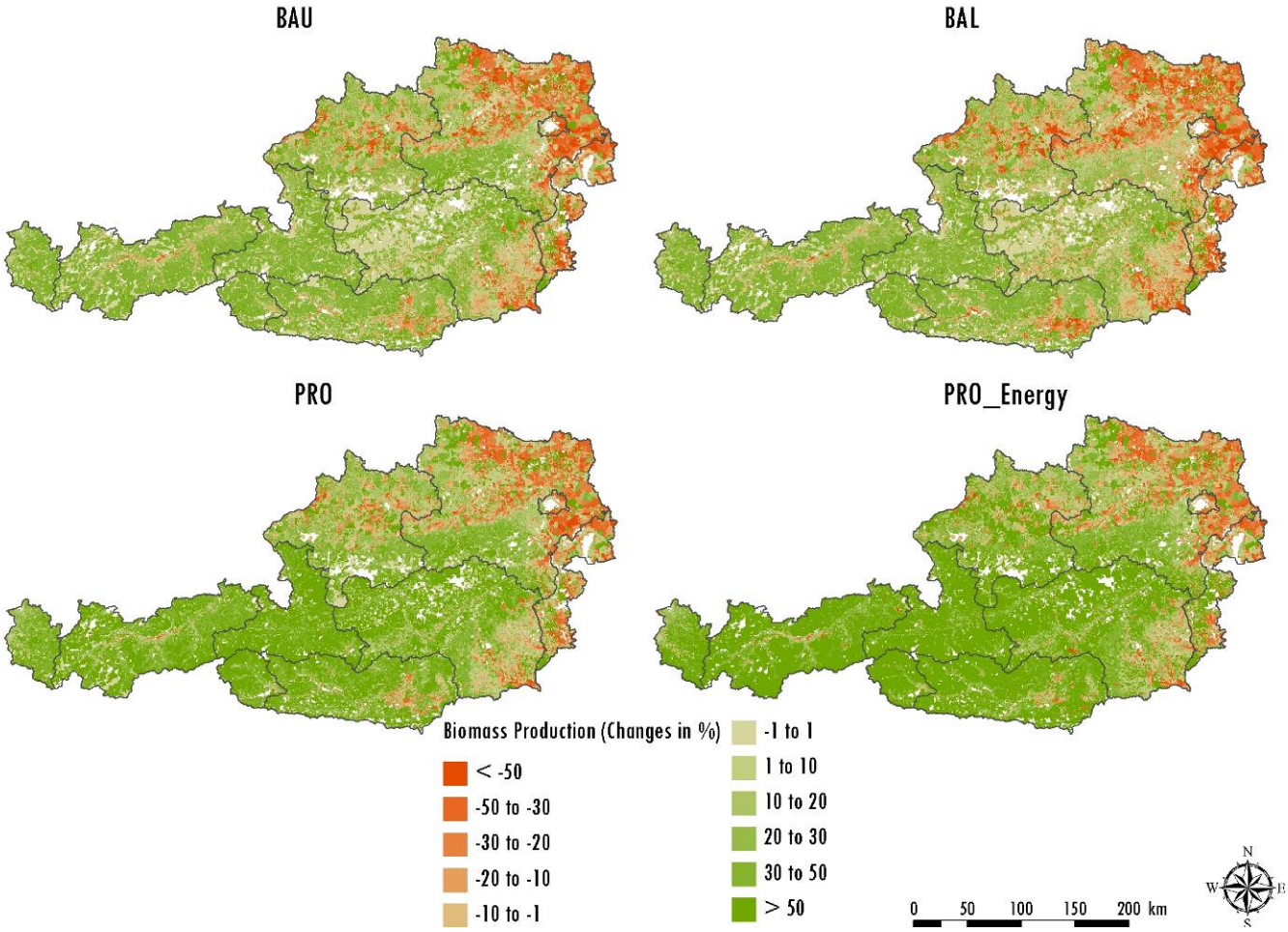

Figure 5: Percent changes in total biomass production on agricultural land (including afforestation) in the *Low* scenarios at 1km grid resolution (compared to *REF*)

Ecological Integrity

Spatial heterogeneity and differences are further crucial with regard to impacts on ecological integrity. As shown above, the country results on the *degree of naturalness* are somewhat mixed for *PRO_Energy* (Table 2). Figure 6 illustrates these impacts at a 1km grid resolution. It depicts gains in naturalness for afforested areas along the alpine ridges in the West and Alps (bright green colour) and strong increases in cropland areas with a high share of short rotation coppice (dark green colour), most of them situated in flatlands around the Danube in Upper Austria, in the western part of Lower Austria, southern Burgenland and South-East Styria. The remaining area (cropland and intensively managed grassland) is mostly negatively affected due to more intensive land use. Figure 6 further reveals some substantial local increases in the *degree of naturalness* in the North-East of Austria in *Low* and *Shift*. In these semi-arid areas, farmers adapt to negative climate change impacts on crop yields by lowering fertilizer inputs as well as by increasing the share of short rotation coppice plantations. This explains the positive net impact of *PRO_Energy* on the *degree of naturalness* in *Low* and *Shift*.

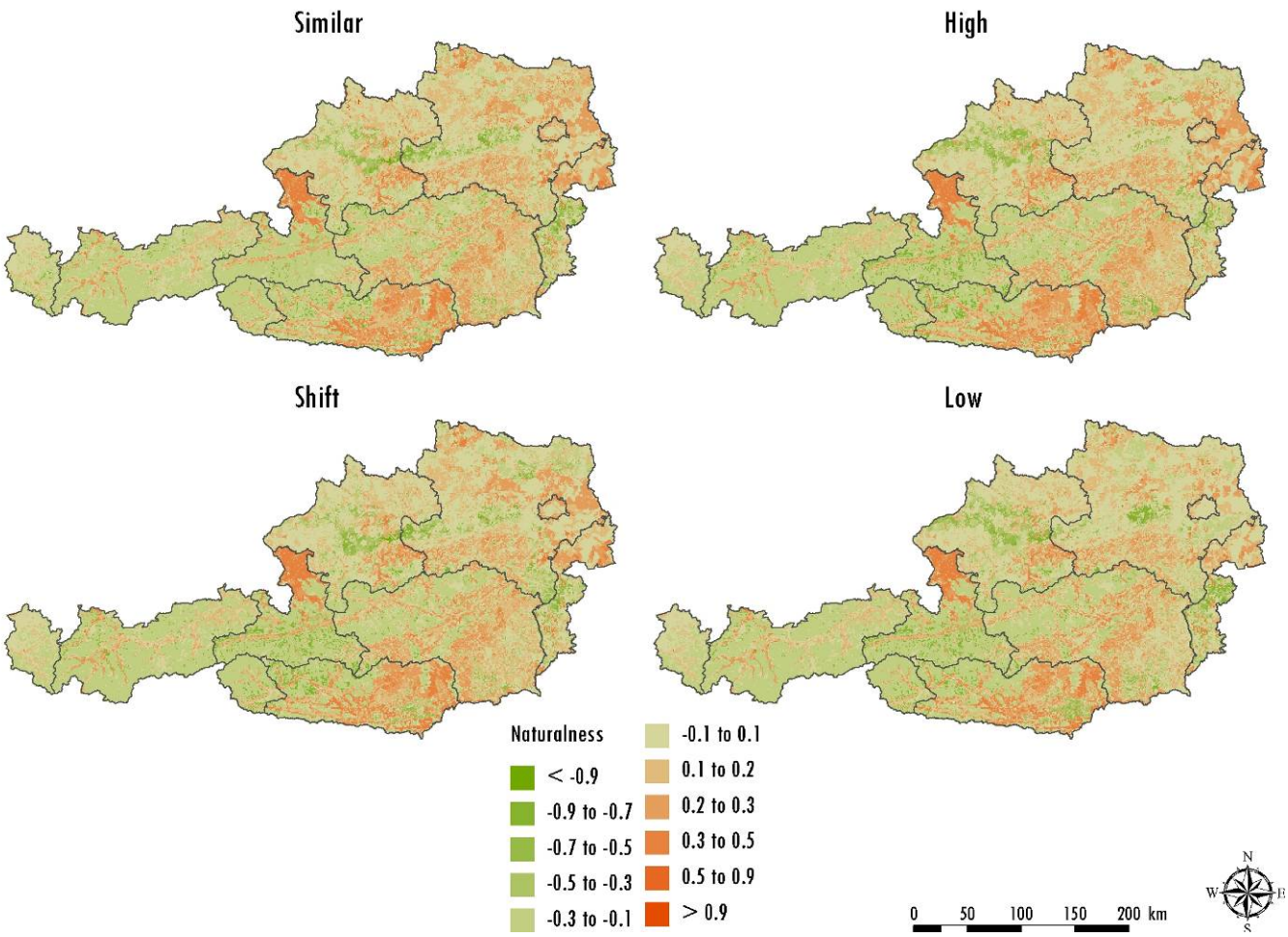

Figure 6: Absolute changes in the degree of naturalness in the *PRO_Energy* scenarios at 1km grid resolution (compared to *REF*). Negative changes indicate a move towards more naturalness.

Spatial impacts for the *mean species richness of vascular plants* across the policy scenarios in climate change scenario *Shift* are displayed in Figure 7. The importance of spatial differences is best represented in BAL. Although the national net impact is positive (see Table 2), large areas are negatively affected. On the one hand, there is a strong increase in the mean species richness of *vascular plants* in the alpine foreland of Lower Austria as well as on some cropland (dark green patches) due to increases in ecological focus areas. On the other hand, many grassland areas (e.g. major alpine valleys, northern Salzburg and in the South) are intensively utilized. This indicates that the opportunity costs for extensification is much higher in these areas (and probably amplified due to climate change) than in the East. The *PRO_Energy* scenario is a counterpart example to *BAL* with an overall decrease, but regional improvements in ecological diversity. Short rotation coppice plantations provide a higher *mean species richness of vascular plants* than most other crops. This leads to positive changes along major cropland areas where most of the short rotation coppice plantations take place (e.g. Danube flatlands in Upper and Lower Austria, north-west Lower Austria, southern Burgenland as well as south-east Styria). In the *BAU* and *PRO* scenarios a steady intensification in almost all areas can be observed, although the scenarios differ in their magnitude. Large local differences in the East are mainly the result of varying crop patterns which offset one another.

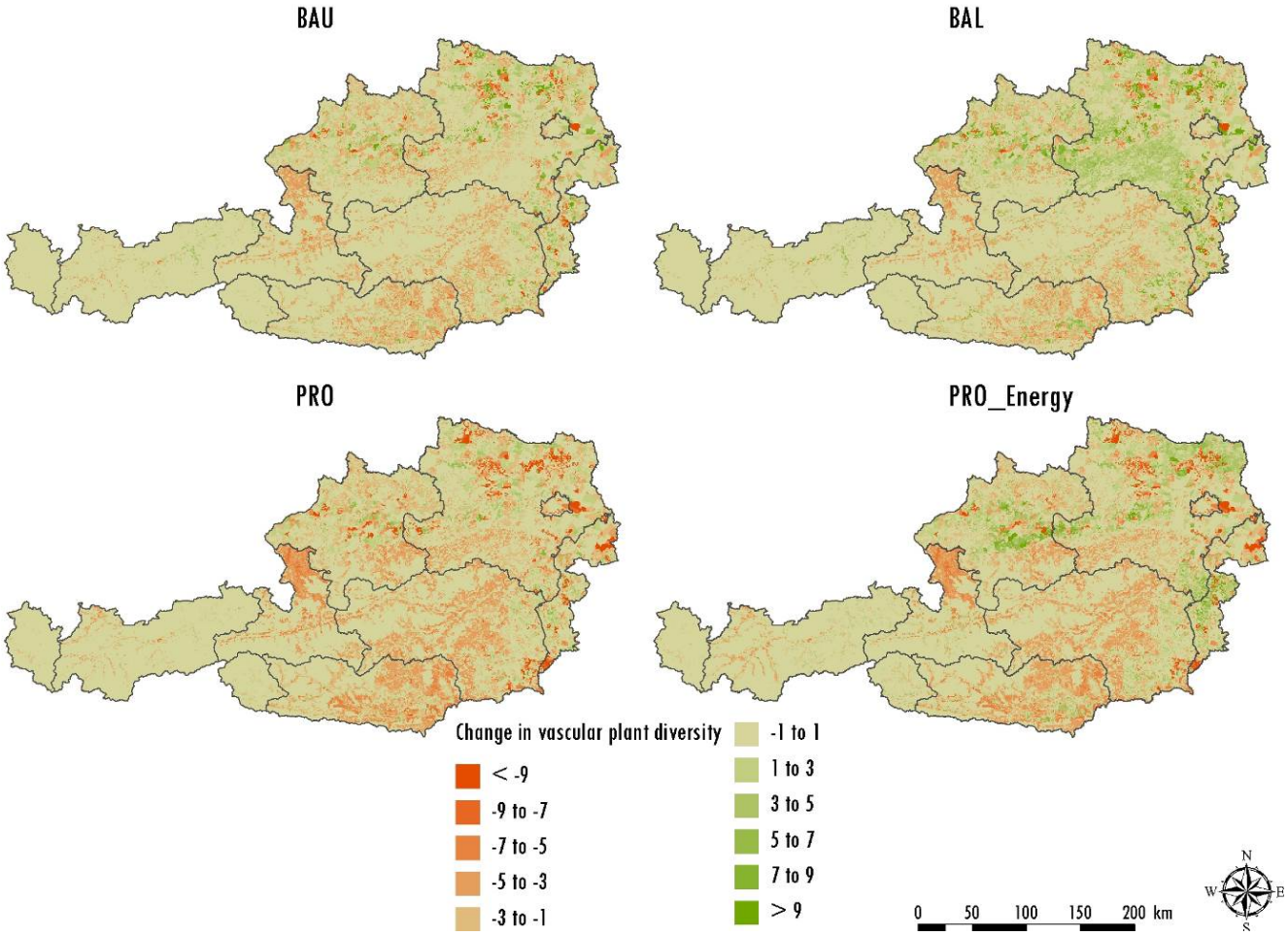

Figure 7: Absolute changes in the mean species richness of vascular plants in the *Shift* scenarios at 1km grid resolution (compared to *REF*)

Landscape Diversity

Landscape diversity is measured using the Shannon Diversity Index, which is a common indicator for this purpose (Frank et al., 2013; Palmer, 2004; Uuemaa et al., 2009b). The spatial dimension of a measuring unit regarding landscape diversity is extended to a 10km grid, as smaller area sizes causes lots of noise in the results. Considering the mean values of changes at country level (see Table 2), very little changes can be identified, but there are significant variances for different regions. The results for the *PRO_Energy* scenarios (Figure 7) show regional differences with partly strong effects on the corresponding landscape. The slightest changes can be observed in the *Similar* climate scenario. The alpine regions are mainly affected due to afforestation on alpine meadows. This leads to a decrease of valuable alpine landscapes and traditional management systems. In the alpine foothills as well as in the flat plains slightly positive effects can be seen because of the establishment of short rotation coppice. This can increase the scenic beauty but can also affect traditional structures like extensive meadows, hedges or orchards, especially when the short rotation coppice areas increase heavily as proposed in the other scenarios. Attention should also be paid on the achievable level of detail for the analysis. An analysis raster of 25m contains detailed information in the land use and the field sizes and structures but misses a lot of details like the above mentioned hedges or orchards that play an important role for the visual diversity of a landscape. Therefore, changes in landscape diversity need to be discussed regionally depending on specific site conditions.

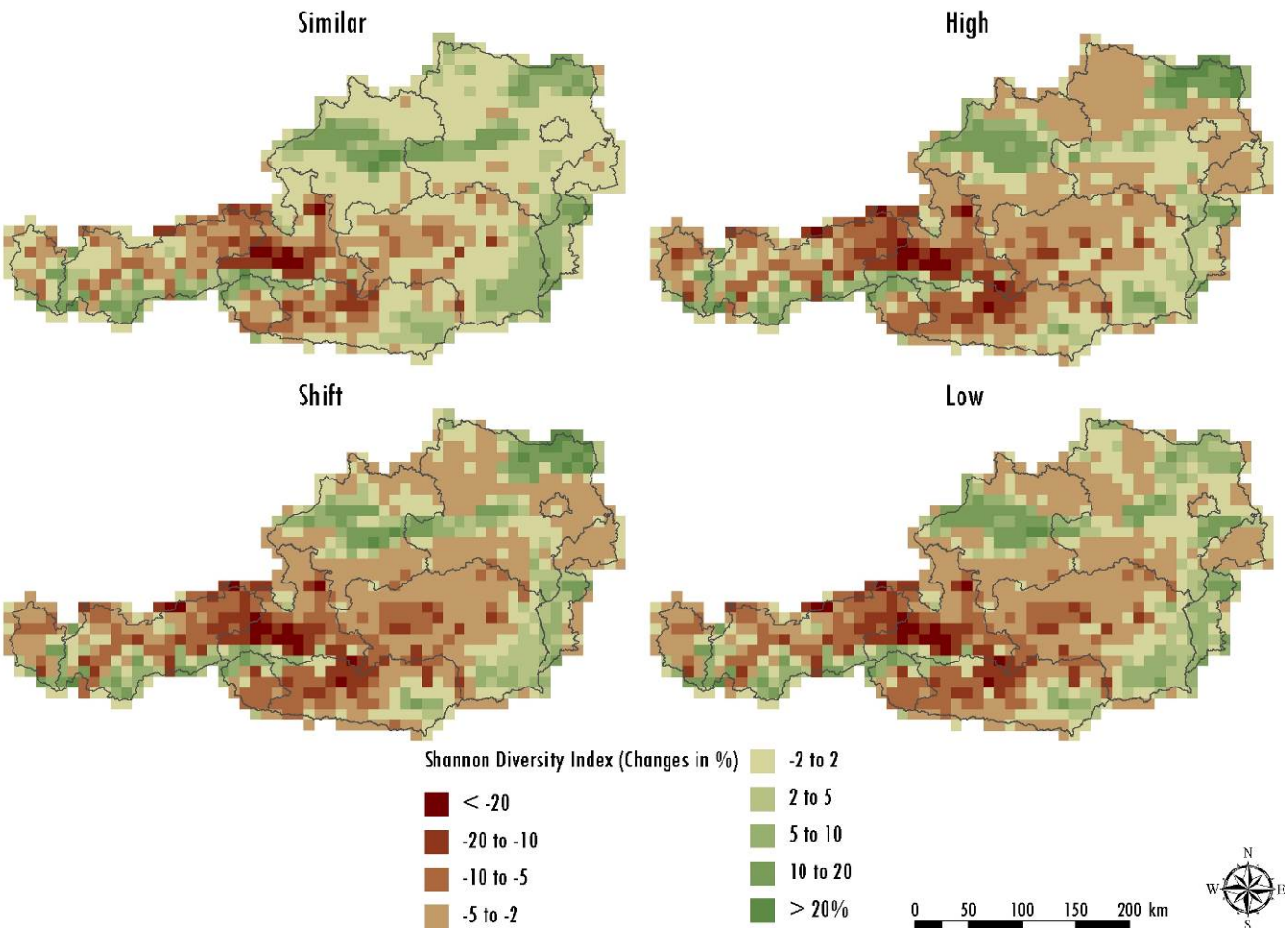

Figure 8: Percent changes in the Shannon Diversity Index in the *PRO_Energy* scenarios at 10km grid resolution (compared to *REF*)

Economic Impacts

Regional differences in economic impacts of climate change and policy scenarios are due to heterogeneities in environmental conditions, sector composition, trade and resource endowments (see Figure 9). For instance, the federal state of Burgenland is most depending on agriculture and forestry among all NUTS 2 regions and therefore shows the highest impacts on regional GDP. In contrast, the federal state of Vienna is hardly affected.

The scenarios *PRO* and *PRO_Energy* incur the highest positive impacts in all federal states, while in *BAL* regional GDP is lowest and negative in some (i.e. Burgenland, Lower Austria and Styria). The spreads of GDP impacts between the climate change scenarios are little in most federal states, except for Burgenland and Lower Austria. These two federal states are vulnerable to precipitation changes as most crop production is located in semi-arid regions with annual precipitation sums of about 500mm. Hence, crop yield differences between *Low* and *High*, and their consequent impact on GDP can be – relative to the other changes – considerable.

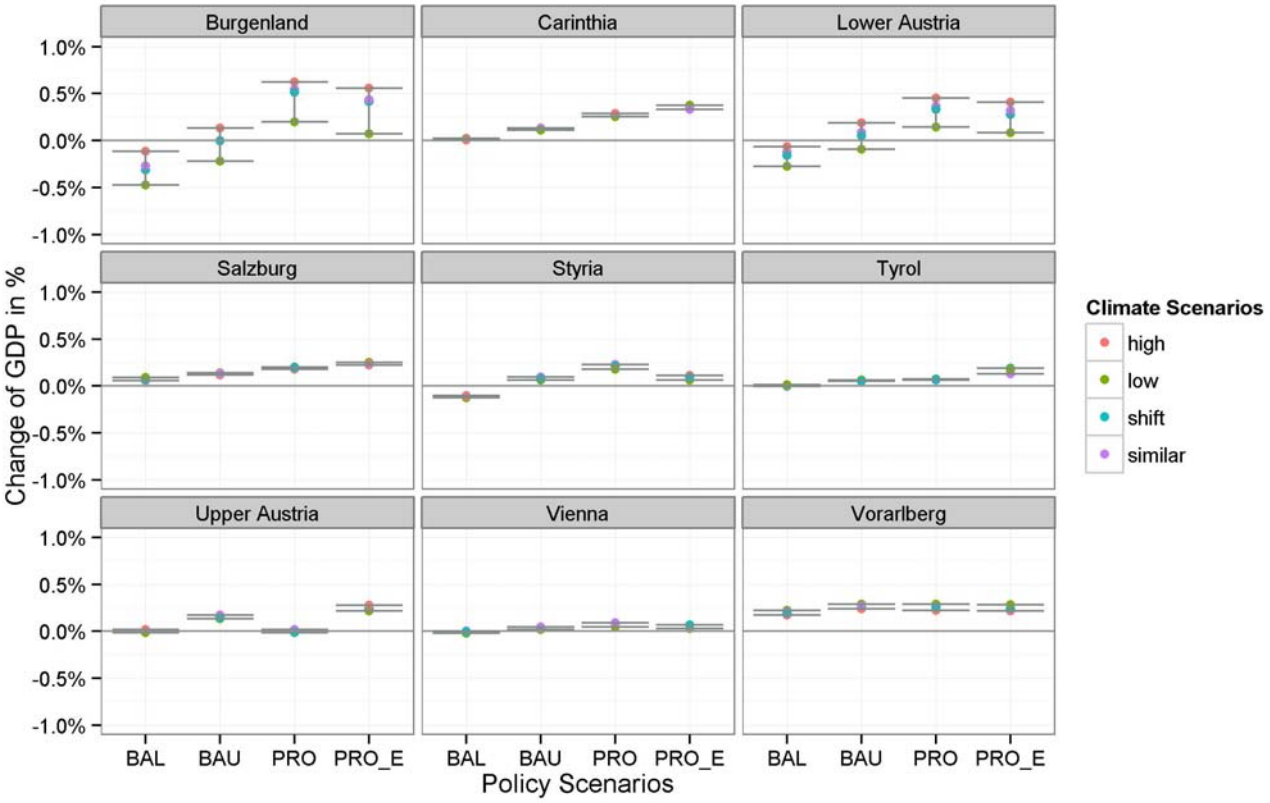

Figure 9: Impacts on Austria's regional GDP at NUTS2 level in %

4 Conclusions and Recommendations

Policy and Climate Impacts

At country level, the alternative policy pathways have a stronger impact on most indicators than the regional climate change scenarios in the period of investigation (2025-2040) (see Table 2 and Table 3). This is also a very common finding among other global change studies (c.f. Audsley et al., 2006; Metzger et al., 2006; Lehmann et al., 2013; Schönhart et al., 2014). Nevertheless, regional climate change leads to substantial variation in many indicators and in some cases also influences the direction of impacts at national scale (i.e. sector value and biomass production in *BAL*; GHG emissions in *BAL* and *PRO_Energy*; SOC in *BAU* and *BAL*; see Figure 2). Moreover, there are also many instances in which the *BAU* climate change scenario impacts outweigh alternative policy impacts. Comparing the alternative policy scenarios to the respective *BAU* climate change scenario (e.g. *PRO_High* vs. *BAU_High*, see Table 3) shows, for example, that (i) water use for irrigation in *BAU_Low* is only marginally affected by alternative policy scenarios; (ii) *BAL* has a lower impact on biomass production and SOC than most *BAU* climate change scenarios (except for *BAU_Low* and *BAU_Similar*, respectively); and (iii) *PRO_Energy* impacts biodiversity indicators and GHG emissions less than the *BAU* climate change scenarios (except for *BAU_Low* in the case of GHG emissions). Climate change can be a dominant factor particularly in regions and sectors vulnerable to changes in temperatures and precipitation. The negative impacts on biomass production in the North-East of Lower Austria and in the North of Burgenland occur across all scenarios, even in *PRO_Energy* (see Figure 5). It demonstrates that climate change impact and uncertainty assessments need to anticipate spatial and regional heterogeneity and future policy pathways.

Trade-offs, Synergies and Spatial Heterogeneity

We analyse trade-offs and synergies of ES and economic indicators at spatial, regional, landscape and national scales. At national scale, most trade-offs follow the common pattern of increasing *provisioning* ES (biomass) at the cost of *regulation and maintenance* (GHG emissions and ecological integrity), and landscape diversity. These trade-offs are especially strong in *PRO* and, conversely, in BAL. Climate change (*BAU*) amplifies these trade-offs as it leads to an intensification of land use. *PRO_Energy* however reveals some potential synergies between biomass production and *regulation and maintenance* ES (e.g. naturalness and GHG emissions). Furthermore, synergies between biomass production and SOC is found across all scenarios, as higher biomass production and thus residues leads to increased C input. The relationship between economic indicators and ES differs between macro-economic (i.e. production value, GDP, employment) and micro-economic impacts (i.e. RPS). RPS is positively correlated with increases in *regulation and maintenance*, and *cultural* ES in *BAL*, *PRO* and *PRO_Energy*, because farmers receive subsidies for adopting measures that are supposed to increase these ES. The production value of the agricultural and forestry sector, GDP and employment are, however, negatively correlated with these ES as extensive land use usually provides lower economic output (as long as these ES are not marketed).

Spatial results emphasize the importance of heterogeneity in impacts. For example, although climate change impacts lead to an increase in total biomass production at the cost of *mean species richness of vascular plants* in most areas (due to land use intensification), opposite trade-offs are visible for semi-arid cropland areas in the East, especially in *Shift* and *Low* (compare Figure 4 and Figure 7). In addition, increases in afforestation measures and short rotation coppice plantations in *PRO* and *PRO_Energy* indicate that local synergies between many ES can be achieved. These two land use options can increase both biomass and macro-economic output and the *degree of naturalness* at landscape level (see Figure 6). In contrast to afforestation, short rotation coppice plantations – in adequate size – can further raise the *mean species richness of vascular plants* (see Figure 7), provide more landscape diversity (see Figure 8), as well as decrease GHG emissions due to less fertilizer application. However, short rotation coppice plantations provide a completely different type of biomass than traditional agricultural crops, i.e. woody biomass cannot be directly used as food or feed but is destined to energy, pulp and paper, and paperboard industries. Possible indirect land use change effects and related impacts on biodiversity and greenhouse gas emissions due to lower food and feed production in Austria may more than offset the positive regional impacts. This also applies to the BAL scenario which has lower overall biomass production.

Comparison of Results

Our regional climate change impacts (*BAU*) are similar to most other studies, e.g.: intensification of land use (van Meijl et al., 2006; Leclère et al., 2013; Schönhart et al., 2014), and regional differences with intensification in favourable areas and extensification in marginal areas (Audsley et al., 2006; Henseler et al., 2009), the vulnerability of crop production regions in the North-East (Alexandrov et al., 2002; Kirchner et al., 2012; Strauss et al., 2012; Thaler et al., 2012), increases in forage yields on alpine grassland (Smith et al., 2005; Henseler et al., 2009; Briner et al., 2012; Schönhart et al., 2014) and the positive impact of increased biomass output on SOC on alpine grasslands (Smith et al., 2005) have been observed in other studies. Positive RPS impacts are more moderate than in Schönhart et al. (2014) and Leclère et al. (2013), but confirm the general trend.

Our policy results are more difficult to compare, as the policy scenarios differ from most case studies. Nevertheless, our findings reflect the outcomes of other studies with focus on ES trade-offs and synergies. As mentioned before, trade-offs between *provisioning* ES and the other ES categories, either scenario based (Goldstein et al., 2012; Nelson et al., 2009) or empirically derived (Raudsepp-Hearne et al., 2010; Tilman et al., 2002) are very common in the literature. Other studies further point to the complex relationship of individual ES (Bryan and Crossman, 2013; Swallow et al., 2009) as well as potential synergies between *provisioning* and the other ES categories (Badgley et al., 2007; Pretty et al., 2006), albeit in very different contexts and with the consideration of different management activities (e.g. conservation tillage, organic agriculture).

Feedback of Stakeholders

The stakeholders, in general, appreciated the outcomes of the project. In particular, they stressed that the detailed spatial resolution of the modeling chain is of high value, as regional differences in climate impacts are visible and help identifying adequate and focused policy responses. Stakeholders emphasized that the overall positive impact of climate change up to 2040 may reverse after 2040 when temperatures increase further. This should be made explicit in the communication of results – as well as the high spatial diversity in positive and negative impacts. Stakeholders stated that they would have expected more extreme outcomes in the climate scenario that assumed a decrease of 20% in precipitation (*Low*).

However, stakeholders also pointed at some issues that may be addressed in future research projects. For instance, they stated that climate extremes are not adequately represented in the project (e.g. changes in rainfall intensities) and that the integration of the forestry model into the modeling chain was achieved only rudimentarily. The *PRO* and *PRO_Energy* scenarios were not considered to be fully realistic by stakeholders as a complete abolishment of subsidies for agri-environmental measures is currently no on the political agenda.

With respect to the stakeholder process, stakeholders pointed out that involvement in such processes is of high relevance, particularly as they have little resources available to visit conferences. Also, stakeholder processes are very important ways of keeping the science - policy interface alive. However, in future projects, more emphasis should be put on finding and motivating additional stakeholders – the low number of only three stakeholders participating in the final workshop was not considered to be sufficient.

Modelling Constraints

Our integrated modelling framework mainly allows for comparative static impact analysis. We could not consider dynamic time effects in biodiversity, e.g. the legacy effects of intensive agriculture (Horrocks et al., 2014). Positive impacts on biodiversity and naturalness have therefore to be viewed with caution as it may take decades for ecosystems to develop to a status that resembles low anthropogenic pressure (Tasser et al., 2008; Dullinger et al., 2013). In addition, we assume that agri-environmental measures are fully effective, which might be a too optimistic assumption (Kleijn et al., 2001; Whittingham, 2011).

The coupling of $PASMA_{[grid]}$ and BeWhere does not consider market feedbacks between food, feed, and energy crops. Hence, the high levels of short rotation coppice production as observed in *PRO_Energy* may only be achieved if either prices for bioenergy crops completely decouple from prices for food and feed, which is unlikely to occur, or if policy makers guarantee high subsidies to the producers of bioenergy crops.

The scale of the modelling linkages in the IMF and the accompanying large data sets exacerbate the possibility to assess the sensitivity of our and additional drivers to ES outcomes (c.f. Bryan and Crossman 2013) as well as to include a larger set of land use measures that could produce better synergies among the ES indicators (e.g. conservation tillage). Such assessments are crucial, given that uncertainties are high with regard to climate change, policy changes, market developments as well as the linkages between land use activities and ES supply. Moreover, these uncertainties are likely to increase with each model linkage. While scenario analysis is a recommended tool to explore possible future pathways and thus uncertainty ranges (Metzger et al., 2006), it could be worthwhile to provide a more extensive analysis of sensitive parameters with high uncertainty and impact (e.g. food and energy prices). This might be overcome in future assessments when more efficient model linkages and a permanent software structure are established, similar to the meta-modelling approach of Helming et al. (2011a, 2011b).

As we do not provide an economic evaluation of non-market ES (c.f. Ehrlich et al., 2012) or a multi-criteria assessment (c.f. Fontana et al., 2013) we cannot derive a 'best' scenario outcome. However, information on the changes of biophysical indicators provides at least an objective way of communicating changes in ES, reveals trade-offs and synergies, and provides the necessary foundation for policy evaluation (Zhang et al., 2007).

Given these constraints, the applied spatially explicit IMF still goes beyond most existing modelling advances. It considers most aspects required by state-of-the art ES research, such as an *interdisciplinary* approach (Carpenter et al., 2009; Rounsevell et al., 2012), spatial *heterogeneity* (Metzger et al., 2006; TEEB, 2010;

Rounsevell et al., 2012), multiple *drivers* (Carpenter et al., 2009; Crossman et al., 2013), integration of key *stakeholders* (Rounsevell et al., 2012; TEEB, 2010), an unusually *wide range of ES indicators* (Tallis et al., 2008; TEEB, 2010; Kinzig et al., 2011), and, in contrast to most studies, *macro-economic* effects (Bryan, 2013).

Main Conclusions

While our findings confirm the common trade-offs between *provisioning* ES (e.g. biomass) and other ES categories (e.g. ecological integrity), we identify exceptions (e.g. SOC), particularly for certain land use activities at landscape level (e.g. short rotation coppice). Furthermore, non-market ES are negatively correlated with increases in macro-economic outputs (e.g. GDP). Our findings thus illustrate the complex relationships between different ES and the economy in agricultural landscapes (Bryan, 2013), and underline the importance of eliciting spatial heterogeneity. In addition, considerable climate change impacts on many indicators emphasize the necessity to account for regional climate change uncertainty.

These findings provide an extensive foundation on which agri-environmental schemes can be improved in order to provide a more balanced and efficient supply of ES. In further steps, multi-criteria analysis could help to prioritize policy pathways (Fontana et al., 2013), spatial targeting could help to improve the efficiency of agri-environmental payments (Babcock et al., 1997; Newburn et al., 2006; Schönhart et al., 2011a), and additional IMF applications could reveal the trade-offs between “land sparing”, i.e. focus on intensive land use and natural reserves patches, and “land sharing”, i.e. focus on more heterogeneous and generally less intensively used land, developments (Fischer et al., 2008).

Stakeholder involvement in the project helped to define policy scenarios which are in line with expectations by the public administration. We also hope to allow for better dissemination of the results to the relevant policy makers, as our project results may help in designing new agricultural and environmental policies.

B) Project details

5 Methodology

This section provides a brief justification for the use of our methodological approach and, additionally, gives a description of this approach, with a focus of the interface between the different models and indicators. An in-depth description can be found in the appendix.

Review of Methods used for ES assessments

Besides some theoretical approaches (Barraquand and Martinet, 2011; Hussain and Tschirhart, 2013) a bulk of ES research applies GIS or spatial mapping based approaches (Goldstein et al., 2012), multi-criteria analysis (Fontana et al., 2013) or integrated modelling frameworks (Schönhart et al., 2011a; Briner et al., 2012) with the aim of providing support for policy. The overarching objective of applied ES research is thereby to foster a more sustainable supply of all ES by eliciting causal relationships, trade-offs as well as synergies (Carpenter et al., 2009).

GIS based and spatial mapping analyses are usually sophisticated in providing detailed information on ES indicators, revealing potential trade-offs, impacts or vulnerabilities for both temporal changes or land use scenarios. Nonetheless, there are shortcomings that our study can address. First, some of the studies reviewed assess a wide range of ES indicators (c.f. Raudsepp-Hearne et al., 2010) but only few focus on biodiversity (Bryan and Crossman, 2013; Nelson et al., 2009) or landscape aesthetics (Reyers et al., 2009), and none on both at the same time. Second, country or supranational analyses are still rare (c.f. Metzger et al., 2006; Lorencová et al., 2013) and regional case studies remain a dominant approach. Third, none of these approaches provides a detailed bottom-up economic modelling of land use and management choices, although economic values for alternative land use are usually accounted for (Goldstein et al., 2012; Swallow et al., 2009), and some even provide a monetary valuation of ES under scrutiny (Bryan and Crossman, 2013; Bryan et al., 2010; Naidoo and Ricketts, 2006; Nelson et al., 2009). The usage of profitability of land use options or economic valuation of non-market ES integrates very important economic and policy aspects, but still lacks the consideration of, inter alia, management intensities (i.e. they often only consider land cover change), resource constraints, trade or feedbacks to the whole economy. This limits the extent to which the impact of policy and climate change on land use and management choices and their subsequent effect on ES supply and economic impacts can be modelled and remains a “frontier of ES science” (Bryan, 2013, p. 131).

Integrated modelling (IM) offers an approach with the potential to deal with these shortcomings adequately. IM tries to combine both biophysical and economic modelling and is thus suitable to disentangle the complex interactions between the human system and the environment (Lavalle et al., 2009; Falloon and Betts, 2010; Zuazo et al., 2011; Laniak et al., 2013) which enables the quantification of ES impacts and trade-offs (Rounsevell et al., 2012). More precisely, IM aims to build impact chains by linking disciplinary data and models, e.g. from climatology, soil sciences, agronomy, animal husbandry, and economics. This ideally helps to derive better recommendations on mitigating ES trade-offs and supporting synergies, because by nature the system under scrutiny has complexities that hamper diagnoses performed by reduced models. IM can thus provide ex-ante assessments and insights into the impact chains of climate and policy changes (Ewert et al., 2009; Janssen et al., 2011).

So far, similar IM studies have only focused on a few ES, usually *provisioning* as well as *regulation and maintenance* ES (Barthel et al., 2012; Briner et al., 2012; Leclère et al., 2013). Schönhart et al. (2011a) provide an analysis of a broad range of ES indicators, including *cultural* services (e.g. landscape aesthetics), but only at local level. The modelling framework of SIAT (Sustainability Impact Assessment Tool; c.f. Helming et al., 2011a, 2011b; Sieber et al., 2013) has many similarities to our approach. While their framework goes beyond many

aspects of our framework (e.g. recursive modelling chains, spatially explicit at European scale, large scale indicator set, use of response functions for meta-modelling) it lacks the consideration of climate change impacts, biophysical simulation models and detailed bottom-up economic land use modelling. Hence, despite the advances in IM and numerous applications (Laniak et al., 2013), multi-regional IM at a high spatial resolution with focus on ES supply, trade-offs and supporting synergies are still rare but heavily required to derive conclusions based on a broader range of heterogeneities (Crossman et al., 2013).

The Integrated Modelling Framework (IMF)

Figure 10 illustrates the models and linkages of the integrated modelling framework (IMF). The IMF has been designed to explore the interfaces between climate, biophysical, and economic factors in land use management at a high spatial resolution (ranging from national level to a 1km grid resolution).

The Austrian Climate model based on Linear Regression Methods *ACLiReM* applies regression and bootstrapping procedures to observed datasets from 1975-2007 in order to project temperature trends and different possible precipitation patterns until 2040 (Strauss et al., 2013). The result is a variety of different climate change scenarios in form of daily time series of solar radiation, maximum and minimum temperatures, precipitation, relative humidity and wind speed on a 1km grid in Austria. Considering the period until 2040 ('near future'), the major advantages of the ACLiReM scenarios compared to the multitude of climate change scenarios from General Circulation Models (GCMs) and Regional Climate Models (RCMs) are the consistency with respect to the physical interdependencies and the spatio-temporal correlations of the six weather parameters, and the well represented small scale climates in the complex topography of Austria. One limitation is that changes in the inter-annual variability as suggested in several studies (c.f. Seneviratne et al., 2006) are not considered. However, the magnitude of these changes is rather uncertain (Christensen et al., 2007; Cayan et al., 2008). For the next three decades, it seems more important to capture a realistic local inter-annual variability, which is indeed provided by the ACLiReM model.

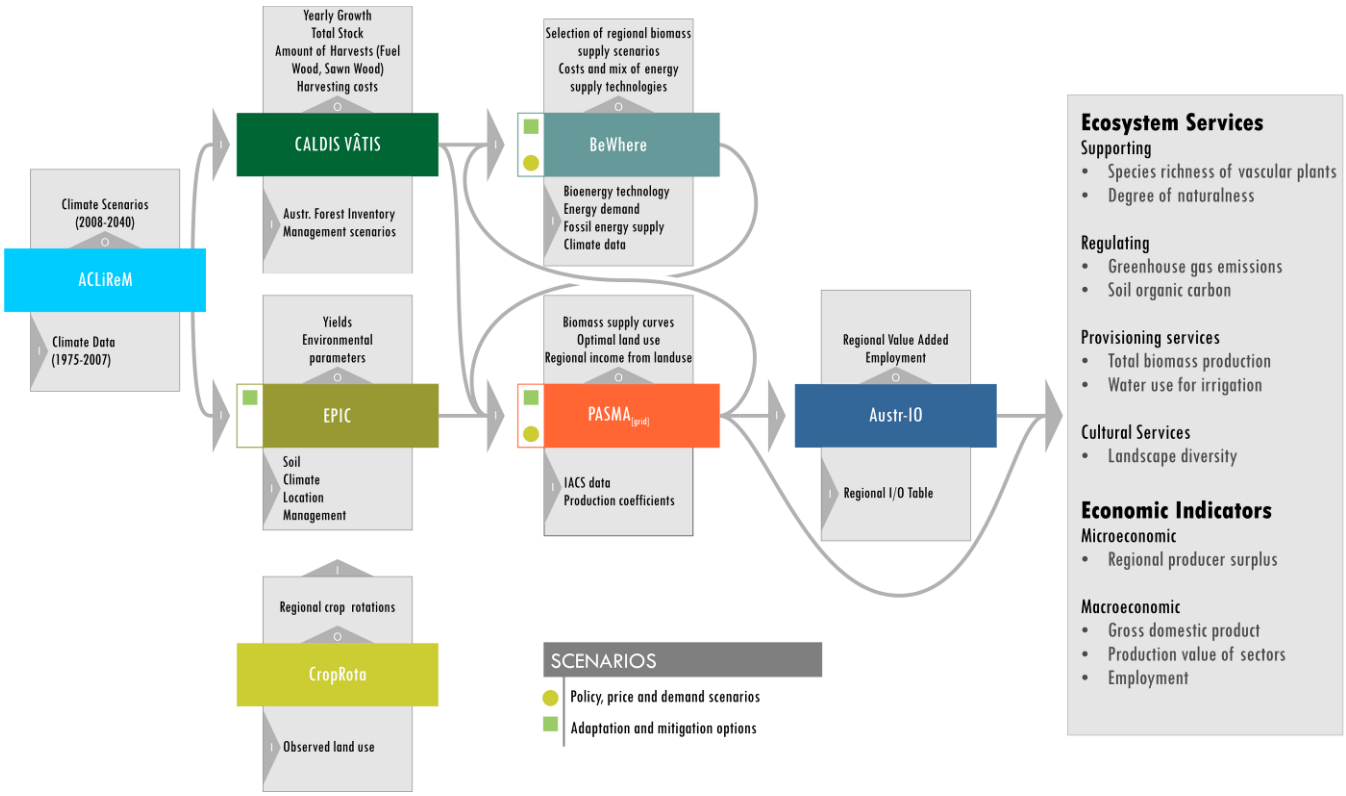

Figure 10: The integrated modelling framework (IMF)

The *CropRota* model derives typical crop rotations at municipality level, taking into account observed crop shares, suitable crop sequences, and agronomic constraints (Schönhart et al., 2011b). The biophysical process model *EPIC* (Izaurralde et al., 2006; Williams, 1995) provides important information on the level and variability of crop yields as well as on environmental outcomes (e.g. soil organic carbon stocks – SOC) of alternative crop production choices. Outputs are differentiated at a spatial resolution of 1km and with respect to topography, soil characteristics, agronomic measures (e.g. fertilization intensity) and weather.

Caldis vâtis is a forest growth model that simulates potential forest growth productivity (i.e. incremental growth rate) at a spatial resolution of 3.89km (Kindermann, 2010). The model is based on observed data from the Austrian National Forest Inventory and uses climate and soil variables as regressors and therefore can, to a certain extent, take short term climate changes into account. It is a distance independent single tree growth model and the single tree data can be summed up to get stand level estimates. The prediction interval is 1 year and it can be used for short term (1 year) up to long term (several decades) estimations of forest development.

Land use choices are depicted by $PASMA_{[grid]}$ which is a spatially explicit version of the bottom-up economic land use model PASMA (Schmid and Sinabell, 2007; Schmid et al., 2007). It derives optimal 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. $PASMA_{[grid]}$ represents the structural and environmental heterogeneity of the agricultural and forestry sector in Austria at a spatial resolution of 1km for cropland, grassland, and permanent crops (i.e. wine, fruit orchards and short rotation coppice). In addition to historical land endowments, we account for the emergence of land use types that have not yet been observed in the past, e.g. short rotation coppice or afforestation measures. Livestock production is modelled at NUTS3 level. Choices on land uses are driven by factors such as commodity prices, costs, subsidies, yields and nutritional value for livestock activities. At the same time, choices are also made with regard to land management intensities (e.g. fertilizer intensity, soil management options). Management intensities are affected by differences in yield, costs, and subsidies. In this study, we consider four distinct management intensities including rainfed agriculture with (1) high, (2) medium, and (3) low fertilization intensity and (4) irrigated agriculture with high fertilization intensity (the latter is only available on cropland). $PASMA_{[grid]}$ is solved for one point in time. Hence, it only allows for comparative static scenario analysis. Major data sources for $PASMA_{[grid]}$ are the Integrated Administration and Control System (IACS), the farm structure survey, the Austrian Farm Accountancy Data Network (FADN), standardized gross margin tables for Austrian agriculture (BMLFUW, 2008), standardized farm labour estimates, and product prices from Statistics Austria as well as the OECD-FAO agricultural outlook (OECD/FAO, 2013). In a regional case study, $PASMA_{[grid]}$ has already been applied (Schmidt et al., 2012). This article provides a first country wide application of $PASMA_{[grid]}$. The model has been successfully validated against the reference year 2008.

BeWhere is a spatially explicit energy system model (Leduc et al., 2009; Schmidt et al., 2011) that minimizes the costs of supplying regions with fuel, electricity, and heat considering fossil (gas combined heat and power, gasoline, diesel, fuel oil furnaces, gas furnaces) and biomass technologies (biomass and biogas combined heat and power with and without gasification, pellets plants and furnaces, 1st and 2nd generation biofuels). BeWhere models the whole bioenergy supply chain from supply points over conversion to end use, including the competition with forestry based industries such as pulp and paper mills, and particleboard industry. Residuals from saw mills are taken into account as possible feedstock for material and energy uses. Fossil reference energy sources are modelled with less detail of logistics. The spatial resolution of the model ranges from a 1km grid (Schmidt et al., 2012) to the level of NUTS3 regions in this study.

In order to assess macroeconomic and sectoral impacts of climate change and policy scenarios we use *AUSTR-IO*, a dynamic multiregional input output model of Austria. The main model structure and parameterization is based on Fritz et al. (2003) and follows the traditional input-output framework of demand driven behavior (e.g. for an overview see Miller and Blair, 2009). However, the model goes beyond traditional input output modelling approaches by using more flexible functions such as translog cost functions and auto-distributed lag functions

instead of the usual Leontief representation of production and demand functions (for details see Kratena and Streicher, 2009; Kratena et al., 2013). The model is calibrated to the base year 2008 and solves recursively until 2040. In terms of dynamic evolution, the model solves stepwise by connecting static equilibria to each other via accumulation of certain stocks (e.g. capital, durable and on-durable goods). Thus, behavior of firms and households depends on current and past states of the economy and there is no inter-temporal foresight (see Kulmer, 2013). The model uses regional supply and use tables of Austria. The model comprises 41 economic sectors which produce 59 commodities. In addition, the model is of the multi-regional type (NUTS2-level) and considers all nine federal states of Austria. Thus, trade and demand between the regions is determined endogenously. However, other countries are not explicitly considered in the model and hence, regarding cross-border trade, we follow the small open economy assumption.

Model interfaces

Daily climate data at a 1km grid resolution from ACLiReM serves as an input to both EPIC and *Caldis vâtis*. This allows assessing climate change impacts on crop and foraging yields as well as forest growth. Further, crop rotations simulated in EPIC depend on the typical shares of crop rotations derived from the CropRota model. Due to computational and modelling constraints, forest growth data from *Caldis vâtis* has only been used for potential afforestation measures on agricultural land. This biophysical endowment data is then integrated into $PASMA_{[grid]}$ by the means of homogenous response units (HRUs) (Schmid et al., 2005; Stürmer et al., 2013). An HRU shares similar natural characteristics such as elevation, slope and soil type. $PASMA_{[grid]}$ integrates unique biophysical endowment data (i.e. land quality) provided for each HRU at municipality level. Optimal land use and management choices are thus derived for each spatial HRU considering the opportunity costs of agricultural and forestry production. Although some local information is lost due to the aggregation of grids to their respective HRU, information on land endowments and biophysical data is available more explicitly than in many other studies currently considered. The HRU concept thus saves valuable computational resources and eases the integration of large biophysical data sets without losing important information on regional heterogeneity. While PASMA has already successfully incorporated climate induced yield changes from EPIC at NUTS3 level (Schönhart et al., 2014) an even finer resolution in $PASMA_{[grid]}$ can help to better account for local heterogeneity in opportunity costs as well as local hot-spots.

$PASMA_{[grid]}$ provides input data for the remaining models. It produces biomass supply curves which are used in BeWhere to determine optimal bioenergy utilization pathways. The supply curves consist of price-quantity relationships for all NUTS3 regions. BeWhere selects, individually for any region, a point on the supply curve and thus, different intensities of biomass production and prices in the NUTS3 regions are observed. This is justified by biomass transportation costs that differ between the regions. While $PASMA_{[grid]}$ output includes supply curves for forestry wood on afforested agricultural land, wood harvests in existing forests are provided by *Caldis vâtis*. The quantities harvested are fixed to the respective results of the respective *Caldis vâtis* scenarios, i.e. instead of supply curves, *Caldis vâtis* provides fixed quantities of forestry products to BeWhere.

The dynamic multiregional input output model AUSTR-IO incorporates the representation of the production and demand structure of the agricultural and forestry sector in $PASMA_{[grid]}$. In particular, factor (e.g. labor input in production) and intermediate demand (e.g. consumption of intermediate goods such as energy and chemicals) as well as output levels and revenues of agriculture and forestry are provided by $PASMA_{[grid]}$. Furthermore, $PASMA_{[grid]}$ gives information on relevant policy parameters such as taxes and subsidies. Data is delivered on the spatial aggregation level of NUTS2 (the level of spatial resolution in the dynamic input-output model). Summarizing, all data comprising the agricultural sector in the dynamic multiregional input-output model corresponds with PASMA. Prior to model integration and scenario simulation, benchmark data on the agricultural sector of the multiregional input-output model has been aligned to and reconciled with PASMA data. Finally, HRU land use data from $PASMA_{[grid]}$ provides the basis for spatial GIS analyses.

Ecosystem Service Assessment

The aim of the described modelling framework is to assess the consequences of scenario assumptions on a broad range of ES in agricultural landscapes. On the basis of expert interviews (Haida et al. subm.) and former studies (Fontana et al., 2013; Tasser et al., 2012) an indicator set was chosen for detailed evaluation of the scenario results. Landscape functions (cf. Haines-Young and Potschin, 2009) and resulting ES depend to a large extent on the integrity of ecosystems. Biodiversity and ecological integrity are usually not only an important precondition for many ES but can also be seen as a 'storage' for potential future ES. Therefore biodiversity relevant environmental indicators, such as *Naturalness of habitats and Area weighted mean species richness of vascular plants* were included in the analysis (Rüdisser et al., 2012).

In addition, we use a set of landscape metrics (*Shannon Diversity Index*) to measuring landscape structure and scenic beauty (Uuemaa et al., 2009). It was necessary to develop a methodology to downscale the results of the agricultural models in order to measure the distribution, size, and structure of landscape elements. Model results are provided spatially explicit for a regular 1km grid (INSPIRE, 2009) and were transformed to a spatially implicit land cover model of increased spatial resolution for assessing biodiversity and impacts on recreation values. Two landcover maps (Rüdisser and Tasser, 2011; Wrbka, 2003) were combined and merged with derivatives from a digital elevation model (slope classes) and a road network from Open Street Maps to receive a more detailed Austrian land cover map for the year 2008. The result is a raster layer at 25m resolution containing information about topology and land use for each pixel. The water and road-network divides the landscape into feasible homogenous units. The model output is processed using a stepwise allocation using database operations and a defined hierarchy order of the modelled land use categories. A raster dataset is calculated for each scenario. As landscape-based indicators rely on the analysis of a larger area, analysis units at a 10km grid are extracted (INSPIRE, 2009). Landscape metrics are calculated for these sub regions.

The final selection of spatially applicable indicators (Table 4) cover all types of ES groups using a classification according to MEA (2003) and the Common International Classification of Ecosystem Goods and Services (CICES) (Haines-Young and Potschin, 2010) and include important ES relevant in agricultural landscapes.

In addition, we also provide a quantitative assessment of economic impacts due to changes in *provisioning* ES (i.e. food, timber and biomass-based energy production). We thereby focus on traditional economic indicators for regional development such as economic value-added, regional producer surplus (RPS), revenues, employment and gross domestic product (GDP).

6 Workplan and Schedule

Figure 11 shows the final work schedule of the project, indicating the start, length, and end of the 11 work packages. The work packages dealing with project management (WP0) and dissemination activites (WP10) were running throughout the whole project. Dissemination activities included the workshops with stakeholders who accompanied the project during the whole project time. At the beginning of the project, we started with the preparation of indicators (WP1) and definition of interfaces between the models and of shared scenarios (WP2), as those were necessary to start with model development in work packages WP3 (Climate data), WP4 (Caldis – Forestry), WP5 ($PASMA_{[grid]}$), WP6 (BeWhere), and WP7 (Austr-IO). $PASMA_{[grid]}$ is a very central component of the model chain, as it receives inputs from many models and feeds many models with outputs. Also, the adaptation from a previous version was quite complex. Therefore, this work package took considerably more time than the others. In WP8, the models were integrated in 2 steps. First, the climate data, EPIC, and CropRota outputs where integrated with $PASMA_{[grid]}$, which fed the energy system model BeWhere in a regional case study in the Sauwald region in Upper Austria. Also, the ecosystem service indicators were partly tested in this case study. In a second integration step, the whole model chain was coupled for the whole of Austria. Eventually, we run all scenarios for the entire model chain. An in-depth description of all work packages can be found in the appendix.

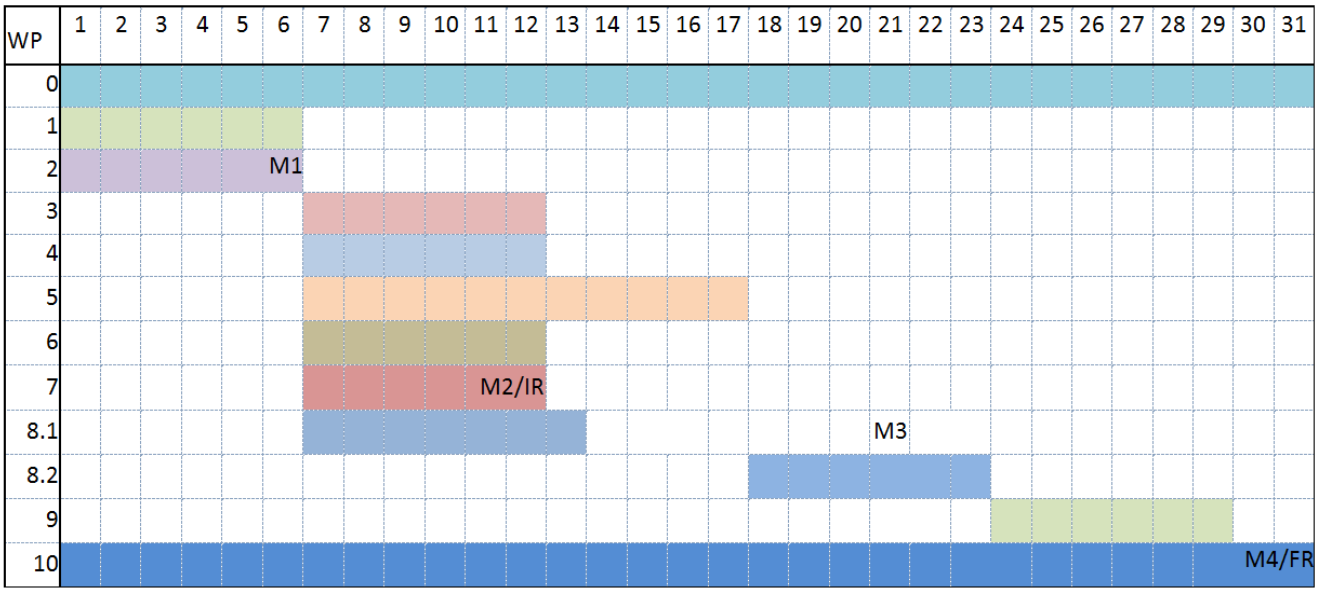

Figure 11: Final work schedule

7 Publications and Dissemination Activities

Dissemination to Stakeholders
See Appendix – WP10
Journal Articles
Kirchner, M., Schmid, E. (2013a) Trade policy and climate change impacts on regional land use and environment. Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie 22(2), 23-32.
Kirchner, M., Schmid, E. (2013b) Integrated regional impact assessment of agricultural trade and domestic environmental policies. Land Use Policy 35, 359-378.
Kirchner, M., Strauss, F., Heumesser, Ch., Schmid, E. (2012) Integrative model analysis of adaptation measures to a warmer and drier climate. Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie 21(1), 177-186.
Mitter, H., Kirchner, M., Schönhart, M., Schmid, E. (2013a) Assessing the Vulnerability of Cropland to Soil Water Erosion under Climate Change in Austria. Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie 22(2), 13-22.
Mitter, H., Kirchner, M., Schmid, E., Schönhart, M., 2013b. The participation of agricultural stakeholders in assessing regional vulnerability of cropland to soil water erosion in Austria. Reg Environ Change 1–16.
Schmidt, J., Schönhart, M., Biberacher, M., Guggenberger, T., Hausl, S., Kalt, G., Leduc, S., Schardinger, I. and Schmid, E., 2012. Regional energy autarky: Potentials, costs and consequences for an Austrian region. Energy Policy 47, 211–221.
Stürmer, B., Schmidt, J., Schmid, E. and Sinabell, F., 2013. Implications of agricultural bioenergy crop production in a land constrained economy – The example of Austria. Land Use Policy 30, 570–581.
Chapter in collected volumes
Kirchner, M., Schmid, E. (2013c) How do agricultural trade policies affect the regional environment? An integrated analysis for the Austrian Marchfeld region. In: Bahrs, E., Becker, T., Birner, R., Brockmeier, M, Dabbert, St., Doluschitz, R., Grethe, H., Lippert, Ch., Thile, E. (eds.), Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e.V. 48, 273-282; Landwirtschaftsverlag GmbH., Münster; ISBN 978-3-7843-5313-5
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. *In press*
Conference publications
Kirchner, M., Schmid, E. (2013d) Trade policy and climate change impacts on regional land use and environment. In: 14. Österreichischer Klimatag**,** Wien
Kirchner, M; Mitter, H; Schönhart, M; Schmid, E; Kindermann, G (2013): A spatially explicit integrated assessment of agricultural policy and climate change impacts on Austrian land use and environment. 133rd EAAE Seminar "Developing Integrated and Reliable Modeling Tools for Agricultural and Environmental Policy Analysis", JUN 15-16, 2013, Chania, Crete, GREECE
Kirchner, M., Schmid, E. (2012a): Trade policy and climate change impacts on regional land use and environment. Ökosystemdienstleistungen und Landwirtschaft - Herausforderungen und Konsequenzen für Forschung und Praxis - 22. Jahrestagung der Österreichischen Gesellschaft für Agrarökonomie, Wien, SEPT 20-21, 2012. Tagungsband 2012, 103-104

Conference publications (continued)
Kirchner, M., Schmid, E. (2012b): How do agricultural trade policies affect the regional environment? An integrated analysis for the Austrian Marchfeld region. 52. Jahrestagung der GEWISOLA „Herausforderungen des globalen Wandels für Agrarentwicklung und Welternährung“ , Universität Hohenheim, Stuttgart, http://ageconsearch.umn.edu/handle/137160 , 26. bis 28. September 2012
Kirchner, M., Strauss, F., Heumesser, Ch., Schmid, E. (2011): Integrative model analysis of adaptation measures in the Marchfeld region. 21. Jahrestagung der Österreichischen Gesellschaft für Agrarökonomie, Europäische Akademie Bozen, OKT 4-6, 2011. Tagungsband 2011, S 3-4.
Mitter, H., Heumesser, C., Schmid, E. (2013c): Measuring climate-induced risks in crop production in Austria. [Grenzen der Qualitätsstrategie im Agrarsektor – 41. Jahrestagung der Schweizer Gesellschaft für Agrarwirtschaft und Agrarsoziologie & 23. Jahrestagung der Österreichischen Gesellschaft für Agrarökonomie, Wien, SEPT 12-14, 2013], Tagungsband 2013, 43-44
Mitter, H., Schmid, E., Sinabell, F. (2013d) Climate change impacts on crop supply balances in Austria. Grenzen der Qualitätsstrategie im Agrarsektor – 41. Jahrestagung der Schweizer Gesellschaft für Agrarwirtschaft und Agrarsoziologie & 23. Jahrestagung der Österreichischen Gesellschaft für Agrarökonomie, Wien, SEPT 12-14, 2013], Tagungsband 2013, 81-82
Mitter, H., Heumesser, C., Schmid, E. (2013e): Analyzing climate-induced risks in Austrian crop production. 133rd EAAE Seminar "Developing Integrated and Reliable Modeling Tools for Agricultural and Environmental Policy Analysis", JUN 15-16, 2013, Chania, Crete, GREECE
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Appendix – Activities & Methodological Details

Within this appendix, we aim at giving a more in-depth overview over project activities and the applied methodology. The subsections are also related to the respective work packages WP1-WP10.

WP1 - Ecosystem services: indicator definition

The aim of this working package was to define usable indicators, to assess consequences of scenario assumptions on ecosystem services (ES), and to develop a methodology to spatially downscale results of the agricultural models which are reported on the level of 1km to a level that allows the application of the landscape-based indicators which rely on spatially more refined data.

Landscape functions (Haines-Young and Potschin, 2010) and resulting ecosystem services depend to a large amount on the integrity of ecosystems. Biodiversity and ecological integrity in general are not only an important precondition for many ecosystem services but can also be seen as a 'storage' for potential future ecosystem services. Therefore biodiversity relevant environmental indicators such as *Naturalness of habitats, Area weighted mean species richness of vascular plants,* and *Shanon Diversity Index of habitats* were included in the final indicator set. On the basis of 53 expert interviews (Haida et al. subm.) and former studies (Erich Tasser, 2012; Fontana et al., 2013a) a final indicator set was chosen for detailed evaluation of the scenario results. The final selection of spatial applicable indicators (Table 4) not only covered all types of ecosystem service groups using a classification according to MEA (Millenium Ecosystem Assessment, 2005) and the Common International Classification of Ecosystem Goods and Services (CICES) (Haines-Young and Potschin, 2010) but included the most important single ecosystem services relevant in agricultural landscapes.

For landscape-based indicators to assess landscape aesthetics and structure we use a set of landscape metrics, as there application for measuring landscape and scenic beauty is well established (Uuemaa et al., 2009). As these indicators measures the distribution, size, and structure of landscape elements, it was necessary to develop a methodology to downscale the results of the agricultural models. Model results are provided spatially explicitly for a regular 1km Raster (INSPIRE Thematic Working Group Coordinate reference systems and Geographical grid systems, 2009) and were transformed to a spatially implicit landcover model of increased spatial resolution for assessing biodiversity and impacts on recreation values. Two landcover maps (Rüdisser and Tasser, 2011; Wrbka, 2003) were combined and merged with derivatives from a digital elevation model (slope classes) and a road network from Open Street Maps to receive a more detailed Austrian landcover map for the year 2008 (see Figure 12). The road network was used to identify field borders as the Open Street Maps data contains also trails and field paths.

The result is a raster layer at 25m resolution containing information about topology and landuse for each cell. The water and road-network divides the landscape into feasible homogenous units. The model output is processed using a stepwise allocation using database operations and a defined hierarchy order of the modelled land-use categories. For each scenario, a raster dataset is calculated. As landscape-based indicators rely on the analysis of a larger area, analysis units at 10km size are extracted (INSPIRE Thematic Working Group Coordinate reference systems and Geographical grid systems, 2009) and landscape metrics are calculated for these sub regions.

In addition to these services, we also include an assessment of the benefits of *provisioning* ES, i.e. the economic-added value of biomass production, measured both as regional producer surplus (RPS) and its contribution to regional and national gross domestic product (GDP). Besides we go beyond gross domestic product and also account for employment and output of key economic sectors (e.g. agricultural and forestry sector, energy sector).

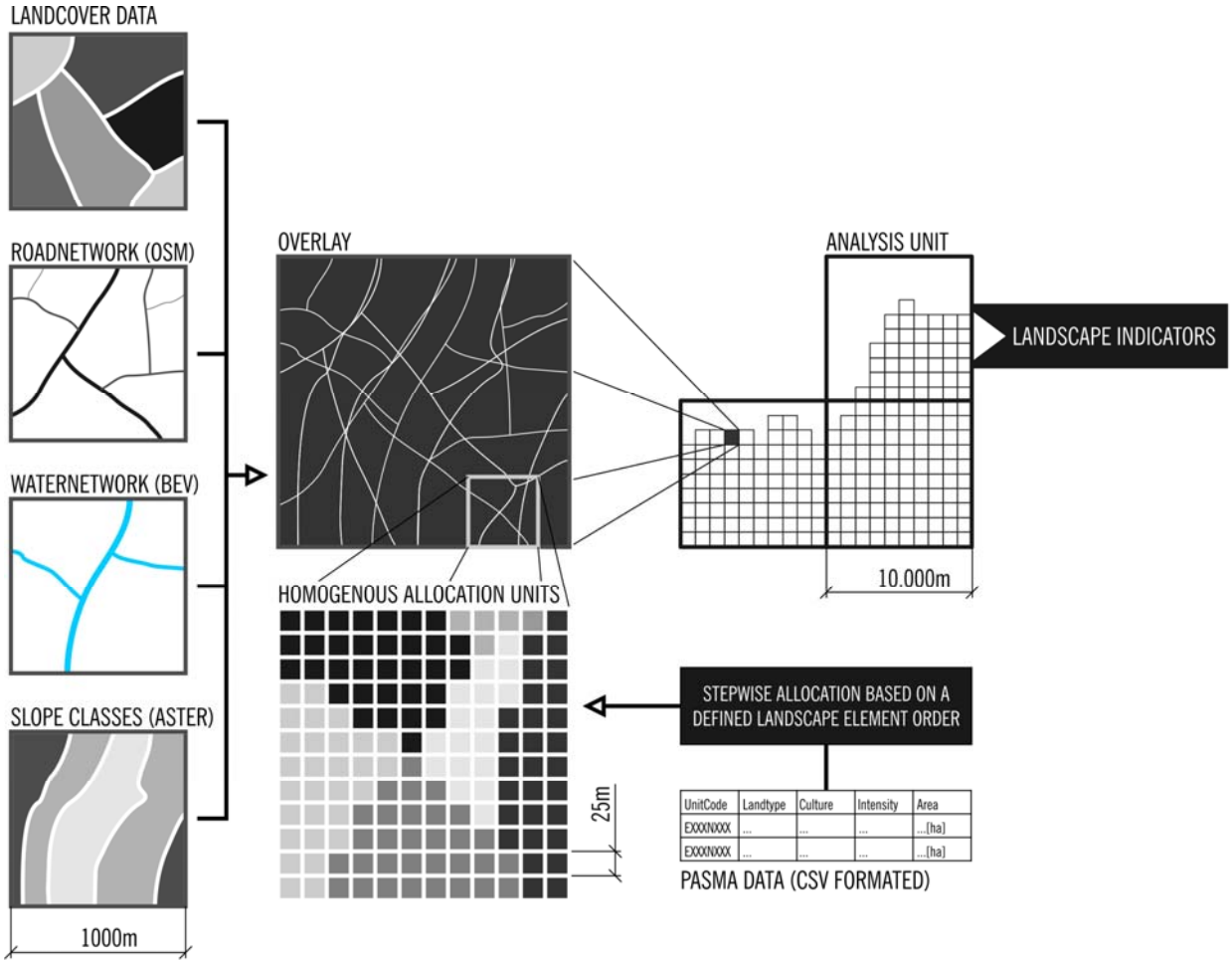

Figure 12: Downscaling of land-use data

Table 4: Ecosystem service indicators (CICES V4.3)

MEA Category	CICES Category	Sub-Category	Service(s)	Measurement	Data Source[1]
Provisioning	Provisioning	Biomass	Nutrition Materials Energy	Total biomass production on agricultural land (dry matter tons);	*Crops, forage and short rotation coppice:* EPIC *Afforestation:* CALDIS
		Water (Materials)	Water for non-drinking purpose	Freshwater abstracted for irrigation (m³)	EPIC
Regulating	Regulation and Maintenance	Soil formation and composition	Decomposition and fixing processes	Soil organic carbon (SOC) in top-soil layer (t)	*Agriculture:* EPIC *Forestry:* regional estimates (Anderl et al., 2013)
		Climate regulation	Global climate regulation	GHG emissions from agriculture (Gg CO^2_{eq})	Emissions factors from Anderl et al. (2013)
Supporting		Gene pool protection (and the stability of eco systems)	Naturalness	Degree of naturalness	Rüdisser et al. (2012) Tasser et al. (2012) Fontana et al. (2013b)
			Biodiversity	Area weighted mean species richness of vascular plants	
Cultural	Cultural	Intellectual and representative interactions	Landscape aesthetic	Shannon Diversity Index	Frank et al. (2013) Palmer (2004)

WP2 - Scenario definition and interface design

In this working package, the scenarios used in the model runs have been defined and extensively discussed with the stakeholders in a stakeholder workshop (16th November 2012) and follow up meetings to parameterize policy options (4th May 2013), in particular with respect to the reform of the Common Agricultural Policy.

Additionally, we discussed and defined interfaces between the models in detail and exchanged data between the models for several times to formalize the data interfaces. A detailed description of scenarios and interfaces follows here.

Scenarios

As decided in the kick-off workshop, we aim at scenario analysis up to the year 2040. We propose to analyze a reference scenario that encompasses a future BAU policy pathway for the period 2025-2040 (i.e. the new CAP reform 2014) and current climate data2. Using such a reference scenario allows holding price and market developments constant and helps thus to better identify alternative policy and climate change impacts. This reference scenario is consequently compared to policy scenarios of the period 2025-2040 which include climate change data (see Figure 13).

We consider two major drivers in the scenario developments within the CAFEE project: The first major driver is climate change. Consequently, four different climate change scenarios are selected with respect to changes in precipitation patterns. The uncertainties in precipitation are much larger than the uncertainties in temperature (we assume an average temperature increase of +1.5 °C in the time span 2010 to 2040 and do not model uncertainty in temperature changes). Together with stakeholder facilitation we selected four scenarios, i.e. (1) similar annual precipitation sums like in the years 1975-2005, (2) +20% annual precipitation sums, (3) -20% annual precipitation sums, and (4) shifts in precipitation sums between summer and winter seasons. All four climate change scenarios are combined with four different policy scenarios which is the second major driver. In total, we will perform 17 applications of the model cluster (all scenario combinations + the reference scenario). We mainly follow the OECD-FAO forecasts for agricultural and energy prices and propose to not vary these prices forecasts between the future scenarios, because the focus of the analysis is put on climate change and policy impacts and not so much on different international price developments. Imports of feed and biomass are possible in $PASMA_{[grid]}$ and BeWhere.

2 The historical analysis for the forestry sector will be based on the period 1981-2009 and for the EPIC crop yield simulations on the period 1996-2005.

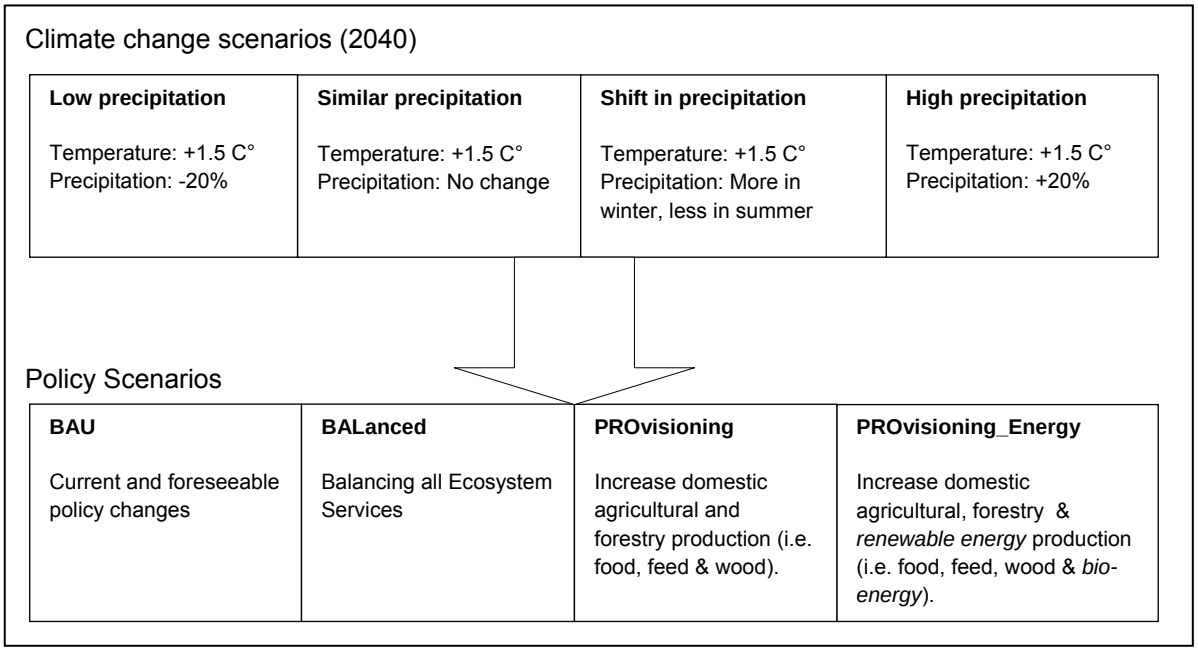

Figure 13: Scenarios

We have described four policy scenarios to capture different policy instrument settings in the CAP and bio-energy policy. Besides a BAU scenario, two contrasting policy scenarios are proposed to model significant impacts in the model output along the model chain.

Considering adaptation, we aim to focus on the question how climate, energy and agricultural policy instruments and measures affect the autonomous adaptation of farmers and foresters. Policies aim to provide incentives for certain production activities by changing opportunity costs, which may increase or decrease adaptation costs to farmers and foresters. E.g., certain premiums in the ÖPUL program may economically limit the choice of crops and management systems to ones that are less suited in changing climate conditions. The *BAU scenario* captures current and foreseeable policies (i.e. CAP and climate and energy policy) until 2040. For example, dairy quotas will phase out and direct premium systems will be transferred from historical to regional payments in *BAU*. The *PRO* scenario will introduce policy instruments that aim at increasing/intensifying the agricultural and forestry biomass production. The *PRO_Energy* scenario adds a focus on renewable energy production. This scenario reverses the current agricultural policies of extensification by the ÖPUL. However, it meets the actual debate on the increasing importance of agriculture and forestry within a bio-based economy for the provision of food, fiber, and fuels instead of environmental goods and services. The *BAL* scenario introduces policy instruments that aim at increasing the level of ecosystem services other than *provisioning* and therefore accepting a reduction in biomass production levels – policy measures will therefore mainly focus on internalization of external effects of agricultural and forestry production (i.e. increased subsidies for the agri-environmental program). A detailed description of scenarios can be found in Table 5.

Table 5: Scenario parameters

	Model Parameter	BAU	PRO	PRO_Energy	BAL
Market measures & direct payments	Price & costs development	OECD-FAO forecast to 2022			
	Sealing of cropland	-3% in 2040 (same for each grid)			
	Milk quota	abolished			
	Suckler cow premium	abolished			
	Payments for less favored areas	- 15%			
	Ecological focus areas (EFA)	+ 3%	0%		+10%
Agri-environmental program	Environmentally friendly management	abolished	abolished		-50%
	Renunciation of agro-chemical inputs	no change	abolished		+100%
	Extensive grassland (one cut)	no change	abolished		+25%
Renewable energy focus	Forcing the utilization of fuel wood and short rotation coppice for energy uses by implementing high oil prices in BeWhere. Demand for final energy is forecasted according to the Austrian Renewable Energy Action Plan (Karner et al., 2010a).	No	No	Yes	No
Forestry	Thinning	No change	Increase		Increase
	Harvest	No change	Increment optimal rotation times		Avoid clear cuts
	Harvesting residues	No change	Increase use		Some dead trees remain
	Fertilizer and irrigation	No change	On short rotation plantations		No
	Reforestation	No change	High yielding trees		Mixed species

Model Interfaces

Interfaces between the models have been defined in the kick-off workshop, refined in detail in bilateral workshops, and have been discussed again in the second project workshop. In the last project year, we tested the interfaces by exchanging data between all models, and, finally, run all of the scenarios linking all models. The results of the model interface definition can be found in Table 6.

Table 6: Definition of model interfaces

Interface		Description	Data exchanged	Spatial / temporal resolution
Clim CALDIS	–	Use climate data and recalibrate Caldis on the observed increments in the timespan 1981-2009	Temperature, Precipitation	1km, daily
EPIC PASMA$_{[grid]}$	–	EPIC simulates crop yields and other biophysical processes that are used as technical inputs for agricultural management activities in PASMA$_{[grid]}$	Crop yields in dry matter tonnes; For forage yields on grasslands and alpine meadows only changes and not absolute values were used	Average annual data (1996-2005 and 2025-2040). Original output 1km - aggregated for each spatial HRU
CALDIS PASMA$_{[grid]}$	–	CALDIS simulates annual stock increments that are used as technical inputs for afforestation activities in PASMA$_{[grid]}$	Total stock increment for different harvesting periods	Outputs for each climate scenario and the reference scenario (simulation for a full rotation period, i.e. 250 years); Original output at 3.78km - calculated averages for each spatial HRU
PASMA$_{[grid]}$ BeWhere	-	PASMA$_{[grid]}$ produces biomass supply curves which are used in BeWhere to determine optimal bioenergy utilization pathways	Quantity produced (MWh) Price (€/MWh) 4 crop groups (agriculture): Ethanol crops, Biodiesel crop, Biogas crops, Short rotation wood (agriculture) 3 wood groups (afforestation on agricultural land): Fuel woo, Industrial wood, Saw wood	Average annual data (15 years period) for all NUTS3 regions
CALDIS BeWhere	-	Forest harvests	Quantity produced (MWh) for wood on exisiting forests: Fuel wood, Industrial wood, Saw wood	Average annual data (15 years period) for all NUTS3 regions
PASMA$_{[grid]}$ AUSTR-IO	–	For the agricultural and forestry sector PASMA$_{[grid]}$ provides data on intermediate inputs, revenues and subsidies in each scenario	Revenues (€) Intermediate and factor inputs (€) Subsidies (€)	Average annual data for all NUTS3 regions and federal states
PASMA$_{[grid]}$ Biodiversity indicators	–	PASMA$_{[grid]}$ aggregates land use and management data into categories; these categories were used to calculate the indicators *Naturalness of habitats and Area weighted mean species richness of vascular plants.*	Spatially explicit land use categories for biodiversity assessment: Area of land use type (m²) per 1km ETRS-Raster cell subdivided for all land use and land culture types used by PASMA$_{[grid]}$.	Average annual data (15 years period) at 1km Raster (ETRS-LAEA-Raster).
PASMA$_{[grid]}$ Landscape indicators	–	PASMA$_{[grid]}$ transfers land use at spatial HRU back to the original 1km resolution; data is then further downscaled to 25m for the assessment	Spatial land use activities	Average annual data (15 years period) at 1km Raster (ETRS-LAEA-Raster)[

WP3 - Preparation of Climate Data

One important driver of future changes is the uncertainty about future regional climatic conditions. This uncertainty is considered by analyzing the effects and impacts of four different climate change scenarios which all include a temperature trend but different assumptions on future precipitation developments, i.e. (i) similar annual precipitation sums, (ii) +20% annual precipitation sums, (iii) -20% annual precipitation sums, and (iv) shifts in precipitation sums between seasons, all with respect to the past period (1975-2005). These scenarios have been generated with the help of the Austrian Climate change Model using Linear Regression (ACLiReM, cp. (Strauss et al., 2013)). It linearly extrapolates the measured temperature trend of the past period to the future period, and re-allocates the past observations of precipitation, solar radiation, relative humidity and wind speed by applying bootstrapping methods. Additionally, precipitation is manipulated according to the particular scenario assumption. The respective weather stations have been selected after classification of temperature and precipitation climatologies (ÖKLIM, cp. (Auer et al., 2000)) into clusters of homogeneous climates ('climate cluster'), and represent the weather and climate conditions of the climate cluster. ACLiReM therefore allows representing consistent physical and spatio-temporal correlations between all the weather parameters.

WP4 - Preparation of CALDIS

A comparison between the climate data used for model creation and the climate data from INWE was done. The climate estimates from BFW are done by interpolating weather information from surrounding weather stations to the position of the inventory point using a flexible altitude gradient. Precipitation in northern Alps show higher values with the method from INWE. The method of BFW shows higher precipitation in central alpine. These differences are in regions which have high precipitation rates and in both estimates even the lower precipitation estimate might not limit tree growth. In regions where precipitation will limit tree growth both estimates are similar. A change between the precipitation data set in the forest growth model is possible.

The estimated temperature from INWE and BFW are similar. Only in high altitudes BFW estimates significantly lower temperatures than INWE. These altitudes are currently not suitable for trees, so it will not cause a problem to change to the climate data set from INWE in the forest growth model. However, Caldis might estimate that a region with high altitude is suitable for trees due to the moderate temperature. This can be handled by setting altitude limits for certain species.

Temperature and precipitation will not be adjusted with point specific factors. The climate data from INWE are taken as they are and the growth functions of Caldis are calibrated to reproduce the observed wood increments of the time span 1981-2009 with these new climate data.

Differences between model estimates and observations are iteratively corrected by adjusting model coefficients until the species specific differences in basal area, tree height and crown ratio are eliminated. As Caldis is currently a pure forest growth model it does not estimate harvesting costs. So an estimation of harvesting costs needs to be developed. Observations and estimates from the Austrian national inventory are used which show harvesting cost. The harvest costs are estimated by using the stem volume, the amount which is removed, the slope, the share of coniferous of the total harvested volume, the average diameter of the removed trees and the share of harvested volume to total stocking volume. The harvesting costs can be calculated for tractor, harvester or cable distinguishing between full tree harvest or debranched and cut trees and if the work is done by a farmer or a forest worker.

One scenario will assume that thinning and harvests is performed like observed in the past. Therefore the behavior of the past, which was observed during the forest inventories, was described by equations. The equations will describe different causes why a tree was removed, including clearcut or thinning.

Besides simulating past harvest behavior, an optimizing harvest regime needs to be developed. Therefore, the species specific and tree size dependent maximum stand density is estimated as reference for a thinning regime.

In addition, the increment optimal rotation time will determine the age of final harvest. For single tree harvest the tree size will be used instead of age to determine harvest time.

To estimate the potential yield at each inventory point young trees of 10000 stems per hectare for each of the currently observed species are generated in the forest growth model. These trees grow in the simulator for 400 years at the highest possible stem number. The optimal rotation time is at the age when the relation of total growth and simulation time is at maximum. Such estimates will be done for each of the climate scenarios.

The sawn wood share is estimated by assuming that only trees with diameters above 15cm may be used as sawn wood. The sawn wood share in a single tree is increasing linearly up to a diameter of 55cm for which a share of 80% is assumed if the tree is coniferous and a share of 40% is assumed for broad leaved trees. The harvest losses are estimated by calculating the form factor for merchantable wood but using a tree height reduced by 0.5 meters and a diameter reduced by 1.5cm to estimate the losses by the stump and the bark. These harvesting losses are increased by 10% for losses like damages or saw dust.

The forest growth model needs site specific information like soil type and vegetation type. This information was only observed on points currently covered by forest. To enable predictions on new afforested areas this site information is estimated from the adjoining forest inventory points. The altitude, slope and exposition were taken from the ASTER digital elevation map with a grid size of 30mx30m and the values have been adjusted to be consistent with the inventory observations. The growing region was estimated with the 3 nearest neighbors. The relief, soil group, vegetation type, water regime and soil depth was estimated by using latitude, longitude, altitude and slope.

WP5 - Preparation of CropRota/EPIC/PASMA$_{[grid]}$

In WP5 the land use modeling system is prepared. It consists of the crop rotation model CropRota, the bio-physical process model EPIC and the land use optimization model PASMA$_{[grid]}$. CropRota has been applied to derive a set of alternative crop rotations from historical land uses at municipality level. Furthermore, a set of homogeneous response units (HRU) has been derived to capture the heterogeneity in the natural production conditions of Austrian agriculture and forestry. In particular, data on elevation, slope and soil types have been classified to delineate 443 HRUs for Austria. Climate and land use data are not directly part of the HRU, but have been merged with the HRU layer in a consecutive data processing step. Consequently, only those parameters of landscape have been used in the HRU delineation, which are relatively stable over time and hardly adjustable by farmers and foresters. It allows assessments of climate change impacts as well as consistent integration in economic land use optimization models. The HRUs are derived from 6 elevation classes (from sea level to above 2100 m), 7 slope classes (from smaller 5% to above 100%), and 15 soil types. These HRU data are merged with data from 60 climate clusters, i.e. climate change.

Currently, biophysical impacts of all climate change scenarios have been simulated with EPIC for cropland and grassland management options such as crop rotations, irrigation and fertilization. Data transfers require consistent and efficient model interfaces, which are prepared in WP5 as well. First results of such interface have been successfully tested for a case study region (Schmidt et al., 2012) while a simplified PASMA$_{[grid]}$ model was coupled with EPIC and CropRota for the whole of Austria (Stürmer et al., 2013). Furthermore, a spatially explicit version of PASMA$_{[grid]}$ – the bottom-up economic land use optimization model PASMA$_{[grid]}$ – has been developed in order to better represent the structural and environmental heterogeneity of the agricultural and forestry sector. PASMA$_{[grid]}$ integrates the biophysical simulation data in order to derive optimal geo-referenced production portfolios of profit maximizing farmers. Land use such as cropland, grassland, alpine meadows and permanent crops (i.e. wine, fruit orchards and short rotation coppice) as well as managed forests can now be provided at a 1km resolution. PASMA$_{[grid]}$ shares the same model philosophy, design and structure as PASMA$_{[grid]}$ (described in detail by Schmid and Sinabell, 2007). But, due to the import of large biophysical data sets as well as more detailed information on land use it differs from PASMA$_{[grid]}$ in some aspects, such as spatial resolution (HRU instead of NUTS3), optimization technique (linear programming instead of positive mathematical programming)

and model constraints (historical mixes instead of calibration). Outputs from $PASMA_{[grid]}$ have been prepared to streamline the data export to BeWhere, AUSTR-IO and GIS-analyses. Post-model scripts have been written to provide the necessary economic input data for AUSTR-IO, biomass supply curves for BeWhere and geo-referenced data for biodiversity and landscape diversity analyses.

WP6 - Preparation of BeWhere

BeWhere is a spatially explicit energy system model applied to different countries. The Austrian version is developed since 2008. Within this project, the main challenge in adapting BeWhere was to couple the model with $PASMA_{[grid]}$ and Caldis. BeWhere has been already successfully coupled with $PASMA_{[grid]}$ in a regional case study: $PASMA_{[grid]}$ provides supply curves for crops from agriculture to BeWhere, while BeWhere selects points on this supply curves and thus determines the level of feedstock production for bioenergy purposes in Austria. In the regional case study, $PASMA_{[grid]}$ output was directly used by BeWhere with a resolution of 1km. At Austrian scale however, $PASMA_{[grid]}$ results had to be aggregated to NUTS3 regions to reduce computational complexity. While $PASMA_{[grid]}$ output includes supply curves for forestry wood on afforested agricultural land, wood harvests in forests existing already today are provided by Caldis. Therefore, an interface between BeWhere and Caldis had to be defined too. The quantities harvested are fixed to the respective results of the Caldis scenarios, i.e. instead of supply curves, Caldis provides fixed quantities of forestry products to BeWhere.

Possible imports and exports of bioenergy products (i.e. biofuels) and bioenergy feedstock (e.g. fuel wood, industrial wood, and plant oil) to and from Austria were implemented into BeWhere. The integration of demand for woody biomass from existing wood industries (saw mills, pulp&paper mills and the paperboard industries) allows to better account for the competition between material and energy uses of woody biomass resources.

To define consistent energy demand scenarios, we updated the demand for final energy (heat, electricity, fuels) based on historical demand trends and on energy efficiency scenarios (Karner et al., 2010b; Krutzler et al., 2009). Also, we assumed that persistence in the energy system due to long-term investments limits the options for

Table 7: Technologies implemented in BeWhere

	Fuel	Products
Large scale technologies		
Natural Gas Combined Cycle	Natural Gas	Power, Heat
Natural Gas Steam Engine	Woody biomass	Power, Heat
Biomass Integrated Combined Cycle	Woody biomass	Power, Heat
Biomass Steam Engine	Woody Biomass	Power, Heat
Synthetic natural gas	Woody Biomass	Synthetic natural gas, Heat
1st generation ethanol plant	Starch and sugar crops	Ethanol, Heat, Feed
Biogas plant	Biogas crops	Power, Heat
Pellets	Woody biomass	Pellets
Household technologies		
Oil furnace	Oil	Heat
Pellets furnace	Pellets	Heat
Wood furnace	Fuel Wood	Heat
Heat Exchanger	District heat	Heat
Gas furnace	Natural gas	Heat

adaptations to new price levels, i.e. investments in the energy system are only slowly replaced. We therefore also limit the option to introduce new technologies in the respective modelling periods. This work package was also used to define the technologies that may be used by the model to satisfy demand for final energy. Table 7 shows the set of technologies implemented into the model. Previous model studies applying the BeWhere model (Schmidt et al., 2011, 2010) were used as basis for choosing this set of technologies, i.e. these assessments indicated which bioenergy options do not have to be implemented in the model as costs are far too high to be competitive with the other conversion chains.

WP7 - Preparation of AUSTR-IO

Methodologically we draw on the dynamic multiregional input-output model AUSTR-IO, an updated version of the former input-output model MultiREG (Fritz et al., 2003; Kratena et al., 2013). In order to assess macroeconomic and sectoral impacts of climate change scenarios as well as policy scenarios in the agriculture and forestry sector, AUSTR-IO incorporates the respective presentation of production and demand structure of $PASMA_{[grid]}$. Therefore, several integration steps are undertaken:

1. Base year compatibility check: Aligning and reconciling AUSTR-IO data on production and demand of the agriculture and forestry sector to $PASMA_{[grid]}$ data for the base year 2008. AUSTR-IO also uses data on subsidies and prices for agriculture and forestry products provided by $PASMA_{[grid]}$
2. Calibration to the baseline scenario: The baseline scenario serves as reference scenario, to which all scenarios are compared to. Aligning with $PASMA_{[grid]}$, AUSTR-IO is calibrated to the baseline scenario, which describes based on plausible assumptions the development of key economic parameters over time and abstracts from additional policy induced changes. Furthermore regarding climate change, the baseline scenario only considers past climate conditions.
3. Scenario simulation: For scenario simulation AUSTR-IO incorporates changes in production structure (output level and revenues) and consumption pattern (intermediate and factor demand) of the agriculture and forestry sector from $PASMA_{[grid]}$. More precisely, AUSTR-IO uses relative changes to the baseline scenario of the respective variables and parameters.
4. Output of AUSTR-IO: As dynamic, multiregional input-output model AUSTR-IO considers sectoral and regional linkages in the Austrian economy and is thus able, by using the relative changes in production and demand structure in the agriculture and forestry sector of $PASMA_{[grid]}$, to depict changes in national, regional and sectoral variables.

For the purpose of this study AUSTR-IO shows impacts of policy and climate scenarios on *benefits* of *provisioning* ES, in particular on regional GDP, employment and output value of economic sectors.

WP8 – Model integration

Within this working package, the distinct models were, after their individual development was completed, sequentially coupled. We exchanged datasets between the models to test and adapt the pre-defined interfaces so that the complete model chain was prepared for running the scenarios. Within this working package, the coupling between the climate data, EPIC, CropRota, $PASMA_{[grid]}$, and BeWhere was already successfully tested and published for a small regional case study in the very first project year (Schmidt et al., 2012). The $PASMA_{[grid]}$ output of this particular case study was subsequently being assessed with the Ecosystem Services Indicator framework developed in WP1 (Schönhart et al., 2012).

The climate data was already successfully integrated into EPIC and Caldis in the first year. For the second half of the project, the expansion of the case study to the whole of Austria and coupling of $PASMA_{[grid]}$ results to AUSTR-

IO and to the tools calculating ecosystem service indicators mainly determined the contents of this work package. This involved debugging, refining the interfaces developed in WP2 and exchanging output of models – therefore communication between the respective developers of the models was a core part of this work package. By the end of WP8, all coupled models had exchanged data and were prepared for the final simulation runs in WP9.

WP9 – Model application and scenario analysis

Within this work package, we performed the final scenario analysis, running the whole model chain with the scenarios previously defined in WP2. Due to the large number of optimization runs necessary for $PASMA_{[grid]}$ and BeWhere, the Vienna Scientific Cluster was used to perform the calculations. Configuring the cluster, running the simulations, and analysing the output took most of the resources in this work package. In particular the analysis of final outputs was important to understand the final logic of all involved models and to validate results.

The last project workshop was used to finalize the story lines that could be derived from the model outputs and to define some additional final runs which were performed to generate the final project output as presented in the last stakeholder workshop, in the publishable final report and in this activity report.

WP10 – Dissemination

Within this work package, we aimed at disseminating project results to both, stakeholders and the scientific community.

Stakeholder process

The stakeholder process was initiated in August 2011 by first contacting relevant institutions in public administration and in the civil society. 5 out of 9 institutions have been willing to participate. Mainly non-governmental organizations declined because of the lack of funding. In future projects a budget should be reserved for these purposes. An overview over all stakeholder workshops and participants is given in Table 8.

The first stakeholder workshop took place on the 9th of November 2011 at BOKU and representatives of all stakeholder institutions, of BOKU-INWE, BFW, and the subcontractor Joanneum Research were present. We presented an overview of the research project and then discussed in detail climate and policy scenarios.

The following changes to the scenarios were proposed by the stakeholders in the workshop and afterwards in a written communication:

- Climate scenarios with increasing precipitation were not regarded to be realistic by most stakeholders. Also, a climate scenario with a shift of precipitation from summer to winter was recommended. After internal discussion, we decided to include a seasonal shift scenario. However, although a scenario that assumes increasing precipitation may seem unrealistic, it cannot be ruled out from a statistical point of view.
- Carbon capture and storage (initially included as mitigation option) is currently not allowed by law in Austria and stakeholders therefore proposed to not include it in the assessment. We agreed to remove it from the scenario assessments as the energy system and associated mitigation options are not in the center of the CAFEE project.
- Deforestation was ruled out as adaptation option by both, stakeholders and project participants.
- The stakeholders indicated that extensification (such as afforestation) may also have a negative impact on biodiversity and that our indicators should be able to account for it.

Table 8: Stakeholder Workshops

Date	Content	Participating Institutions
9.11.2011	Presentation and discussion of scenarios	Lebensministerium, Abteilung Emissions- und Klimaschutz und Abteilung II 9b Umweltbundesamt, Abteilung Landnutzung und biologische Sicherheit AIT Tulln Land NÖ, Abteilung Landentwicklung Institut für Nachhaltige Wirtschaftsentwicklung, BOKU, Joanneum Research, BFW
16.11.2012	Presentation of bio-physical inputs, refining of scenarios	Lebensministerium, Abteilung Emissions- und Klimaschutz Umweltbundesamt, Abteilung Landnutzung und biologische Sicherheit AIT Tulln Land NÖ, Abteilung Landentwicklung Institut für Nachhaltige Wirtschaftsentwicklung, BOKU, Joanneum Research, BFW
04.03.2013	Meeting Lebensministerium	Lebensministerium, Abteilung Emissions- und Klimaschutz und Agrarumweltprogramme/ Invekos Institut für Nachhaltige Wirtschaftsentwicklung, BOKU
22.11.2013	Final presentation	Lebensministerium, Abteilung Emissions- und Klimaschutz Umweltbundesamt, Abteilung Landnutzung und biologische Sicherheit AIT Tulln Land NÖ, Abteilung Landentwicklung Institut für Nachhaltige Wirtschaftsentwicklung und Institut für Landschaftsentwicklung, Erholungs- und Naturschutzplanung BOKU, Joanneum Research, BFW

- It was indicated, that trade is an important issue for Austrian agriculture and forestry and that it has to be regarded in the scenarios somehow, particularly in the bioenergy sector. We allow for imports of biomass in the bioenergy model. With respect to the food- and feed sector, we are able to show shifts in the levels of national production. However, we do not explicitly include trade for these goods in the BeWhere model. AUSTRI-IO, however, accounts for trade.

In a second stakeholder workshop on the 16th of November 2012 at BOKU, we presented the results of the bio-physical assessments of climate change impacts on forestry and agriculture and the results of the first coupling for the case study region Sauwald. Also, scenarios were presented in detail and discuss. Mainly, assumptions on the concrete policy framework for the reform of the common agricultural policy up to 2020 were discussed, such as premiums for suckler cows, the share of fallow land and regulation with respect to short rotation plantations on grass land and cross compliance standards. As a follow up, Mathias Kirchner, Erwin Schmid, and Johannes Schmidt met with stakeholders from “Lebensministerium” to finalize the parameters for the BAU scenario on the 4th of March 2013.

Also, stakeholders pointed out that national parks should be correctly included in the assessments and that introducing leakage effects as indicator may be interesting.

The final results of the project were presented on the 22nd of November 2013 at the final stakeholder workshop at BOKU. Climate change impacts as well as impacts of policies on all indicators were presented – the results are comparable to the final results published in the project report. The stakeholders, in general, were satisfied with project outcomes, however, they pointed out that

- Climate extremes are not adequately represented in the project

- Project communication has to carefully address that impacts of climate change are spatially diverse and that negative impacts of climate change may be visible severely only after 2040
- Forestry is underrepresented in the model chain. Future work should therefore include an enhancement in the modeling of forestry economics.
- Stakeholders expected more extreme outcomes in the climate scenario that assumed a decrease of 20% in precipitation
- The provisioning scenario is not considered to be realistic as a complete abolishment of subsidies for agri-environmental measures is currently not on the political agenda while the balanced scenario seems to be more realistic in terms of political feasibility.

With respect to the stakeholder process, stakeholders pointed out that involvement in such processes is of high relevance, particularly as they have little resources available to visit conferences. Also, stakeholder processes are very important ways of keeping the science - policy interface alive. However, in future projects, more emphasis should be put on finding and motivating stakeholders – the very low number of stakeholders in the final workshop was not considered to be sufficient.

Scientific community[3]

The project and its aims were presented at 9 conferences and additionally, project results were disseminated in eight peer reviewed publications. A first overview of the project was shown at the ACRP Conference in May 2011, and, also in 2001, a poster was presented at the Austrian Climate Day 2011 (Schmid et al., 2011). The coupling of EPIC, CropRota and a simplified version of PASMA is published in the journal Land Use Policy (Stürmer et al., 2013). A first regional application of coupling CropRota-EPIC-PASMA$_{[grid]}$ and BeWhere is published in the journal Energy Policy (Schmidt et al., 2012). The assessment of effects of different production schemes for the same small region was presented at the “Strategies for Sustainability: Institutional and Organisational Challenges” conference in Switzerland by the end of August 2012 (Schönhart et al., 2012).

The use of ecosystem service related environmental indicators for a comprehensive evaluation and interpretation of modeled scenario results within CAFEE was presented at the “AGIT 2012 - Symposium für Angewandte Geoinformatik” (J Rüdisser et al., 2012).

The vulnerability of Austrian cropland to soil water erosion as well as the effectiveness of specific adaptation measures are published in the “Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie” (Mitter et al., 2013b). A reflection on integrating stakeholder knowledge into integrative modelling studies is published in the journal Regional Environmental Change (Mitter et al., 2013a). Climate-induced risks in Austrian crop production were presented at the 133rd EAAE Seminar in Greece (Mitter et al., 2013e). Optimal crop production portfolios which aim at reducing climate-induced variability in gross margins have been presented at the 41st SSA-Annual Conference & 23rd ÖGA-Annual Conference in Zürich (Mitter et al. 2013c). Potential impacts of climate change and policy change on the competitiveness of protein crop production in Austria have been presented at the 41st SSA-Annual Conference & 23rd ÖGA-Annual Conference in Zürich (Mitter et al. 2013d).

A regional case study on climate change impacts and adaptation in the Marchfeld region, with focus on drier conditions was presented at the 21st annual ÖGA conference in Bozen (Kirchner et al. 2011) and subsequently published in the Austrian Journal of Agricultural Economics (Kirchner et al. 2012). This analysis has then been extended to also include trade policy impacts. These results were presented at the 22nd annual ÖGA conference in Vienna (Kirchner and Schmid 2012a) as well as at the 14th Austrian Climate Day (Kirchner and Schmid 2013d) and published in the Austrian Journal of Agricultural Economics (Kirchner and Schmid 2013a). Another study

3 The references in this section can be found in section 7.

focused primarily on policy impacts (i.e. agri-environmental program and trade policy). A first manuscript was presented at the 52nd annual conference of the the German Society of Economic and Social Sciences in Agriculture (Kirchner and Schmid, 2012b) and published in the proceedings (Kirchner and Schmid, 2013c). A finalized paper was then accepted in the Journal Land Use Policy (Kirchner and Schmid, 2013b). At the 133rd EAAE Seminar we could present first results of CAFEE modelling framework and scenarios (Kirchner et al., 2013). A current report on spatial climate change impacts on Austria, which also takes global feedbacks into consideration, is soon available (Kirchner et al., 2014).