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Adaptation to Climate Change in Austria: Agriculture and Tourism (ADAPT.AT)

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1 Introduction

The impacts of climate change are already palpable in Europe. It has warmed by almost 1°C over the last century. Therefore Europe may face major impacts that vary in magnitude and likelihood on its natural environment and many areas of society and economy (such as agriculture and tourism). Due to the inertia in the climate system, temperatures are predicted to continue rising even if all greenhouse gas emissions stopped at once. To deal with the unavoidable impacts of climate change, adaptation plays a crucial role to cope with a changing climate and to reduce the vulnerability to adverse climate effects. Hence, also the European Commission in its Green Paper on Adaptation (2007) has bound itself to develop and gradually refine its adaptation policy.

It calls for more research on the mechanisms of adaptation, as well as the functional interplay of regional and sectoral vulnerability. Due to the cross-cutting nature of adaptation, the assessment of the vulnerability of climate-sensitive economic sectors to future climate and their scope for adaptation requires an integration (or coupling) of climate, regional, sectoral and economic models. This coupling of models requires a common understanding across disciplines (e.g. between geophysics, agricultural economics, and climate economics) and the recognition of mutual modelling requirements (interfaces).

The aim of this project was to develop an integrated modelling framework to describe the requirement for and economic consequences of adaptation in Austria. We focused on the two climate sensitive sectors agriculture and tourism. The integrated modelling framework consists of coupling high-resolution climate change simulations derived from four regional climate models with detailed sectoral models for agriculture and tourism. To take also account of the feedback effects on the rest of the economy, results from the tourism and agriculture models were integrated into a computable general equilibrium (CGE) model of the Austrian economy.

A second focus lies on the options for adaptation. While agriculture is a sector prepared from the past for responding to climatic changes and is therefore also an example for mostly autonomous adaptation, winter tourism depends on snow availability such that adaptation has to take place not only on a larger scale but also requires targeted policy response, e.g. to increase artificial snow making capacities.

A third focus is on questions of model validation and reliability since there are huge uncertainties involved both in climate scenarios and economic development over the time scales relevant for climate change analysis. We analyze uncertainties involved in the overall modelling approach, from uncertainties in climate scenarios to uncertainties in economic modelling.

This project contributes to the 1st call of the ACRP research program in primarily Thematic Area 3 “Integrated Assessment of Climate, Energy and Economy” by providing two types of integrated modelling frameworks for agriculture and tourism, reaching from regional climate modelling to detailed sectoral modelling to macroeconomic modelling. Moreover, this project contributes to Thematic Area 1 “Climate and Climate Impacts“ by investigating the consequences of climate change for Austria, both considering impacts as well as adaptation.

In this final report, we summarize key findings of the project. Section 2 is devoted to a summary of methods employed. As we focus on two sectors, results and conclusions for agriculture are presented in Section 3, while those for tourism are found in Section 4. Section 5 provides an outlook and recommendations for future work.

2 Substantive presentation

2.1 Selection of climate scenarios

In order to cover the uncertainty inherent to climate projections and to reduce computational costs for the impact models at the same time, a comprehensive uncertainty analysis based on the regional multi-mode ensemble of the EU FP6 integrated project ENSEMBLES (www.ensembles-eu.org), aided by additional analysis of an even larger ensemble of global climate models has been conducted. Based on the results of this uncertainty analysis, four representative regional climate simulations have been selected out of an available sample of 19 GCM/RCM combinations (Figure 1), namely the ETHZ_CLM (driven by the global climate model HadCM3), CNRM_RM4.5 (driven by APREGE), SMHI_RCA (driven by BCM), and ICTP_RegCM (driven by ECHAM5). In summer, ETHZ_CLM and CNRM_RM4.5 represent over average warming, with ETHZ_CLM being drier and CNRM_RM4.5 wetter than the multi-model median. SMHI_RCA and ICTP_RegCM represent under average warming, with SMHI_RCA being drier and ICTP_RegCM being wetter. In winter, the cold-wet and warm-dry quadrants are hardly populated and some simulations change their characteristics compared to summer. ETHZ_CLM remains warmer than the median, and shows (slightly over) average precipitation increase. CNRM_RM4.5 shows (slightly under) average warming and drier conditions than the median, ICTP_RegCM and SMHI_RCA are colder than the average as in summer, but change characteristics regarding precipitation.

The selection of four climate simulations representing the range of 19 ENSEMBLES simulations based on combined seasonal temperature / precipitation changes is unique for the Austrian climate research community. Until now, these ranges have not been investigated so far. This allows for the selection of representative climate simulations for arbitrary areas of interest in studies beyond ADAPT.AT and for developing an integrated uncertainty analysis capturing the entire chain of uncertainty from GCMs, RCMs, and impact models in order to derive robust model-independent climate change effects for developing reliable adaptation strategies.

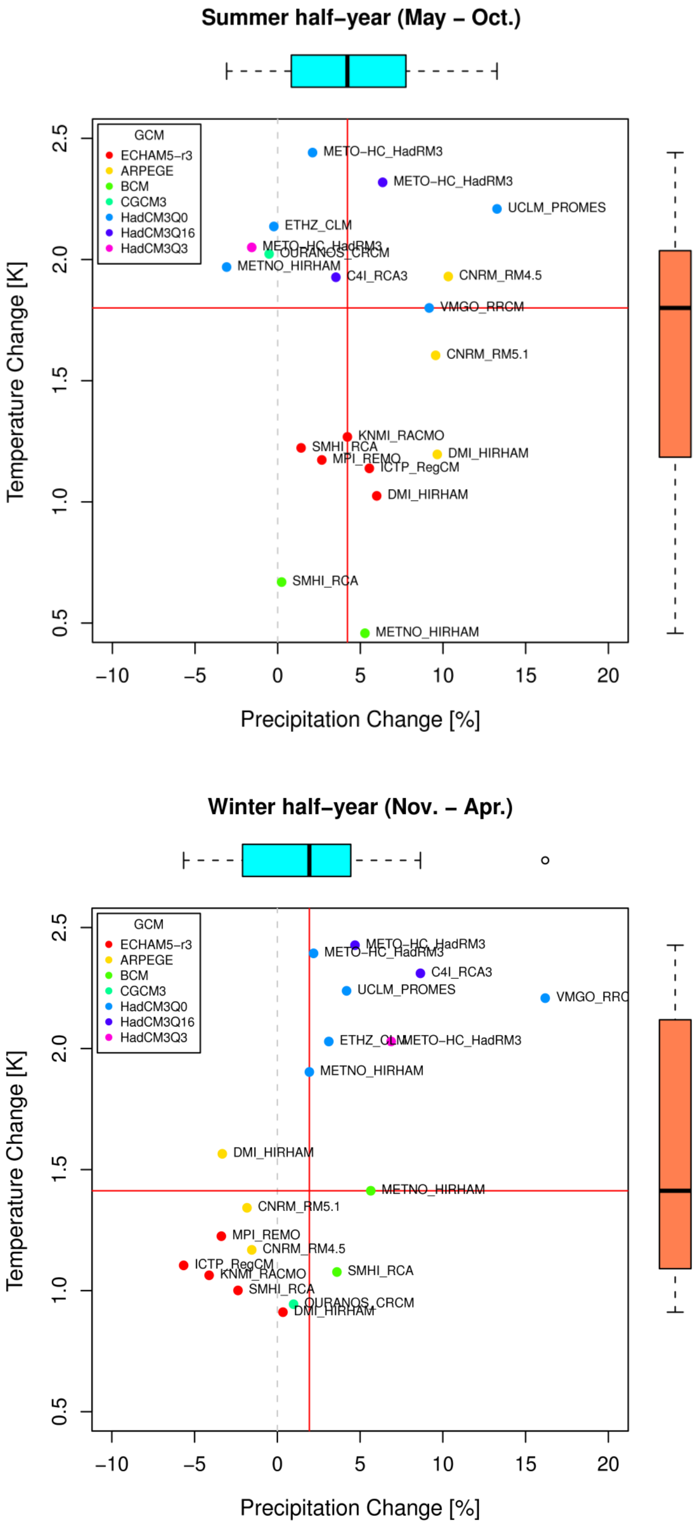


Figure 1: Projected seasonal mean changes between 1961–1990 and 2021–2050 in air temperature and precipitation over Austria for the ENSEMBLES regional climate models. Precipitation changes are relative with respect to the baseline period. Red lines display the multi-model medians.

2.2 Assessment of climate change impacts for agriculture in Austria

2.2.1 Direct impacts on agriculture

The modelling approach to analyse climate change impacts and adaptation effects of agriculture consists of the crop rotation model CropRota (SCHÖNHART et al. 2011), the bio-physical process model EPIC (Environmental Policy Integrated Climate; WILLIAMS 1995), the bottom-up economic land use model PASMA (SCHMID and SINABELL 2007) and a CGE top-down model for Austria.

EPIC has been applied on homogeneous response units (HRU) and regional climate data (see 2.1) utilizing a rich set of crop management variants including regionally specific typical crop rotations provided by CropRota. Each HRU is assumed to be homogeneous with respect to soil type, slope, and altitude at a spatial resolution of one to several km². Crop yields from EPIC are averaged over two 20 year periods (2011-2030 and 2031-2050) and aggregated to the NUTS-3 level to serve as input to PASMA, an economic land use optimization model for Austrian agriculture. PASMA maximizes gross margins from land use and livestock activities for all Austrian NUTS-3 regions by applying positive mathematical programming methods. PASMA has its strength in the detailed description of the socio-economic, policy and bio-physical systems with high spatial resolution of the production heterogeneity. It builds on major land use data and statistical sources such as the Integrated Administration and Control System (IACS) and farm survey data. Furthermore, PASMA is made widely consistent with the Economic Accounts of Agriculture (LGR).

EPIC and PASMA are applied to compute impacts from the four selected RCMs (see 2.1). Baseline scenarios (BAU) for 2020 and 2040 are modeled without climate change impacts. For the baseline in 2020, expected reforms of the Common Agricultural Policy (CAP) such as the abolition of milk quotas, the transition towards a regional system of decoupled direct payments, greening of the 1st pillar and premium reductions in the 2nd pillar are assumed. Furthermore, we take losses in agricultural land for infrastructure into account. Data on productivity and price developments are drawn from OECD-FAO (2011) forecasts and other literature. For 2040, we assume no changes in productivity and prices due to considerable data uncertainties. Consequently, we can estimate the effects of climate change and corresponding adaptation measures.

Regarding adaptation to climate change, three types of response scenarios are distinguished for the years 2020 and 2040. Farmers respond autonomously to changing climate conditions depending on their awareness, risk attitudes, management skills, financial constraints and other factors. These reactions include e.g. choices on crop species and types, crop management (e.g. tillage, fertilizer application, and irrigation), or farm investments (e.g. irrigation infrastructure). In a first impact scenario (SZEN1), we assume a situation with only limited adaption to the changing climate, including choices on plant sowing and harvesting dates and adjustments of livestock numbers. However, no shift in technology or crop species is allowed, i.e. exactly the same crops are produced with identical crop management and output prices. This should reveal the economic impacts of climate change on agriculture and its vulnerability.

An autonomous adaptation scenario (SZEN2) builds on SZEN1. In PASMA, adaptation of land use, crop types, land use intensity, and soil management becomes possible in this scenario. SZEN3 represents induced adaptation stimulated by policies in order to utilize climate change opportunities and alleviate negative environmental effects. Irrigation of crop land is introduced and considered in the model with its costs. Only water is available without charge in this scenario. Furthermore, premiums for soil conservation measures, such as cover crops with 160 €/ha and reduced tillage with 40 €/ha, are introduced. This is in contrast to some other agri-environmental premiums in PASMA, which have been represented as payments based on observed levels but without specific management requirements so far.

2.2.2 Assessment of macroeconomic effects

In order to capture the impact of changes in agriculture on the rest of the economy and arising feedback effects on the agricultural sector, we use a static multi-sectoral (25 sectors) small open economy CGE model based on the GTAP 7 database calibrated for 2004 (GTAP 2007).

The CGE model differentiates for four plant and three livestock sectors derived from the GTAP database, contrary to the standard national accounts with just one highly aggregated agricultural sector. In the CGE model, there are three types of production activities which differ slightly in their production functions (see Table 1): (i) agricultural, land using sectors, (ii) resource using (primary energy) extraction sectors, and (iii) non-resource using commodity production. Agricultural crop sectors (GRA, VAF, OSD, OCR) are characterized by land as a factor input.

At the top level of land using sectors, output is produced with a very low elasticity of substitution (0.1) between land and a non-land composite to acknowledge the fixed factor land. For all types of production activities, nested constant elasticity of substitution (CES) production functions with several levels are employed to specify the substitution possibilities in domestic production between primary inputs, intermediate energy and material inputs. Labor, capital, and land are mobile within the economy but immobile across borders. Moreover, Austria is modeled as a small open economy without influence on world market prices. Following the Armington hypothesis (ARMINGTON 1969), domestic output and imported goods are imperfect substitutes; Armington elasticities are based on GTAP (2007).

Table 1: Sectoral aggregation of CGE model used for impact and adaptation anaylsis in agriculture

Sectors	Code	Sectors	Code
Agricultural (land using) sectors			
Crop sectors (land using)		Livestock sectors	
Wheat and meslin, cereal grains	GRA	Cattle	CTL
Vegetable and fruits	VAF	Milk	RMK
Oil seeds	OSD	Other animal products	OAP
Crops nec.	OCR		
Resource using sectors			
Energy carriers	NRG	Mining	OMN
Forestry	FRS	Fishing	FSH
Non-resource using sectors			
Electricity	ELY	Rest of energy intensive industry	REIS
Chemicals	CRP	Rest of industry	NEIS
Petroleum products	PC	Food products	FOOD
Other transport	OTP	Trade	TRD
Water transport	WTP	Insurance	ISR
Air transport	ATP	Recreational services	ROS
Real estate and renting	OBS	Rest of services/utilities	SEV

A model chain links sectoral bottom-up data of PASMA (e.g. costs, outputs, subsidies) to the top-down economy-wide CGE model. In this upward link, PASMA values are transferred to the CGE model. The sectoral concordance between PASMA and GTAP is established through detailed PASMA model outputs on all major land use and livestock activities, which are mapped to three livestock and four plant production sectors in the CGE model (see Figure 2). For example, PASMA output represents livestock as well as land use activities such as the production of one hectare of wheat with a certain management. This bio-physical output has to be aggregated and monetized and is part of the GRA sector in the CGE model. Moreover, each intermediate input, expressed in variable production costs in PASMA, is matched with one (non-)agricultural GTAP sector. The third linking element is established via agricultural subsidies (with land-based subsidies in crop sectors and capital-based subsidies in livestock sectors).

PASMA and the CGE model are thus linked to utilize their individual strengths. The sector model is necessary to achieve detailed information on production levels, producer rents, costs and land use allocation. PASMA has its strength in the detailed description of the socio-economic, policy and bio-physical systems with high spatial resolution. The CGE model works with aggregated sectors but well represents interactions among sectors and macro-economic outcomes. It is capable of computing general equilibrium states with respective prices and quantities in agriculture. It thus complements demand side effects and implications for foreign trade to the sector model PASMA. The main advantage of the underlying GTAP database is its broad representation of 12 agricultural sectors and its consistent bilateral trade flows for 113 regions/countries and 57 commodities (for further details on the model interface development see SCHÖNHART et al., 2013b).

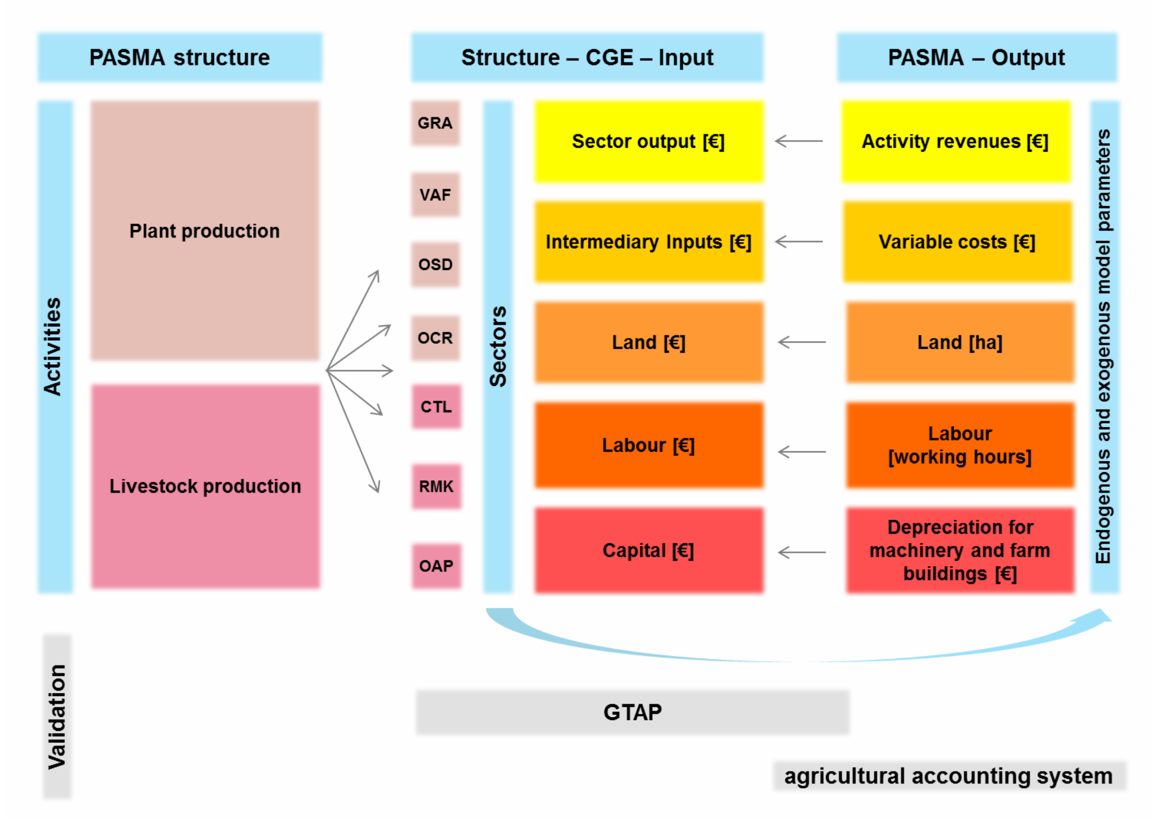
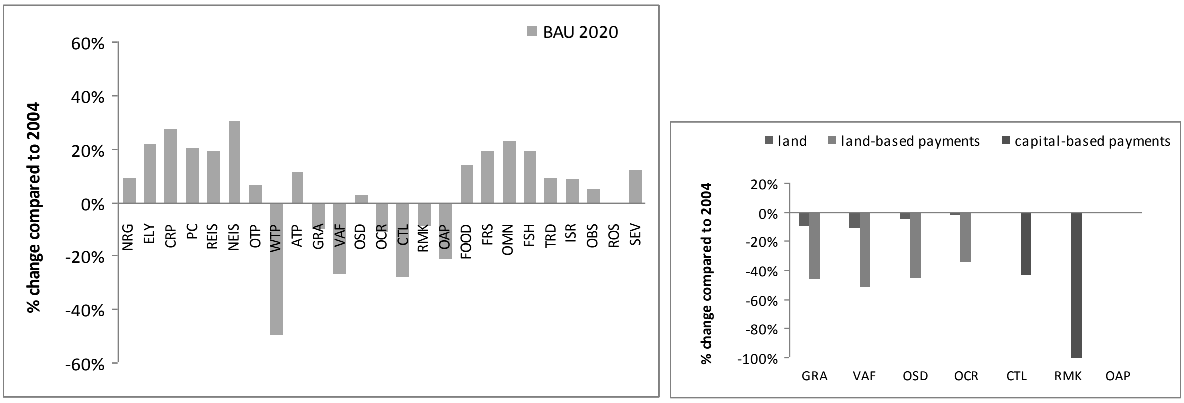


Figure 2: Interface between the agricultural production model PASMA and the CGE model for the Austrian economy

A consistent base year calibration between PASMA and the CGE model is accomplished by the use of various linking variables (see above). Alternative data sources (national accounts, import statistics) were used to complete (and validate) the calibration. In addition, the calibration required SAM balancing techniques as well as price and exchange rate adjustments. Ultimately, the calibration process reproduces the output levels of 2004 (price adjusted, based on OECD food consumer price index) as reported by PASMA. Furthermore, the baseline 2020 and 2040 are developed by extrapolating the macroeconomic framework data for Austria. Three key drivers trigger economic development: (i) factor development (capital stock development, +1.3% p.a. according to PONCET, 2006; work force growth, +0.08% p.a. according to STATISTICS AUSTRIA, 2011; land area development, -0.27% p.a. on average according to exogenously assumed land use shifts towards building areas and decreasing subsidy levels in PASMA), (ii) multi factor productivity (MFP) growth (based on EU-KLEMS database 1995-2004 for non-agricultural sectors; EU-KLEMS, 2009) and (iii) autonomous energy efficiency improvements (AEEI) (1% p.a. based on BÖHRINGER, 1999). To replicate the 2020 and 2040 PASMA baseline runs (without climate change), multifactor productivities, cost structures, subsidies, and resource endowment (land) for each of the agricultural sectors were adjusted accordingly. The same procedure was used for the 2020 and 2040 impact scenarios, but now allowing (minor) behavioral changes by the farmer responding to climate change. For 2040, trends in exogenous developments such as multi-factor growth and efficiency improvements are updated (for further details on calibration see BEDNAR-FRIEDL et al., 2012).

Figure 3 shows the results for the business as usual (BAU) 2020 in terms of sector development (left plot) and expected changes in EU and national agricultural policies aggregated to CGE model values (right plot). Agricultural sector developments have been described above. As for the other sectors, the production level in food rises by 2020 compared to 2004, although the food industry is characterized by strong linkages to agriculture (particularly as main downstream industry) that is impacted through climate change. The reason is productivity gains for food and its largest supplier (TRD). The increase of the food sector is however slowed down by the production declines in agriculture. Energy sectors (NRG, ELY, PC) are subject to an autonomous efficiency improvement. The service sectors (ISR, OBS, ROS, SEV), see rising output levels by 2020 due to factor productivity gains.



Sector codes: NRG = energy carriers, ELY = electricity, CRP = chemicals, PC = petroleum products, REIS = rest of energy intensive industry, NEIS = rest of industry, OTP/WTP/ATP = other/water/air transport, GRA = grain, VAF = vegetable & fruits, OSD = oil seeds, OCR = other crops, RMK = milk, CTL = cattle, OAP = other animal products, FOOD = food, FRS = forestry, OMN = mining, FSH = fishing, TRD = trade, ISR = insurance, OBS = real estate and renting, ROS = recreational services, SEV = rest of services/utilities

Figure 3: Relative changes in agricultural and economy-wide sector output between BAU 2020 and base year 2004 [in %] (left panel); relative changes in land use and subsidy levels in agricultural sectors between BAU 2020 and base year 2004 [in %] (right panel)

2.3 Assessment of climate change impacts for tourism in Austria

2.3.1 Direct effects on tourism

Specific tourism forms rely on different weather or climatic conditions, and they do so to a different extent. E.g. while a hot and dry summer might be good for lake tourism, the same weather conditions might be unfavorable for urban or thermal spa tourism. Thus, climate change impacts are supposed to vary from tourism type to tourism type. Since Austria shows strong regional differences both in the mix of prevailing tourism types and in climatic conditions, a mere analysis on net effects for the Austrian tourism sector could not account for these differences. Therefore, the assessment of climate change impacts for tourism in Austria was carried out separately for different tourism region types. These tourism region types were identified by clustering Austria's 35 NUTS 3 regions according to their regional tourism characteristics, such as tourism intensity and dependency, seasonal focus, feasible types of touristic utilization, relative importance of alpine skiing, and relative shares of the 4-5 stars segment. Figure 4 illustrates the four tourism region types resulting from cluster analysis. The *Urban or thermal spa tourism (URB)* cluster includes nearly all NUTS 3 regions with federal capitals as well as some important thermal spa regions and is characterized by a high share of the 4-5 stars segment. The *Mixed portfolio of lower intensity tourism (TEX)* cluster encompasses the by far largest number of NUTS 3 regions, but only accounts for about 14% of yearly overnight stays. The cluster labelled *Regions with a focus on summer tourism (SUF)* includes some typical lake tourism regions. Despite the clear summer focus, alpine skiing is of high importance for overnight stays during the winter season. The fourth tourism region type, *Regions with a focus on winter tourism (WIF)*, is characterized by the highest tourism intensity. Consisting of only six NUTS 3 regions it accounts for about 50% of yearly overnight stays.

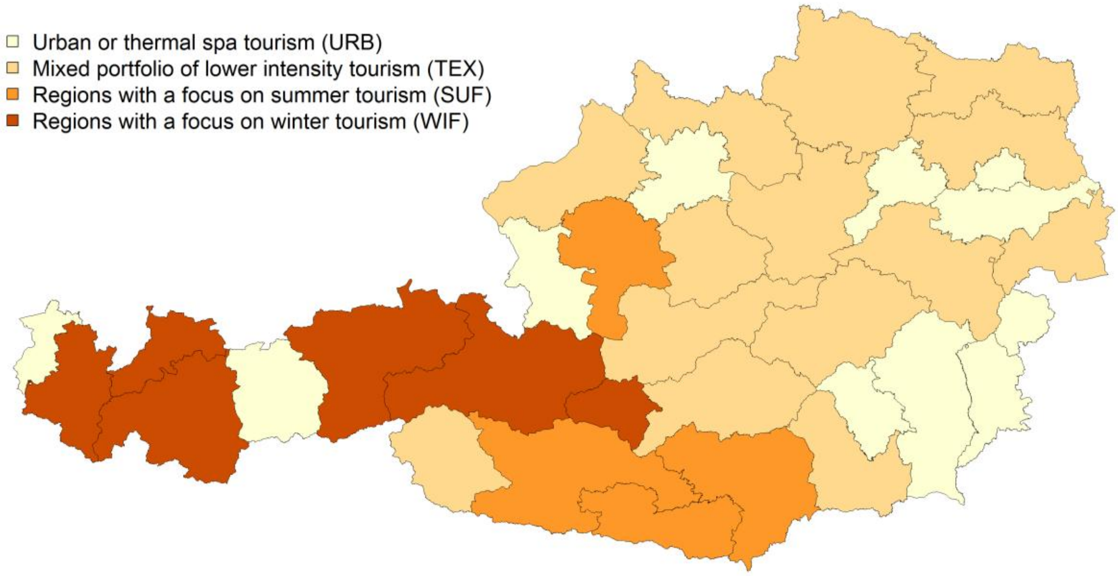


Figure 4: Tourism region types identified by cluster analysis (Algorithm: Ward)

Since tourism is a strongly demand driven sector (PRIDEAUX et al. 2009, MCKERCHER 1998), climate change impacts were assessed by studying the potential impacts of climate change on tourism demand. For this purpose, overnight stays were used as tourism demand indicator. The quantification of the potential impacts of climate change on tourism demand was carried out for each of the four identified tourism region types and separately for winter (November-April) and summer (May-October) season, using a two-step approach. Firstly, the historical weather sensitivity of tourism demand was quantified by means of dynamic, multiple regression models. Secondly, several tourism demand scenarios were simulated until 2050 using the estimated weather sensitivities along with meteorological scenario data from four different climate models on the one hand – resulting in climate change scenarios – and meteorological "baseline" data on the other hand[1] – resulting in a future baseline scenario[2]. Long-term differences between the simulations of tourism demand evolution according to the climate change scenarios and the simulation of tourism demand evolution according to the future baseline scenario indicate the potential impacts of climate change on tourism demand. Results suggest negative impacts of climate change on tourism during the winter season; whereas impacts on tourism during the summer season are indicated to be less clear in their direction and smaller in their extent (see section 5.1). Due to the result of relatively small and unclear impacts of climate change on tourism during the summer season, adaptation scenarios were only generated for the winter season, concentrating on the adaptation strategy "artificial snowmaking" (see section 5.2), which represents one of the dominant and most widely accepted adaptation strategies within snow-based tourism (see e.g. WOLFSEGGER et al. 2008 or BANK and WIESNER 2011).

In order to take into account some indirect impacts of climate change on tourism demand as well, the potential impacts of climate change on the energy demand of the accommodation sector were quantified additionally, assuming autonomous adaptation by the accommodation industry with respect to heating and cooling needs. Assuming that changes in the energy demand and therefore in the energy costs would be (at least partly) passed on to the consumers, results served as starting base for investigating the effects of climate induced accommodation price changes on tourism demand within CGE modeling.

2.3.2 Assessment of macroeconomic effects

To analyze the macroeconomic effects of climate change impacts on tourism as well as adaptation in this sector in Austria, a Computable General Equilibrium (CGE) model for the Austrian economy is developed. In contrast to the CGE model for agriculture, we use the Austrian 57 × 57-sectors national input-output table (IOT) at NACE 2-digit level for the year

[1] Meteorological "baseline data" exhibits the same mean and variability as observed within the period 1971 to 2000.

[2] For simulating future baseline and climate change scenarios, the same functional relationships and trends as observed within the calibration period were assumed.

2006 as database (STASTICS AUSTRIA, 2010). In combination with additional information from the tourism satellite accounts (TSA; STASTICS AUSTRIA, 2012) this database allows the identification of tourism relevant sectors and the disentangling of tourism specific services into four regionalized tourism sectors.

On the sectoral level, we differentiate between 23 economic sectors which were aggregated from the basic 57 × 57 national input-output table at NACE 2-digit level. The aggregation as visualized in Table 2 on the one hand covers sectors which contain tourism relevant services such as sectors 55 (hotels and restaurants), 60 (more precisely 60.21-03: transport by cable railways, funiculars and ski-lifts), 61 (water transport), and 92 (culture, sport and entertainment). On the other hand sectors which deliver important intermediate inputs for these tourism relevant sectors are also modelled explicitly.

Table 2: Sectoral aggregation of the Austrian input-output table (IOT) 2006 for the tourism CGE model

	Sectors	Code	Comprising sectors (ÖNACE-No.)
1	**Energy carriers (CO_2 generating)**	**NRG**	10, 11
2	**Electricity**	**ELY**	40
3	**Refined oil products**	**P_C**	23
4	**Chemicals rubber and plastic**	**CRP**	24, 25
5	**Rest of Energy Intensive Industries**	**EIS**	21, 22, 26, 27
6	**Non energy-intensive industry**	**NEIS**	17, 18, 19, 20, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37
7	**Transport Commodities**	**TRN**	60-63
8	**Agriculture**	**AGR**	01
9	**Food products**	**FOOD**	15, 16
10	**Extraction (natural resource input)**	**EXTR**	2, 5, 12-14
11	**Trade**	**TRD**	50, 51, 52, 55
12	**Insurance**	**ISR**	66
13	**Real Estate & Rental**	**OBS**	70, 71, 72, 73, 74
14	**Recreation, Culture, Sport**	**ROS**	92, 93, 95
15	**Other Services and Utilities**	**SERV**	41, 45, 64, 65, 67, 75-91
16	**Tourism Industry**	**TOUR**	
16a	Urban	URB	**disentangled from 55 (in trd), from 60, 61 (in otp, wtp), and from 92 (in ros)**
16b	Mixed tourism-extensive	TEX	
16c	Summer focus	SUF	
16d	Winter focus	WIF	

In a first step of disaggregation, the national IO table for Austria provided by Statistics Austria has to be regionalized in order to allow the derivation of regionally specific climate change impacts on the Austrian tourism industry. Therefore NACE sectors identified by the TSA (tourism satellite accounts) as containing tourism relevant services, namely sectors 55 (hotels and restaurants), 60 (more precisely 60.21-03: transport by cable railways, funiculars and ski-lifts), 61 (water transport), and 92 (culture, sport and entertainment) are disaggregated into the four tourism region types.

In a second step, these four regionally clustered tourism relevant sectors can be split into tourism specific goods and services (A.1), tourism related goods and services (A.2), and non-tourism specific goods and services (B) (see Table 2). As not all goods and services produced by the relevant sectors that contribute to the tourism industry are consumed by tourists, we extract therefore the respective shares of hotels and restaurants, tourism transport services & travel agencies, and culture, sport & entertainment from the tourism relevant sectors. In a final third step, the tourism specific shares of the regionalized sectors 55, 60.21-03, 61 and 92 could be aggregated to form a single tourism sector for each of the four clusters.

Following the structure of the Austrian IO table, we construct a social accounting matrix (SAM) which forms the data basis for our CGE analysis of the Austrian tourism sector. The representative private household receives total labor and capital income (less depreciations), as well as transfers from the government. On the one hand, the representative household saves a constant fraction of its disposable income. On the other hand, the private households spend their income on the consumption of domestic as well as foreign goods and services. The government receives total tax revenues, which in turn is spent on the provision of public goods as well as on direct transfers to the representative household. We model capital and labor as mobile between the 23 sectors representing the Austrian economy.

In the CGE model, nested constant elasticity of substitution (CES) production functions are employed to specify the substitution possibilities in domestic production between the primary inputs capital and labor, intermediate energy and non-energy inputs. With respect to foreign trade, i.e. the allocation of final and intermediate consumption between domestic and foreign goods and services, we follow the small open economy assumption. It assumes that an economy that participates in international trade is small enough compared to its trading partners that it does not alter world prices because of its policies. This allows the explicitly modeled region to trade as much or as little as it wants at fixed world prices. Trading in the model is therefore represented by functions which allow the economy to transform exports into imports at a single world price ratio. The model is implemented in GAMS MPSGE (RUTHERFORD 1999).

Since our macroeconomic model is designed in a comparative static way, we have to rely on exogenous growth assumptions for our analysis of the Austrian economy until 2050. We rely on projections for the annual work force development by Statistics Austria, which is assumed to grow by 0.008% per annum. With respect to the development of the Austrian capital stock we follow PONCET (2006) and assume an annual growth rate of 1.3%.

With respect to assumptions about technological change, we assume autonomous energy efficiency improvements (AEEI) amounting to 1% per annum for all economic sectors, based on BÖHRINGER (1999) and BURNIAUX et al. (1992). Furthermore, for non energy inputs in production we apply annual multifactor productivity (mfp) growth rates based on the EU-KLEMS database (EU-KLEMS, 2009).

2.4 Climatological uncertainties

In order to derive the uncertainties in changes of 2-m air temperature and precipitation amount between the two 30-year periods of 1961-1990 and 2021-2050 over Austria and three specified agricultural subregions, we used a set of 22 regional climate simulations with a horizontal resolution of 25 km which was produced in the EU FP6 integrated project ENSEMBLES (www.ensembles-eu.org). The ensemble is mainly subject to uncertainties in the formulation of driving global climate models (GCMs) and regional climate models (RCMs). Uncertainties due to future GHG emission scenarios are not regarded. However, it is demonstrated by the analysis of a larger GCM ensemble which includes various emission scenarios that the choice of the emission scenario is of minor importance until the mid of the 21st century and, therefore, only the A1B emission scenario was used. In order to give unbiased uncertainty estimates of the RCM simulations, the missing climate change signals (CCSs) of the ENSEMBLES simulation matrix were reconstructed.

For air temperature, the spatial pattern of the warming for both uncorrected and error corrected RCMs is fairly different for the four simulations at smaller scales. However, some similarities exist at larger scales such as a greater warming in the southern to central and western parts of Austria in spring, summer, and autumn. The projected warming is highly reliable in all seasons. As displayed in Figure 5, the width of the histograms and the associated kernel estimates, and therefore the associated uncertainty, is lowest (largest) in autumn (spring) with a difference of 1.3 K (1.7 K) between the 90th (Q.90) and 10th (Q.10) percentile of the reconstructed ENSEMBLES CCS (climate change signal) matrix for Austria. The entire range of the reconstructed ENSEMBLES CCS matrix is generally better covered in winter and summer than in spring and autumn by the four selected ADAPT.AT simulations. The variance decomposition reveals that the choice of the driving GCM has the largest effect on the total variation, contributing in most cases more than 70 % to the overall uncertainty. For precipitation, the spatial pattern, the magnitude and the sign of change show in general large differences between the simulations. The projected precipitation changes are highly uncertain in Austria and more generally, along the transition zone from pronounced drier conditions in southern Europe to wetter conditions in northern Europe. The width of the histograms and the associated kernel estimates, and therefore the associated uncertainty, is lowest (largest) in spring (summer) with a difference of 14.8 % (26.0 %) between Q.90 and Q.10 of the reconstructed ENSEMBLES CCS matrix for Austria. The range of the reconstructed ENSEMBLES CCS matrix is well covered by the four selected simulations. The variance decomposition reveals that the choice of the RCM is by far more important for precipitation than for 2m air temperature. Especially in spring and summer the RCMs have a larger effect on the total variation than the GCMs.

In summary, the results show that further warming of Austria until 2050 is virtually certain, but considerable uncertainty exists in the projected precipitation changes, which will most probably lie between -10% to +10%. The reason for this uncertainty even in the sign of change is that Austria is situated in a transition zone from pronounced drier conditions in southern Europe to wetter conditions in northern Europe.

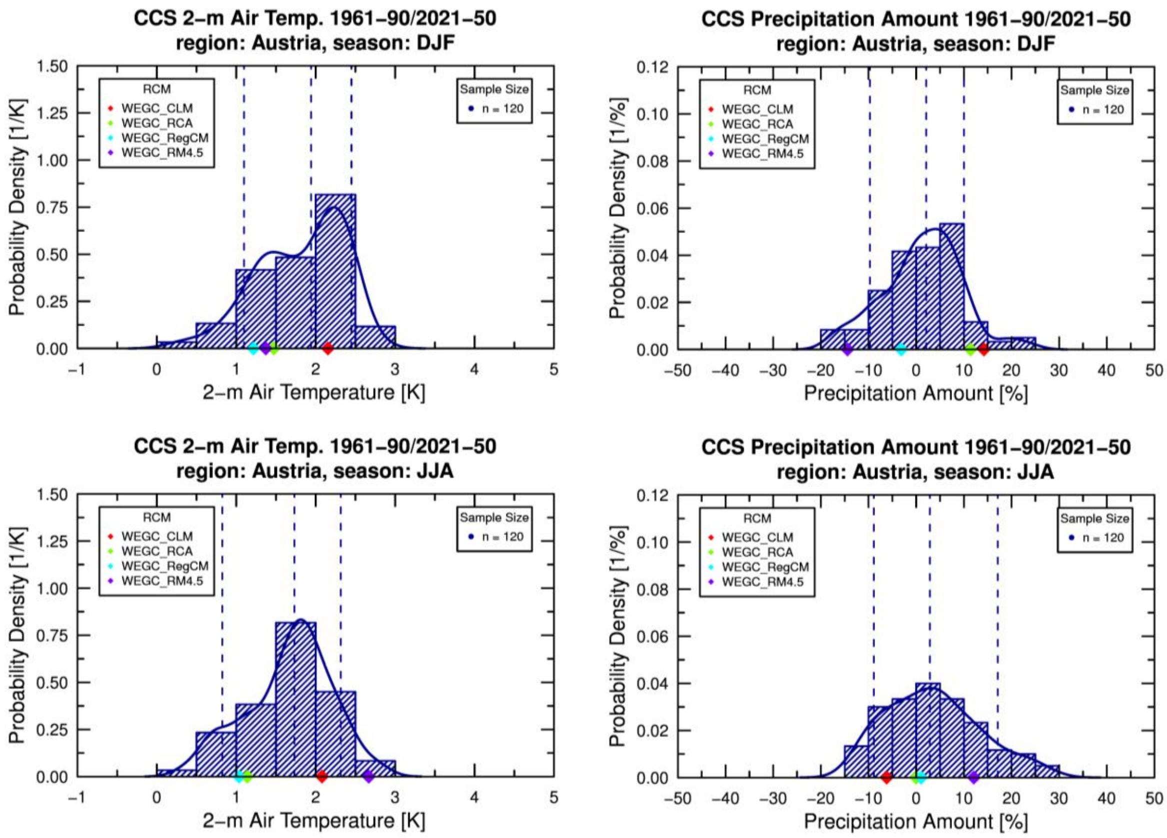


Figure 5: Histograms and kernel density estimates of the reconstructed changes in 2-m air temperature (left panels) and precipitation amount (right panels) between 2021-2050 and 1961-1990 for Austria in winter (upper panels) and summer (lower panels). Changes of precipitation amount are calculated relative with respect to 1961-1990. The dashed lines represent Q.10, Q.50, and Q90.

3 Results and conclusions for agriculture in Austria

3.1 Climate change impacts for agriculture: Direct effects

We have produced a high resolution dataset on crop yield impacts from climate change in Austria. The dataset contains simulation output of bio-physical impacts from four RCMs under a set of well-defined management options for adaptation. It serves as basis for the uncertainty and scenario analyses (see working paper by Mitter and Schmid 2012). An example of the EPIC output is given in Figure 6, which shows the percentage changes of average crop yields on arable land between the periods 1991-2010 and 2031-2050 based on the climate scenario ETHZ_CLM. Impacts from climate change show considerable differences due to regional climates, location factors, and crop rotations. What becomes evident from Figure 6 is that there are no uniform regional trends concerning the direction of changes from the four climate simulations. While impacts of three RCMs show productivity losses for some regions such as south-east Styria, the ICTP_RegCM leads to productivity increases for most Austrian regions according to the model results. In depth analysis indicates precipitation as most important driver on the magnitude and direction of change. However, precipitation projections are highly uncertain.

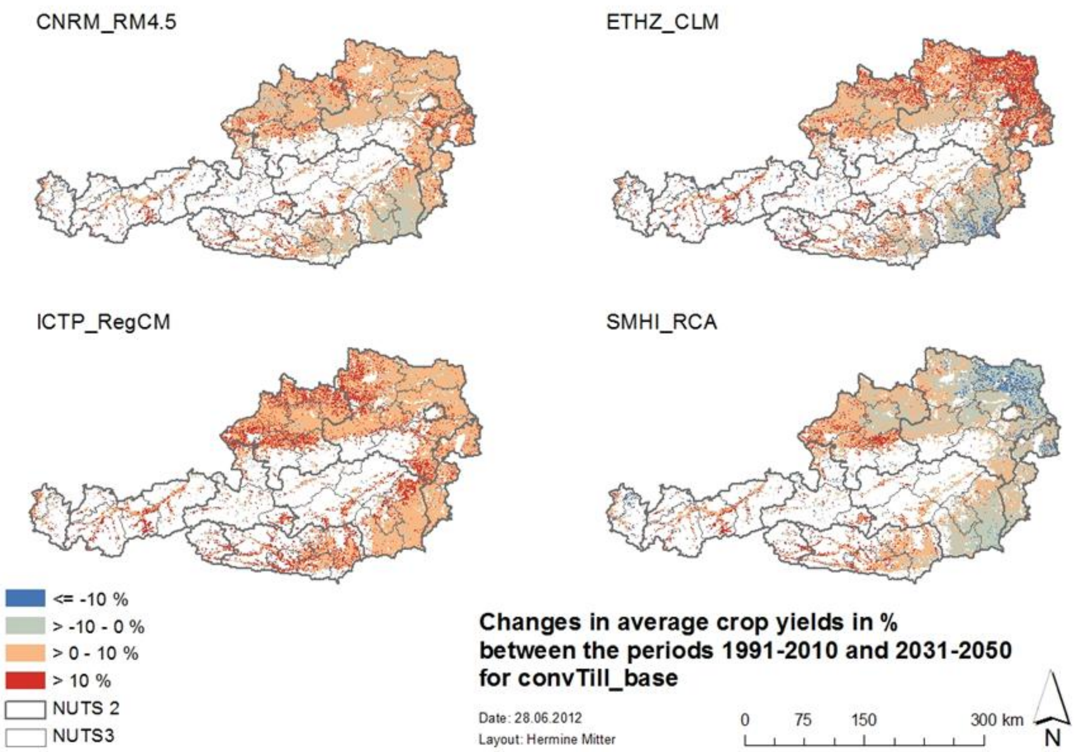


Figure 6: Percentage changes of average crop yields on cropland between the periods 1991-2010 and 2031-2050 for all four climate simulations

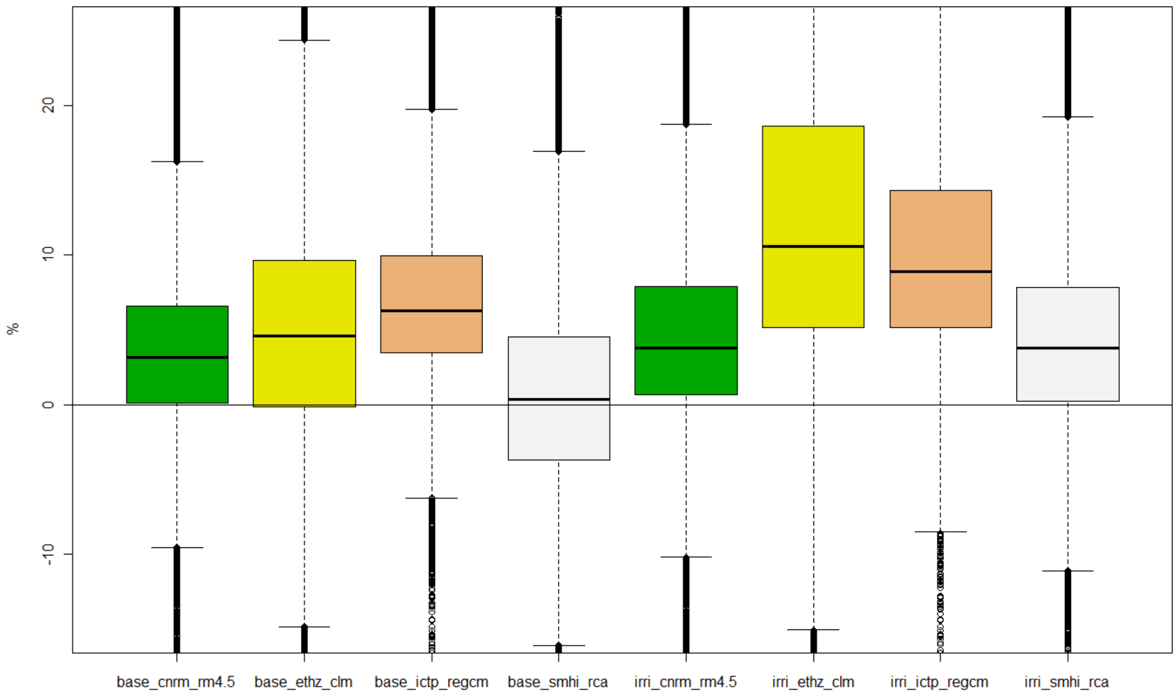


Figure 7: Changes in average crop yields (%) between the periods 1991-2010 and 2031-2050 for all climate scenarios, conventional tillage, high fertilisation intensity (base) as well as without (left) and with irrigation (right)

Figure 7 shows the range of crop yield impacts for all simulated cropland pixels. Three of the four climate simulations show productivity gains in 75% of the pixels. In contrast, the productivity gains and losses are almost equally distributed for SMHI_RCA. Adaptation such as introduction of irrigation can increase productivity for most scenarios (Figure 7, right).

Direct crop yield impacts from EPIC have been integrated in PASMA to model effects of adaptation measures at agricultural sector level. SZEN1 reproduces the baseline scenario with respect to land use (see section 2.2.1). The agricultural producer rents are increasing in three of the four climate simulations due to more favorable production conditions for many crops. Only one climate simulation SMHI_RCA shows minor decreases for the year 2020.

The SZEN1 changes in agricultural outputs range from -1% to +5% in 2020 and -2% to +5% in 2040. The climate simulations lead to increases in total producer rents between ± 0% and +2% in SZEN1 for the year 2020. Higher grassland yields allow for higher livestock numbers and, consequently, increasing livestock production values (ETHZ_CLM and ICTP_RegCM). The impact from climate change increases over time. As a result of increasing temperatures and moderate changes in precipitation patterns, total producer rents are positive for all four climate simulations ranging from ± 0% to +3% in the year 2040. Corresponding sector outputs are between -2% and +8%.

3.2 Climate change impacts for agriculture: Macroeconomic effects

The magnitude of economy wide effects of these structural and climate induced shifts in the agricultural sectors depends on their linkage with other sectors in the economy: Important suppliers for agriculture in Austria include the sectors chemicals (especially for plant production), petrochemicals, rest of industry (esp. for plants), food (esp. for livestock), trade (esp. for plants) and other business, but also within the agricultural sector itself regarding grain and other crops (esp. for livestock). Central downstream industries, i.e. sectors that use agricultural outputs in their production, are first and foremost food, but also trade, as well as – within agriculture – raw milk and cattle (both using outputs primarily from plant production).

A result that can be observed from the macroeconomic analysis is the relatively strong arising structural change compared to the consequences that arise from changed climatic conditions (in terms of agricultural sector output). In SZEN1, relative outputs effects are strong in the agricultural plant (GRA, VAF, OSD, OCR) and livestock sectors (CTL, RMK, OAP) (as described above) as well as for the food (FOOD) industry. Food industry output rises between ±0% (SMHI_RCA) and +1% (ETHZ_CLM and ICTP_RegCM) by 2020 and between +1% (CNRM_R4.5) and +2% (ICTP_RegCM) by 2040 (see Figure 8).

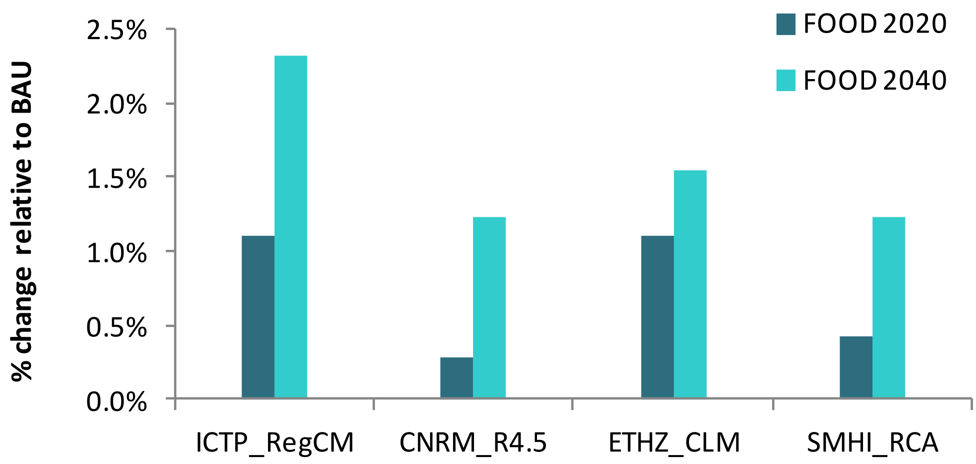


Figure 8: Climate change impacts (SZEN1) of production quantities in the food sector for four climate scenarios in 2020 and 2040 [relative change to BAU 2020 and 2040, respectively]

The observed changes in output for the remaining sectors are small in relative terms (e.g. for industry and service sectors such as CRP, REIS, NEIS, TRD and SEV), but considerable in absolute terms (see Figure 9). Note in this respect the importance of agriculture in Austria (agricultural sectors make up between 0.02% and 0.23% of total output at production costs) relative to e.g. the industry and trade sectors (NEIS, 18%; SEV, 22%; TRD, 11%).

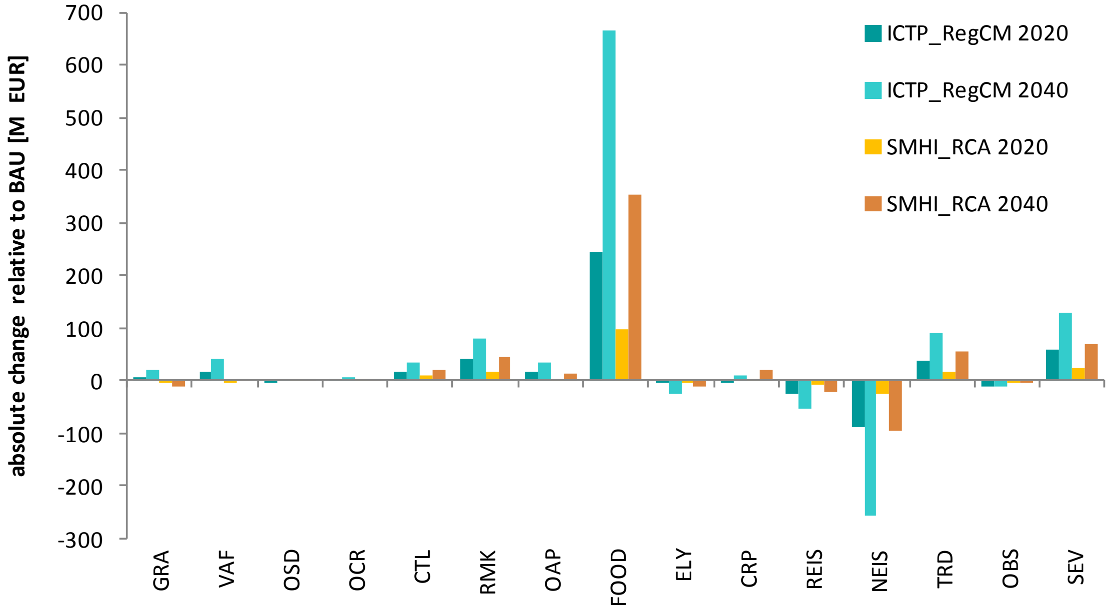


Figure 9: Climate change impacts (SZEN1) of production quantities for selected sectors and two climate simulations (ICTP_RegCM and SMHI_RCA) for 2020 and 2040 [absolute change relative to BAU 2020 and 2040, respectively]

3.3 Adaptation of agriculture: Direct effects

With autonomous adaptation (SZEN2) producer rents increase as farmers can on average capture the benefits from a changing climate through adaptive management. In SZEN3 adaptation is induced by availability of additional technology (i.e. irrigation) and among others by offering premiums for sustainable land use practices. Clearly, a changing land use towards more sustainable management reduces farm income without compensation (Figure 10, top). The subsidies in SZEN3 compensate for these losses and lead to further increases in producer rents (Figure 10, bottom).

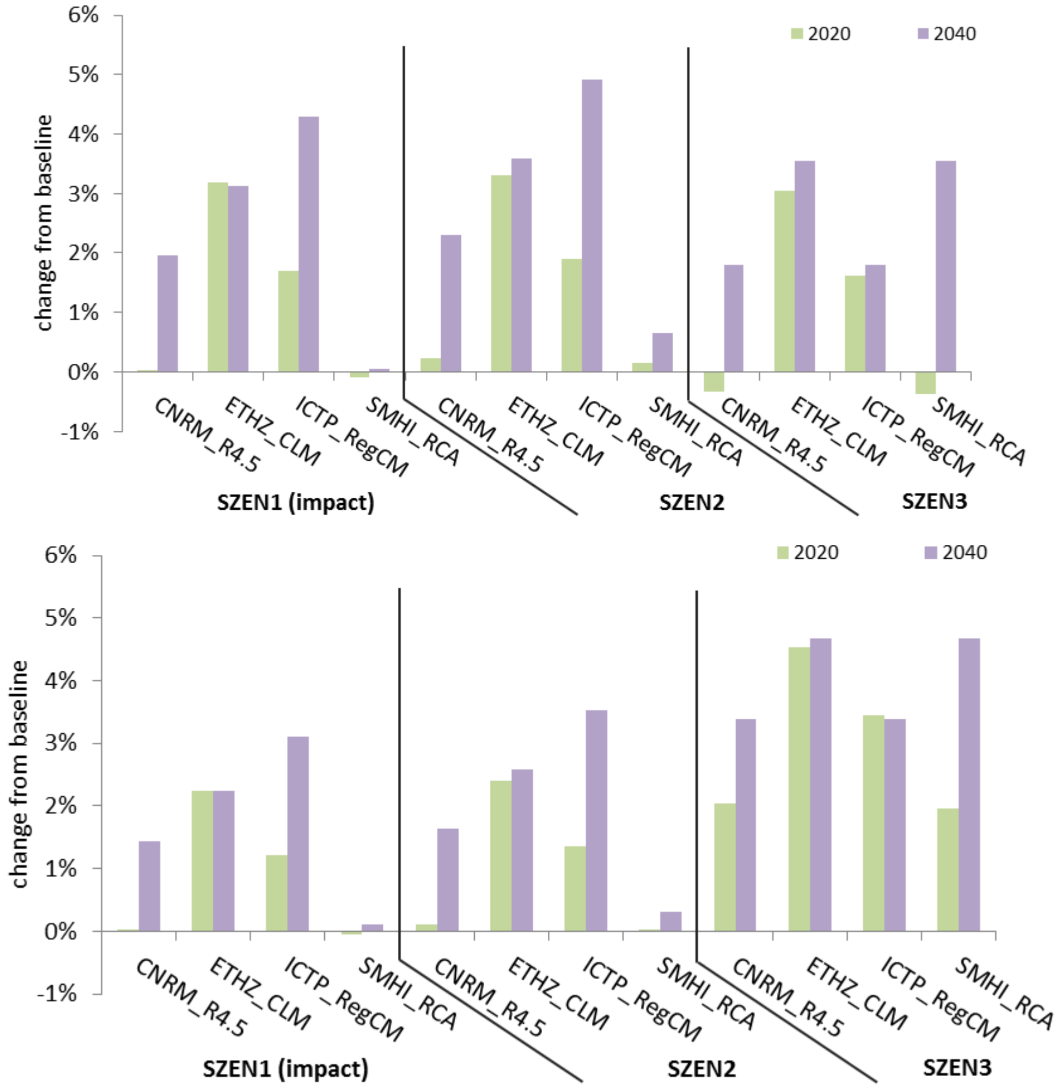


Figure 10: Agricultural producer rent changes (excl. subsidies top; incl. subsidies bottom) of SZEN1, 2 and 3 from baseline for four climate simulations and two periods (2020, 2040)

While aggregated results show benefits from climate change in general, a disaggregated regional assessment reveals considerable variation for the Austrian NUTS-3 regions. Figure 11 shows the distribution of changes among the regions for each combination of adaptation scenario and climate simulation. It indicates that climate simulations determine the variation among regions. Gains and losses in producer rents are likely depending on regional climate change effects, bio-physical conditions and management options i.e. adaptation. Furthermore regionally disaggregated results also indicate diverging effects among regions and climate simulations over time with respect to climate change impacts and adaptation (see Figure 11).

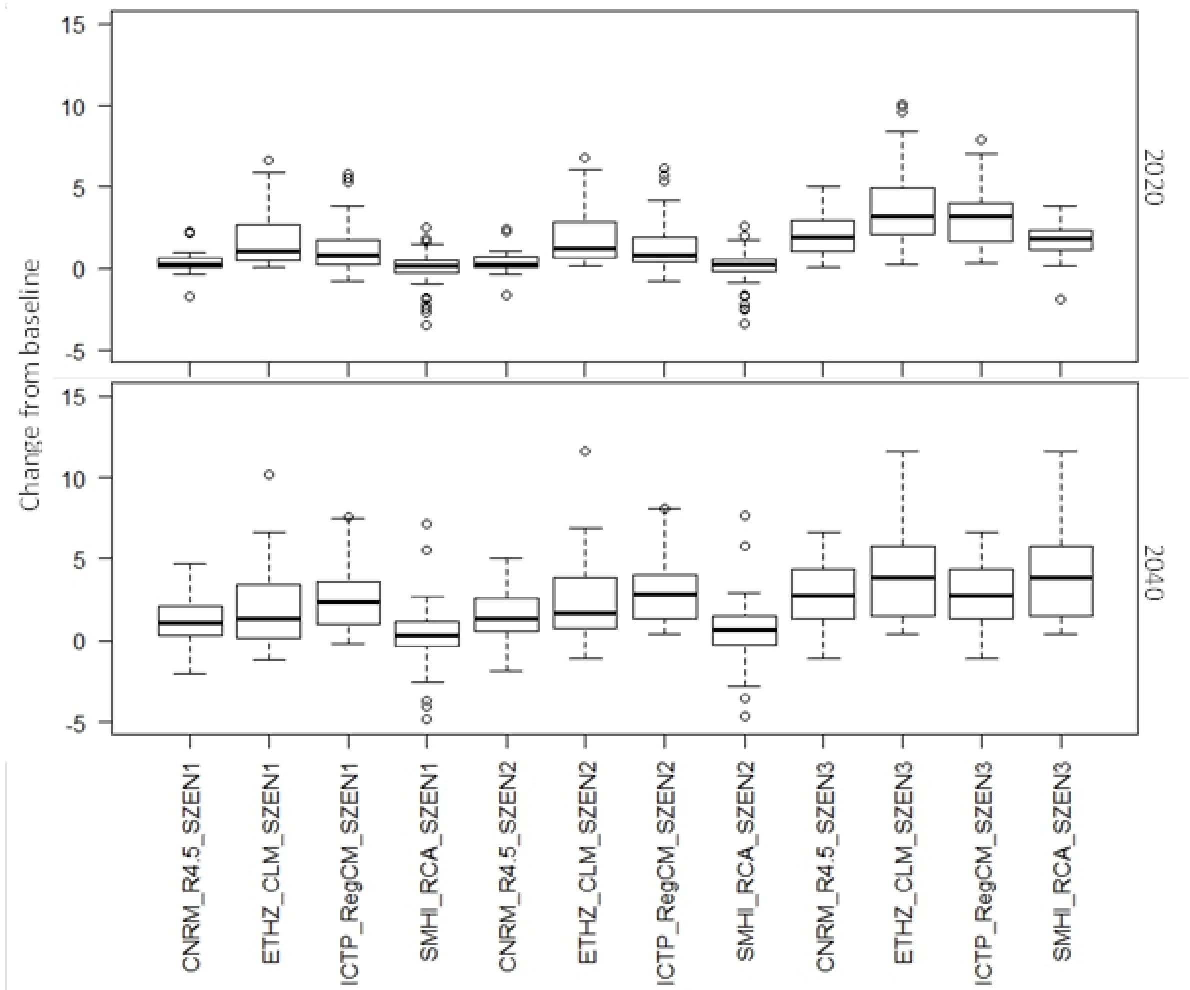


Figure 11: Agricultural producer rent changes (incl. subsidies) of SZEN1, 2 and 3 from baseline for four climate simulations and the period 2020 (top) and 2040 (bottom) (NUTS3 regions, n=35)

3.4 Adaptation of agriculture: Macroeconomic effects

Selected adaptation scenarios are assessed in terms of their effects for the overall economy. As described earlier, autonomous adaptation (SZEN2) increases farm revenues, while this is not necessarily a result of higher production values but changed farm management (e.g. intensity of agricultural production). Figure 12 compares the consequences of autonomous adaptation (SZEN2, 2040) to BAU 2040 for agriculture and selected important sectors of the economy (such as food, industry and service sectors). In terms of production value, adaptation in SZEN2 triggers lower levels in the livestock sectors (CTL, RMK, OAP) compared to the no-adaptation case (SZEN1, not shown in Figure 12); in the crop sectors except OCR (i.e. in GRA, VAF, OSD) farmers' adaptation efforts result in higher production values. The food sector is thus affected as it processes both types of goods (crops, livestock) for vegetarian and livestock products. With autonomous adaptation, total food production is however lower than in the no-adaptation case (-1.6% in ICTP_RegCM and -1% in SMHI_RCA). Effects from farmers adapting autonomously are transferred also to the chemical industry (CRP), rest of industry (REIS, NEIS), trade (TRD) and service sectors (SEV) (compare Figure 8 to Figure 12, right panel).

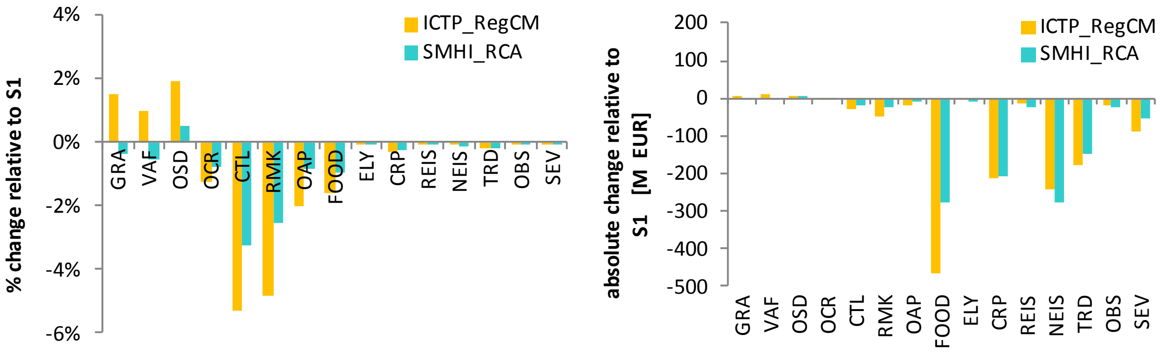


Figure 12: Effects from autonomous adaptation: relative (left, in %) and absolute (right, in M EUR) change in agricultural and economy-wide production value from autonomous adaptation (SZEN2 relative to BAU 2040)

3.5 Uncertainties

Agricultural output is affected by climatological uncertainties, but also by uncertainties in the economic model. In integrated climate change impact and adaptation studies, one may distinguish climate simulation, integrated model and parameter as well as policy scenario uncertainty.

In ADAPT.AT, we specifically addressed climate simulation uncertainty by analysing the effects of four selected climate simulations. Figure 13 shows the effects of these four simulations as well as the effects of the three adaptation scenarios for the years 2020 and 2040. A comparison among regions shows the regional variability and its increase over time. Effects from adaptation options and climate simulations are considerable and may even turn from positive into negative or vice versa. Nevertheless, variability among scenarios appears smaller than among regions as can be seen by a reduced number of outliers (compare to Figure 11). For further results from the ADAPT.AT project on agriculture at regional level, see SCHÖNHART et al. (2013a).

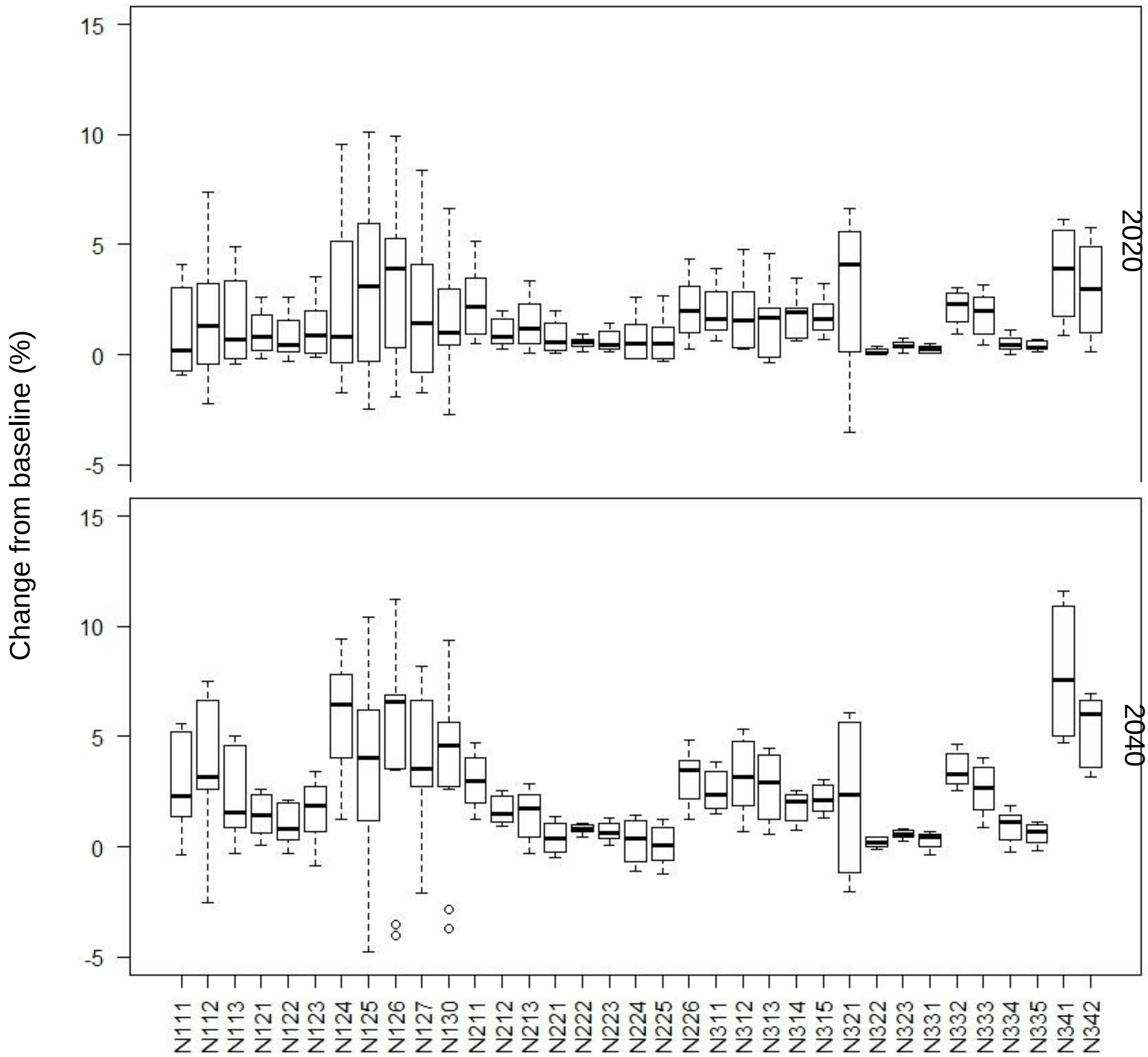


Figure 13: Agricultural producer rent changes (incl. subsidies) from baseline for NUTS3 regions and the period 2020 (up) and 2040 (down) (climate simulations and adaptation scenarios, n=12)

Regarding uncertainties in the macroeconomic model, we can differentiate between parameter uncertainties and methodological uncertainties. Uncertainties of model parameters comprise the choice of central assumptions for 2020 and 2040 projections such as capital stock development, work force growth, multi-factor productivity growth and autonomous energy efficiency, as well as substitution possibilities e.g. in foreign trade.

A sensitivity analysis in foreign trade reveals uncertainties in the macroeconomic model on central results. In particular, elasticities in foreign trade (Armington elasticities) are varied in 0.1 steps increasing simultaneously in livestock sectors (CTL, RMK, OAP) from 1.1 to 1.5 and in plant sectors (GRA, VAF, OSD, OCR) from 1.7 to 2.1. Figure 14 (left panel) plots the effects on domestic output. The responses of domestic production value in the agricultural sectors are not of the same strength and sign. More specifically, an increase in trade elasticities is decreasing VAF (vegetables, fruits) and OAP (other animals) production, while the rest of the agricultural sectors remain more or less unaffected. Also with respect to imports, VAF and OAP import flows react strongest (increase) when assuming that imported (or exported) quantities respond more strongly to changes in prices (=increase in Armington elasticities). This is neither a question of how important the sector is (in terms of total production value) nor how much is imported (or exported) in the base year, yet rather a question of intersectoral linkages among agricultural sectors and of substitution possibilities both of which lead to a high or low price elasticity of flows.

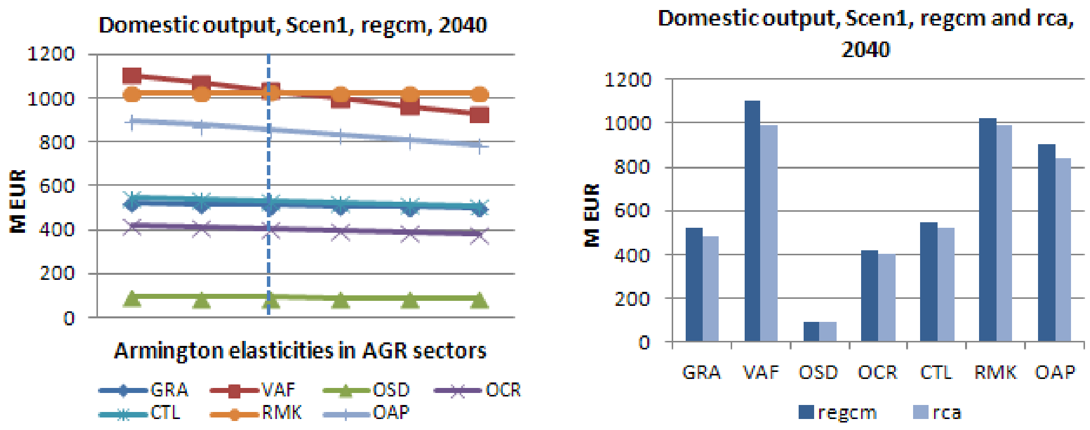


Figure 14: Left panel: Sensitivity analysis of domestic output 2040 in foreign trade for Scenario 1 with increasing Armington elasticities (with climate scenario ICTP_RegCM). Right panel: Change in domestic output value 2040 (with climate scenarios ICTP_RegCM and SMHI_RCA)

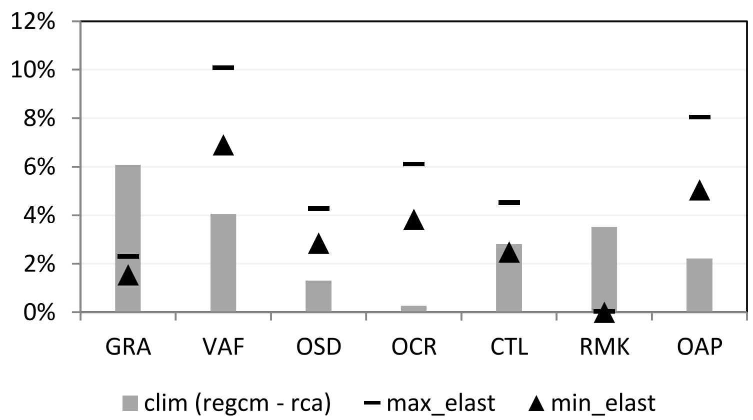


Figure 15: Change in domestic output value in 2040 for Scenario 1 (climate scenario ICTP_RegCM relative to scenario SMHI_RCA) and minimal and maximal case of trade sensitivity analysis, in %

Figure 15 compares the variability in agricultural output when either varying the climate scenario (from ICTP_RegCM to SMHI_RCA) or the trade elasticities (minimum and maximum values displayed). For the grain (GRA) and the milk (RMK) sector, climate variability is considerably higher than variability due to changed trade elasticities. For the other agricultural sectors, the reverse holds. For the agricultural sector in total, climate variability is 3.3 % while trade variability lies between 3.4 % and 5.3 %. Thus, while uncertainties are partly compensated at the aggregate level, there are considerable differences among agricultural sectors which warrant that climate change impacts are not only assessed at a high spatial resolution (to cover regional variability) but also with sufficient sectoral detail (to cover vulnerabilities of specific crops and products).

Methodological uncertainties emerge e.g. in regard to the model interface with PASMA. For instance, PASMA models land use and livestock activities and their complex interconnections in physical units, which have to be valued and transferred into monetary terms (EUR). Moreover, a major challenge is sectoral mapping, i.e. establishing a relation between PASMA values and the CGE model. The CGE model is, in contrast to the very detailed representation of agricultural crops in PASMA, built on an aggregated and consistent global GTAP database. These inconsistencies involved intensive mapping efforts of PASMA activities and GTAP based sectors for (i) production outputs, (ii) factors of production (land, capital, labor) and (iii) support measures in agriculture, as well as the use of SAM balancing routines. Often, there is not a unique solution to the mapping problem.

3.6 Conclusions

The modeling approach used to explore regional climate change and its consequences for Austrian agriculture allows for an economy-wide assessment of impacts. It also allows acknowledging the complex interactions of climate change on crop production and corresponding farm management decisions. It would even enable researchers to go beyond economic analysis and account for environmental effects from agricultural land use (such as soil organic carbon or soil erosion). Despite these advantages, some methodological challenges had to be faced. Main reasons are the different model scopes and structures (i.e. bottom-up activities in PASMA vs. top-down sectors in the CGE model) or deviating data bases. Moreover, PASMA allocates resources (e.g. land and labour) to crop and livestock production activities by considering the complex interconnections. As in any bottom-up to top-down approach, a major challenge is sectoral mapping, i.e. establishing a map between PASMA production activities, inputs to production (intermediate, primary factors) and support measures to (GTAP) based CGE sectors. Treatment of support measures in both models is key for decomposing climate change and policy effects. Often, there is not a unique solution to the mapping problem.

EPIC has been applied to simulate bio-physical climate change impacts on crop yields and adaptation measures for four climate simulations and three periods 1991-2010, 2011-2030, and 2031-2050. Model results show moderately increasing yields for all four climate simulations, which indicates average positive effects for the first half of this century. This appears reasonable considering moderate average temperature increases and rather stable precipitation patterns from four climate simulations until the years 2031-2050 compared to 1991-2010. Adaptation measures such as irrigation can even increase yield growth potentials through rising temperatures by alleviating production factor constraints such as low soil moisture according to the model results. Such positive effects from moderate climate change are well in line with other studies from the northern hemisphere (IPCC, 2007). However, we did neither address changes in production conditions from extreme weather events nor plant pests and diseases as well as changes in livestock productivity. Future research can draw on our results, e.g. by integrating the bio-physical data into consecutive models. Assumptions and model uncertainties can lead to over- or underestimation of adaptability to climate change. For example, we did not take water availability for irrigation into account (overestimation). Furthermore, PASMA by definition only considers predefined adaptation activities. Consequently, farmers in reality are probably more flexible than is assumed in PASMA (underestimation) given sufficient management skills and information. For a further discussion on the model assumptions and limitations, see Schönhart et al. (2013a).

Results of the combined bottom-up and top-down modeling approach indicate small though positive impacts of climate change on Austrian agriculture on average with slight positive consequences for the whole economy due to spillover effects. Cross-sectoral consequences are most significant for the food industry and vary between the climate simulations. Average changes in agricultural producer rents are in the range of ± 0% to +5% in 2020 and 2040, depending on the climate simulation and adaptations scenario. This appears reasonable considering the moderate average yield increases. However, the aggregated results conceal that climate change impacts are much more diverse at NUTS-3 level with winners and losers among the Austrian regions. For example, regional variation in producer surpluses are between < -10% to > +20% depending on the climate simulation, adaptation scenario and considered time period. Further research should focus more on these disaggregated effects and regionally and farm business tailored adaptation strategies in order to better support farm and policy decisions towards climate change.

To conclude, assessing the sectoral and macroeconomic effects along the applied modeling chain is helpful in quantifying and understanding the key triggers for production shifts in agriculture. Compared to e.g. changed subsidy regimes, the consequences from changed climatic conditions remain modest though. The output response is usually important for food supply and the environment and becoming even more important in the future due to the uncertainty in climate projections.

4 Results and conclusions for tourism in Austria

4.1 Climate change impacts for tourism: Direct effects

Figure 16 illustrates the sectoral results on the potential impacts of climate change on tourism demand. Broad bars in Figure 16 indicate the average seasonal deviation of overnight stays over the period 2011 to 2050 that is expected for the respective tourism region type under the considered climate change scenario compared to a situation where the climatic conditions remain the same as in the recent past. Error bars, which are represented by the narrower bars, illustrate model uncertainties. As shown in Figure 16a each of the four considered climate change scenarios indicates negative climatic effects on tourism demand during the winter season in all four tourism region types. Measured in relative terms (left hand-side), winter overnight stays in the *"Focus on summer tourism"* region type show the highest reductions due to potential climate change, whereas absolute decreases (right hand-side) are the highest in the *"Focus on winter tourism"* region type. Compared to the winter season, results for the summer season (see Figure 16b) suggest the extent of potential climate change impacts to be smaller and the impact direction to be less clear.

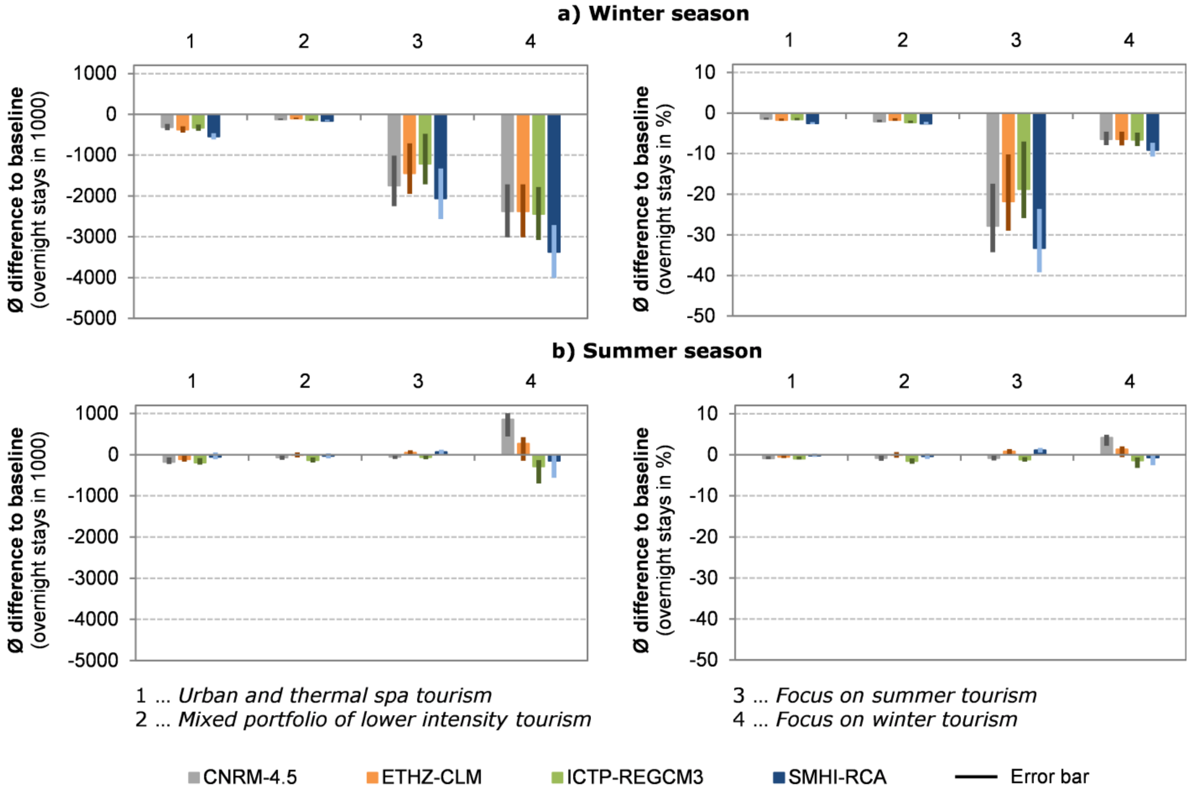


Figure 16: 40-year-averages (2011-2050) with respect to the deviations of overnight stays simulated under a climate change scenario from overnight stays simulated under a future baseline scenario

4.2 Climate change impacts for tourism: Macroeconomic effects

To assess macroeconomic effects of tourism impacts, climate change impacts were modeled in the CGE model as demand shocks, i.e. the development of overnight stays derived from the bottom-up tourism sector analysis in section 5.1, was proportionately translated into a demand increase or decrease, respectively, for the four tourism region types.

Regarding climate change impacts until 2020, we find in all four climate scenarios that tourism sectors are negatively affected by climate change (measured in terms of output reduction relative to BAU 2020). In addition, also non-tourism sectors are negatively affected by climate change impacts. This is due to negative feedback effects and, most importantly, due to a reduction of domestic disposable income triggered by less expenditures of foreign tourists in Austria. Important intermediate input sectors for the tourism industry such as agriculture (AGR), real estate & rental (OBS), and food products (FOOD) are those non-tourism sectors most strongly affected by climate change impacts on the tourism sector over the first modeling period (2011-2030).

For all climate scenarios the trend from period 2020 to period 2040 points in the same direction, namely that impacts are increasing substantially, even though the magnitude of impacts in 2020 as well in 2040 varies across the four climatic scenarios and four clusters. In contrast to the first period, non-tourism sectors in total are eventually gaining in the second period (2031-2050) from climate change impacts on the Austrian tourism sectors. Even though overall disposable income of the Austrian households is reduced due to lower foreign tourists' expenditures, most of this income effect addresses the tourism sectors themselves, and non-tourism sectors in total are profiting from a change in consumption patterns of domestic consumers. Figure 17 summarizes these effects for the two modeling periods explicitly for each climatic scenario. It can be seen that on average over the four clusters, the strongest climate change impacts on the Austrian tourism sector can be associated with scenario SMHIRCA, followed by CNRM, ETHZ and ICTP.

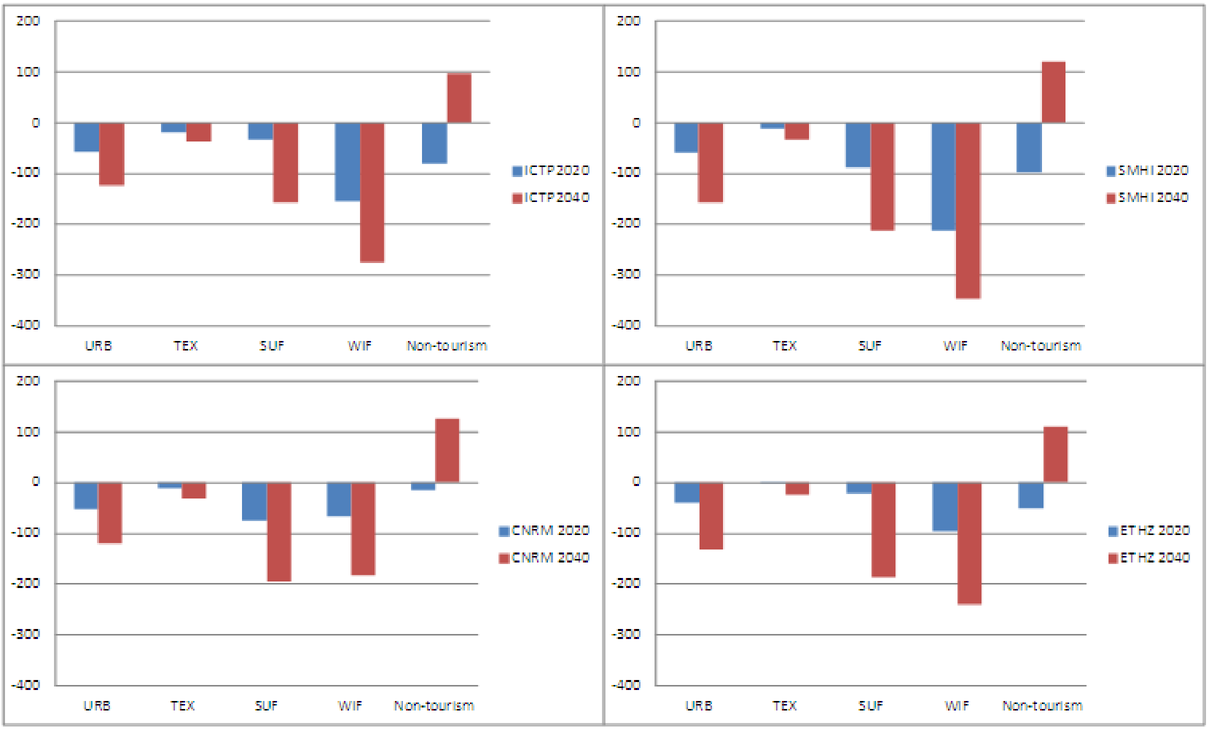


Figure 17: Climate change impacts according to the four climate scenarios 2020 and 2040 (relative to BAU in million Euro)

4.3 Adaptation of tourism: Direct effects

By definition, adaptation measures have the potential to partially counterbalance climate change impacts on the tourism sector. As already mentioned in section 2.3.1, no adaptation strategies were considered for tourism during the summer season, since impact assessment suggested relatively small effects with partly unclear directions. Regarding tourism during the winter season, for which (partly considerable) negative potential impacts of climate change were found, the adaptation strategy “artificial snowmaking” was considered. Since only limited data was available on the costs of artificial snowmaking, some simplifying assumptions had to be made for the present analysis, which rather serves to demonstrate a potential way of considering adaptation in the assessment of climate change impacts than to result in robust cost estimates of artificial snowmaking. Based on expert guess it was assumed that about 75 % of climate caused impacts during the winter season could be counterbalanced by artificial snow production – given current technology and the considered climate scenarios. Based on the simplifying assumption of constant costs of snow production – 3 € per cubic meter[3] – and a constant extent of ski slopes, adaptation costs were roughly

[3] The Association of Austrian Cableways estimates the total costs of artificial snowmaking to be between 1 and 5 € per cubic meter (cited in Agrawala and Fankhauser 2008).

estimated by assessing the amount of artificial snow required for counterbalancing 75 % of the potential climate change impacts. Table 3 outlines the long-term seasonal averages of the additional costs of artificial snowmaking under each considered climate change scenario compared to the baseline scenario, both in absolute (left hand side) and in relative, i.e. per hectare (right hand side), terms. Not surprisingly, results suggest absolute adaptation costs to be highest for the "*Regions with a focus on winter tourism*", which exhibits the by far biggest area of ski slopes. However, measured per hectare, results indicate costs to be highest for the "*Regions with a focus on summer tourism*".

Table 3: Monetarily assessed snow depth required to prevent 75 % of potential impacts (seasonal average for the period 2011-2050)

	Costs in million €				**Costs in 1,000 € per ha**			
	URB	**TEX**	**SUF**	**WIF**	**URB**	**TEX**	**SUF**	**WIF**
CNRM	~1.3	~5.9	~5.3	~33.8	~0.8	~1.8	~2.6	~1.8
ETHZ	~1.6	~5.8	~7.0	~38.5	~1.0	~1.8	~3.4	~2.1
ICTP	~1.4	~6.7	~3.9	~36.9	~0.9	~2.0	~2.0	~2.0
SMHI	~2.2	~7.7	~6.3	~50.9	~1.4	~2.4	~3.1	~2.8

4.4 Adaptation of tourism: macroeconomic effects

Regarding macroeconomic effects of adaptation, we assume on the one hand that the four tourism clusters respond to climate change impacts by undertaking investments in artificial snow making and on the other hand that climate effects would also confront them with changing energy bills due to changes in heating and cooling expenditures.[4] Both effects lead to altered cost structures (Table 4), with most of the changes taking place during the winter season.

[4] Note that neither slope contouring nor landscaping or the expansion to higher altitudes was considered as adaptation measures, mostly for lack of cost data, but also because in Austria strict ecological legislation does not allow slope contouring to the same extent as e.g. in France.

Table 4: Adaptation cost structure in scenario SMHIRCA 2020 relative to 2006 [1,000 €]

	Winter				Summer			
Sectors	**URB**	**TEX**	**SUF**	**WIF**	**URB**	**TEX**	**SUF**	**WIF**
Electricity	500	2,327	1,958	13,246	70	40	50	40
Refined oil products	-1,270	-610	-310	-3,860	0	0	0	0
Real estate and rental	69	321	270	1,827	0	0	0	0
Labor	224	1,043	878	5,938	0	0	0	0
Capital	932	4,334	3,645	24,665	0	0	0	0
Taxes	282	1,391	1,184	7,915	1	1	1	1
Total	737	8,806	7,624	49,730	71	41	51	41
Total (%)	0.01%	0.36%	0.42%	0.86%	0.00%	0.00%	0.00%	0.00%

While artificial snow making leads to cost increases, climate induced reductions in heating partially counterbalance these increases in all four tourism regions and all four scenarios. The highest absolute cost increases in the year 2020 for all four climatic scenarios are found in the focus winter region (WIF), which is highly winter tourism intensive, due to relatively high investments in artificial snow making equipment (see line "CAPITAL", i.e. depreciation) and associated running expenses (see lines ELY, OBS, LAB). The reduced heating expenditures (line PC) only partially offset these cost increases. In total however, all tourism types will be confronted with net cost increases under scenario SMHIRCA ranging from moderate 0.01% for the "urban and thermal spa tourism" cluster to 0.86% for the "focus winter" region type (see Table 4). Moving from 2020 to 2040, heating costs drop even further due to climate change induced temperature increases, but additional costs for artificial snowmaking rise over-proportionally at the same time (especially in the winter focus cluster).

Following the assumption of the sectoral tourism analysis, we assume that 75 % of initial climate change impacts can be counterbalanced if the tourism sector undertakes the necessary investments in adaptation measures. We find that adaptation measures are indeed effective at reducing the negative impacts on the tourism sector, but, in contrast to the sectoral analysis, not exactly 75 % effective (Figure 18). This is due to cross-sectoral general equilibrium feedback effects, which are mainly triggered by higher tourism prices due to the costs of adaptation. While the urban and thermal bath tourism cluster, which is characterized by relatively low climate change impacts and therefore also relatively low adaptation costs (see Figure 17 and Table 4) until 2020 outperforms the 75 % threshold, all other tourism sectors do not achieve a 75 % effectiveness of adaptation measures. On the one hand this implies an intra-sectoral restructuring of tourism expenditures away from TEX, SUF, and WIF to URB and on the other hand, since the tourism sector in total does not achieve a 75 % effectiveness either, a redistribution of private spending to other non tourism commodities. Until 2040 the adaptation measures are even more effective in reaching their target of 75 % effectiveness. This is due to the fact that the intra-sectoral as well as the inter-sectoral consumption redistributions more or less cancel out.

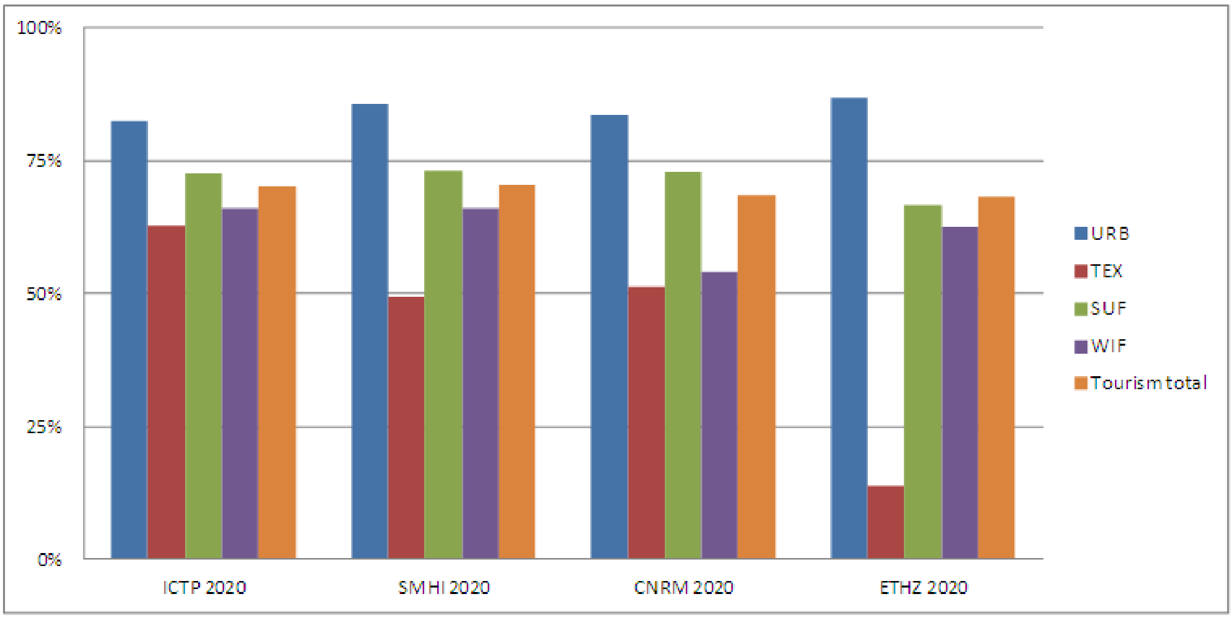


Figure 18: Regained output due to climate change adaptation (in % of output lost due to climate change impacts in 2020)

4.5 Conclusions

The present analysis has shown that climate change impacts on the tourism sector can be severe, especially in the longer term until 2050. For tourism during the winter season, each of the four considered climate change scenarios indicates negative climatic effects on demand in all four tourism region types. For the summer season, the extent of potential climate change impacts are found to be smaller and the impact direction to be less clear.

By distinguishing four different tourism clusters, we found that negative effects on the tourism sector can vary substantially with respect to the focus and the geographical situation of the tourism region in question. While impacts on the tourism regions with a focus on urban and thermal spa tourism are found to be less severe, tourism regions with a high winter tourism intensity – clustered in focus winter tourism cluster – will suffer considerably more. Strongest relative impacts are likely to occur in the tourism cluster focusing on summer tourism, for which however snow-based tourism is also an important source of income during the winter season. Since the relevant ski resorts are situated at relatively low altitudes they will be most strongly affected by reduced precipitation, leading to output losses of the focus summer cluster amounting to 13 % compared to a business as usual output projection (which projects output losses for this cluster even without climate change impacts).

Due to macroeconomic feedback effects, not only the tourism sector is affected by climate change impacts directly, but also non-tourism sectors are. While until 2020 negative effects prevail for the non-tourism sector (due to reduced demand from tourism sectors), the effect becomes positive until 2040. Overall, the indirect effects on other sectors are however found to be smaller than the direct effects on tourism.

Appropriate adaptation measures may counteract a substantial fraction of climate change impacts on tourism. But this increases production costs, in particular for artificial snow making. As the dominance of the winter season differs across tourism types, adaptation leads to price increases in the focus winter tourism region for all climatic scenarios in 2020. In contrast, adaptation in the other clusters may lead to price decreases as cost savings from reduced heating as well as reduced prices from other inputs outweigh additional costs for cooling in summer and artificial snow making.

For further results from the ADAPT.AT project on tourism, see Schinko et al. (2013).

5 Outlook and recommendations

5.1 Agriculture

Agricultural production is directly and indirectly affected by climate change impacts that often vary in magnitude and variability. This leads to regionally diverse impacts and effectiveness of adaptation measures. The climate change impacts on agriculture are likely to be transmitted to other economic sectors (indirect impacts). Adaptation is usually region and sector specific and interacts with climate change impacts, technological, economic, political and structural developments.

Direct and indirect effects have to be taken into consideration. Moreover, agricultural policies are crucial and affect climate change impacts and response options. Compared to e.g. a shift in subsidy regimes, the consequences from changed climatic conditions remain modest up to 2020 according to model results. This response is becoming more important, although also more uncertain, in the future due to the uncertainty in climate projections and global developments. If autonomous adaptation by farmers is not sufficient, policy induced measures such as e.g. investment aids or research subsidies fostering new technologies shall be granted, which have stronger economic implications. This issue shall be considered in more depth in the future. Ultimately, a comparison across different adaptation options shall allow identifying the groups which are required to take action (farmers, extension services, community stakeholders, regional and national policy maker) to respond to future challenges for agriculture, food and the environment.

The developed model interfaces between climate modeling, bio-physical modeling, economic land use optimization, and general equilibrium modeling are important steps towards further research cooperation between the modeling groups. The interfaces allow utilizing the strengths of single models, e.g. detailed bio-physical impacts and sectoral information and full market interactions. Furthermore, the method applied and tested for agriculture gives a broader understanding for linking issues in other sectors as well. These issues include defining the model interface (upward vs. downward) and defining relevant parameters in the linked models to be homogenized (linking items), developing algorithms that send the information over the link (i.e. establishing a map between model activities and endogenous / exogenous variables), providing consistency between exogenous model assumptions, as well as mapping sectors and regions (aggregation issue).

5.2 Tourism

What has not been taken into account within our analysis of climate change impacts on tourism so far are changes in the Austrian climate relative to the climate of tourists' country of origin or the climate of competing destinations. Nevertheless, changes in the climate outside of Austria might as well affect the demand of tourists on spending their holidays in Austria. Due to an increasing amount of heat waves, the Mediterranean, which currently represents the most important summer destination within Europe, is for instance expected to lose some of its attractiveness (AMELUNG and VINER, 2006; UNWTO-UNEP-WMO, 2008). The cooler Alps might benefit from such a process by serving as a substitutional destination. Behavioural changes of foreign as well as residential tourists due to changes in the climate of competing destinations could affect our results. Reduced (increased) expenditures of foreign and residential tourists lead to negative (positive) income effects in Austria, which in turn indirectly influence all other sectors of the economy. An important area for future research would therefore be a comprehensive analysis of changes in international tourism flows between Austria and potential alternative tourism destinations triggered by the impacts of climate change.

5.3 Applicability of results and methods to other climate sensitive sectors

The method applied and tested for agriculture and tourism gives a broader understanding for linking issues in other sectors as well. These issues include defining the model interface (upward vs. downward) and defining relevant parameters in the linked models to be homogenized (linking items), developing algorithms that send the information over the link (i.e. establishing a map between model activities and endogenous / exogenous variables), providing consistency between exogenous model assumptions as well as mapping sectors and regions (aggregation issue).

5.4 Research requirements

While the effects of gradual changes in temperature and precipitation have been analyzed within this project, additional research is needed on extreme weather conditions (droughts, hail, heat waves, …).

Moreover, much more research on climate change impacts is needed; only when the mechanisms of impacts are well understood, it is possible to assess adaptation to climate change and to clarify the scope and limits of autonomous adaptation.

One outcome of this project is that climate change impacts and adaptation cannot be fully assessed without considering linkages through international trade (in agricultural and food products; but also international tourism flows). Thus, different baseline scenarios, e.g. with regard to international energy and food prices, agricultural, energy, and climate policy, but also with regard to demographics and consumption patterns, need to be analyzed.

Not only on the aggregate but also on the sectoral level it is necessary to consider synergies and trade-offs between mitigation and adaptation. Therefore, an integrated assessment of both is needed.

Complex models like our integrated framework limit the assessment of a huge number of simulations which would be necessary for a fully fledged uncertainty analysis. Alternative approaches with simplified structures, but also statistical tools to fill in gaps in simulation runs are needed to get a better grasp of uncertainties from both climatologic and economic models.

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