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Integrated Modelling of the Economy under Climate Change in Application of the Stern Review (STERN.AT)

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Contents

Kurzfassung

Der Stern Report analysiert und bewertet grob quantitativ auf der globalen Ebene die Auswirkungen des Klimawandels, die Anpassung und Minderungsoptionen. Er streicht aber ebenso heraus, dass detailliertere Analysen auf der lokalen Eben folgen müssen, da Auswirkungen, Verwundbarkeit, Anpassung, aber auch Minderung, stark über Wirtschaftssektoren und Regionen divergieren. Das Projekt STERN.AT zielt daher darauf ab, auf regionaler Ebene die Interaktion zwischen Klimawandel, physischer und sozio-ökonomischer Folgen davon und Antworten der Politik zur Emissionsvermeidung zu modellieren. Das Projekt koppelt ein regionales Klimaszenario, sektorale Analysen für zwei Sektoren, Landwirtschaft und Energie, und ein drei-regionales ökonomisches Angewandtes Allgemeines Gleichgewichtsmodell, um die wirtschaftlichen Folgen des lokalen Klimawandels für eine Studienregion in Österreich abzuschätzen. Die Auswirkungen werden für ein repräsentatives Jahr der 2040er Jahre berechnet. Untersucht werden jeweils separat die wirtschaftlichen Auswirkungen des Klimawandels und autonomer Anpassung, die Auswirkungen politikinduzierter Anpassung sowie die Auswirkungen einer Minderungsstrategie. Die Simulationsergebnisse zeigen beispielhaft die Richtung und Größenordnung der Effekte für wirtschaftliche Indikatoren wie Regionalprodukt und regionale Wohlfahrt.

STERN.AT argumentiert, dass die Quantifizierung der Kosten des Klimawandels grundsätzlich eine lokale Frage ist und Berechnungen auf globaler Ebene stark der detaillierten Betrachtungen auf regionaler Ebene bedürfen. Ziel von STERN.AT ist daher die Erarbeitung einer Methodik für eine regionale Modellierung von Minderung und Anpassung, um solche Ergebnisse für eine bestimmte Region abzuleiten. Das Projekt zeigt außerdem den Datenbedarf für einen solchen Modellansatz auf. STERN.AT betont, dass die Abschätzung von Klimafolgen einen zugeschnittenen Modellierungsansatz für jeden Sektor und eine genaue Spezifizierung der Änderung von Klimaparametern erfordert sowohl im Hinblick auf den betrachteten Zeitraum (jährlich, saisonal, monatlich, täglich) als auch auf die betrachte Ebene (global, national, regional, lokal).

Abstract

While the Stern Review analysed and roughly quantified the economic impacts of climate change, adaptation and mitigation at the global scale, it asked for detailed analyses at the regional level as impacts, vulnerability, adaptation and even mitigation strongly diverge across sectors and regions. The project STERN.AT thus aims to model at the regional scale the interactions between climate change, physical and socio-economic impacts thereof and policy responses to mitigate impacts. The project couples a regional climate scenario, sectoral analyses for two sectors, agriculture and energy, and a three-region economic Computable General Equilibrium model to assess the economic effects of local climate change for a study region in Austria. The impacts are computed for a year representative for the 2040ies. The approach separately analyses the economic impacts of climate change under autonomous adaptation, of policy-induced adaptation and of a mitigation scenario. The simulation results illustrate the direction and magnitude of effects for economic indicators such as regional GDP and welfare.

STERN.AT argues that the quantification of the costs of climate change is inherently a local question and that a global figure on these costs needs to be built bottom-up. The present project thus develops methodological experience for deriving such results for a particular region and reveals the availability of the relevant data for such an assessment. STERN.AT demonstrates that the assessment of impacts and adaptation needs a tailored modelling approach for each sector. The project points out that the quantification of damage costs requires a due specification of changes in climate parameters not only with respect to the period of time (annual, seasonal, monthly, daily) but also with respect to the scale under consideration (global, national, regional, local).

G-1 Introduction

The aim of this project is to both analyse and model more comprehensively at the regional scale the interactions between climate change, physical and socio-economic impacts thereof and policy responses to mitigate impacts. Starting from *The Stern Review on the Economics of Climate Change* (Stern, 2007), which focuses on global modelling, regional aspects of the Stern Review are selected and advanced and compared to global approaches.

The present approach thus necessarily complements the global analysis of the Stern review. While an efficient emission reduction level can only be determined by comparing *global* costs of climate change and of mitigation – which is one of the core objectives of the Stern Review -, the quantification of the costs of climate change itself is inherently a local question. Regions are diverse, in climate change impact, vulnerability and adaptation options to climate change. A global figure on climate change costs thus needs to be ultimately built bottom-up, an effort that the Stern Review could not undertake itself as these numbers are not yet available for most world regions. The present project aims to develop methodological experience for deriving such results for a particular region.

The project establishes an interface between a regional climate scenario, detailed analyses for two selected economic sectors and a three-region economic model for a study region in Austria. The focus is on the interaction of the local climate with localised socio-economic change. Climate change impacts are diverse not only across regions, but also across sectors of economic activity. The chosen modelling approach therefore acknowledges a disaggregation by sector and region.

The region of South-East (SE) Styria in Austria at NUTS III level will serve as test site to study climate impacts and adaptation in a regional context. In doing so, the focus is on two sectors which are particularly vulnerable to climate change in the study region: agriculture and energy. Regional climate change scenarios and downscaling techniques are used to provide basic information about future conditions in the study region.

The coupling of models allows quantifying the relevant economic effects of local climate change for the selected region. The quantitative assessment addresses climate impacts on production and consumption structures as well as the adoption of policies (mitigation and adaptation strategies). The impacts are computed for the year 2045 as representative for the 2040ies as the local climate scenario is available for the period 2041-50.

This project yet must be regarded as a pre-feasibility approach for an integrated regional modeling framework of the climate and the economy. This concerns both data availability and methodology. The project team seeks to assess the data requirement for the study region and to find out how this demand can be met. Moreover, the currently used methods are assessed to quantify local impacts of climate change.

The present project builds on past and current work at the Wegener Centre for Climate and Global Change at the University of Graz (WegC). It shall serve as a basis for future projects in integrated assessment modeling at any research institution. In doing so, global climate change scenarios are made accessible to socio-economic analyses at the national and regional scale through downscaling by the WegC ReLoClim (Regional and Local Climate Modeling and Analysis) Research Group.

This report is structured as follows. Section 2 raises the subject of global and regional integrated assessment modelling, while Section 3 reports on the economic model developed herein. Section 4 deals with the sectoral analyses for agriculture and energy and with the regional climate scenario. Section 5 presents the simulations and Section 6 the quantitative results thereof. Section 7 summarises the findings and concludes.

G-2 Integrated modelling

G-2.1 The Stern Review and global assessment models

Existing research on climate change damages has so far focused mainly on the global scale; there is only little literature on climate induced damages on the local scale. According to IPCC (2007), analysis on climate induced damages can be divided into three categories: Firstly, impacts are computed as a percentage of gross domestic product (GDP) for a specified rise in global mean temperature. Secondly, impacts are aggregated over time and discounted back to the present day along specified emissions scenarios and under specified assumptions about economic development, changes in technology and adaptive capacity (see e.g. Nakićenović and Swart, 2000). Some of these estimates are made at the global level, while others aggregate a series of local or regional impacts to obtain a global total. The third type of estimate is the social cost of carbon (SCC).[1] While it is possible to aggregate a series of local or regional impacts to obtain a global total (bottom up), it is not possible to disaggregate global numbers back to a regional level (top down).

In general, global modelling approaches involve only a few sectors. A common practice is to model two damage sectors as done in the PAGE 2002 model (Hope 2006, 2007), which the Stern Review is based on. This global model includes eight world regions and a time horizon of 2200. It involves only two damage sectors: market and non-market damage sectors. The PAGE model allows treating economic, non-economic impacts (e.g. effects on health) and catastrophic impacts, abatement, i.e. the reduction of greenhouse gases (GHG), adaptation, i.e. how to cope with and adapt to climate change impacts[2], as well as uncertainty (probabilistic calculations). When choosing a policy, the aim is to minimise the sum of impact and action costs (aggregated over time and space and all different outcomes in a probabilistic way). The model requires the input of emissions of GHG, the residence time of GHG in the atmosphere (half life of GHG), the climate sensitivity [3], the cooling effect of sulphates, impacts (as a function of change in temperature and as % of GDP), and equity weights. A main feature of the PAGE model is that each uncertain input parameter is represented by a probability distribution. In each calculation with each set of input variables a set of various output variables (e.g. damages, costs of adaptation) are given for the full set. Thus, PAGE builds up probability distributions of results by representing the input variables by probability distributions (Hope, 2006).

While policymakers reacted positively to the Stern report, it was criticised by many scientists. Criticism can be found especially in Weitzman (2007), Nordhaus (2007), Tol (2006), Dasgupta (2006), Sterner and Person (2007), Carter et al. (2006) and Byatt et al. (2006). Critical comments on results of the Stern Review include a too low rate of pure time preference (PTP), a too low discount rate resulting from the combination of the PTP rate and the elasticity of marginal utility of consumption, double counting of catastrophes as well as a too low chance of catastrophes, or utility of impacts not being discounted at the PTP rate (Hope, 2007).[4]

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[1] The SCC it is an estimate of the economic value of the extra (or marginal) impact caused by the emission of one more ton of carbon (in the form of carbon dioxide) at any point in time.

[2] In the PAGE model, adaptation is assumed to be able to increase the tolerable temperature change or reduce the impact from climate change if this threshold is exceeded.

[3] The equilibrium temperature is a linear function of the radiative forcing from human emissions; the slope is given by the equilibrium temperature rise for a doubling of CO_2.

[4] According to Nordhaus (2007), Stern's assumption on a discount rate near zero (0.1) is the main reason for the resulting high price of carbon and the enormous climate relevant damages. The assumption, Nordhaus emphasises, in turn legitimates recommendations for a fast reduction of greenhouse gases. Contrary to Nordhaus (2007), Sterner and Person (2007) argue that the Stern Review is right but for the wrong reasons. They point out that the conclusion

Similar to PAGE most of the other integrated assessment models, such as the Dynamic Integrated Climate and Economy (DICE) model (Nordhaus, 1993), include only a few sectors. An exemption is the WIAGEM (World Integrated Assessment General Equilibrium Model) (Kemfert, 2002). This model is based on 25 world regions which are aggregated to 11 trading regions and 14 sectors within each region. The sectoral disaggregation contains five energy sectors, namely coal, natural gas, crude oil, petroleum and coal products, and electricity. WIAGEM hence combines an economic approach with a special focus on the international energy market and integrates climate interrelations by temperature changes and sea level variations.

G-2.2 Regional aspects of the Stern Review: modelling of impacts, adaptation and mitigation

This project analyses selected aspects of the Stern Review, for which a regional modelling approach is interesting and reasonable. These include the assessment of costs of climate change, the economic modelling of climate change impacts and the modelling of mitigation and adaptation measures. To realise these elements within STERN.AT, the existing modelling approaches are studied and adapted, and ideally advanced.

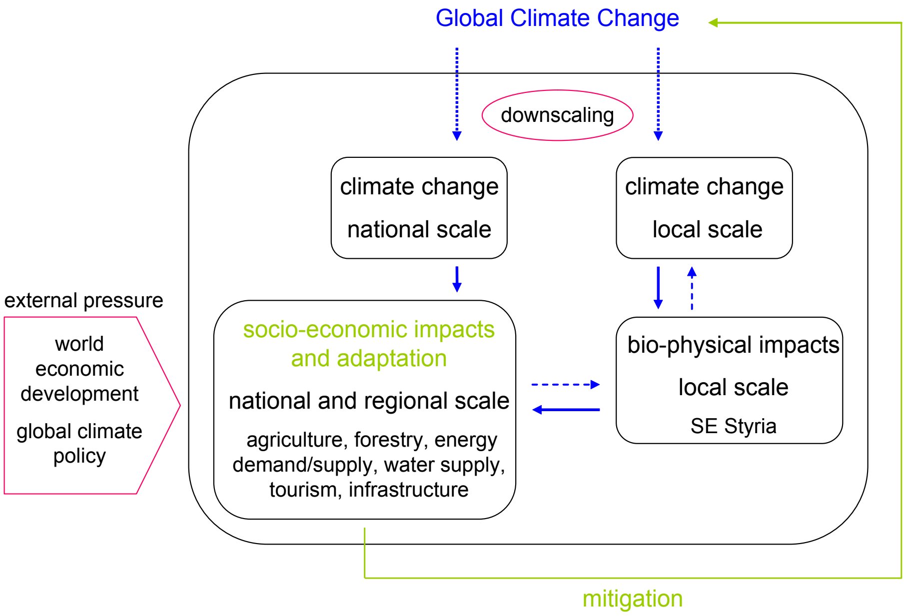

Fig. G-1 : Climate change and its impacts at different scales.

Source: adapted from a research proposal under the lead of Kromp-Kolb, H., and Steininger, K.

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reached in the review can be justified on other grounds than by referring to a low discount rate. The authors argue that future scarcities that will be induced by the changing composition of the economy and climate change would lead to rising relative prices for certain goods and services. This would raise the estimated damage of climate change. Furthermore, Weitzmann (2007) points out that the Stern Review “consistently leans towards assumptions and formulations that emphasize optimistically low expected costs of mitigation and pessimistically high expected damages” from global warming. He shows that the present discounted value of a given global warming loss from a century at the non-Stern annual interest rate of r = 6% is one hundredth of the present discounted value of the same loss at Stern’s annual interest rate of r* = 1.4. On the other hand, Tol (2006) criticises the extreme selective choice of the studies Stern quotes. These relate to relative pessimistic scenarios regarding climate impacts. At the same time Stern takes optimistic scenarios regarding the estimated benefits of reduced emissions. Tol also criticises that all calculations are based on only one model, the PAGE2002 model.

The comparison of cost of climate change with cost of mitigation needs global models. In order to draw conclusions for the local scale, which is important for e.g. adaptation, regionalised models are required. It is not possible to downscale global impact models to the regional scale. The interaction between global climate change and climate change at national and local scale as well as its (direct and indirect) impacts are illustrated by Fig. G-1.

The present project aims at regional assessment modelling. Fig. G-2 illustrates in a very simplified way the structure of an integrated assessment model. The figure also shows how the present project STERN.AT fits into the general approach: By scaling down global climate scenarios (work carried out by ReLoClim Research Group at WegC) and investigating direct impacts (such as impacts on physical crop yields or ecosystems) as well as socio-economic impacts (such as income changes, but also indirect effects via sectoral interdependencies) (work carried out by EconClim and TransLand Research Groups at WegC), a regionalised approach can be developed.

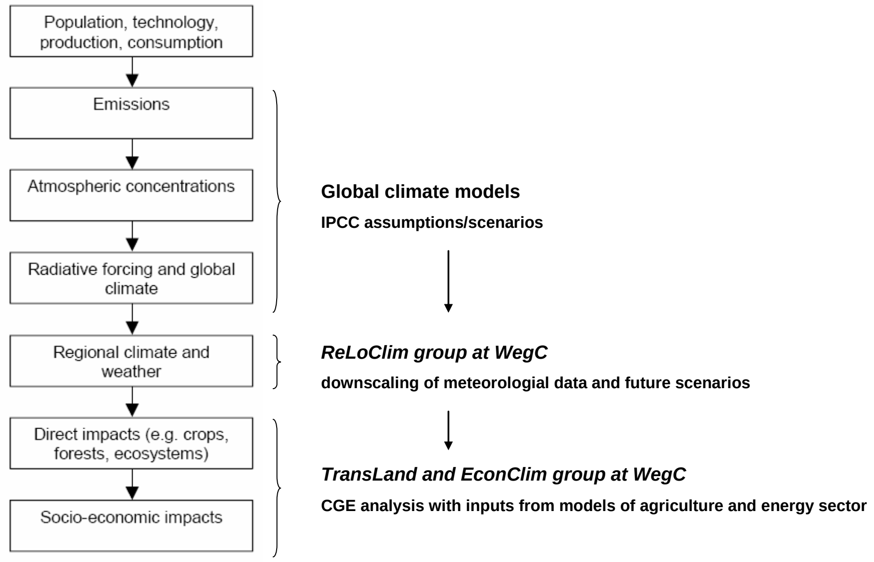

Fig. G-2 : The role of STERN.AT in an integrated assessment framework.

Source: extended from Hope (2005)

Sectoral climate impacts are not only driven by direct effects but also indirectly through impacts on other sectors within the economy. In global modelling approaches, sectoral interdependencies can most of the time not sufficiently be assessed. A regionalised CGE model as developed in STERN.AT therefore allows modelling sectoral linkages and quantifying direct and indirect impacts.

The high aggregation of sectors, as commonly realised in global models, also hampers the modelling of adaptation costs. Adaptation measures and their costs are very specific for a certain region and certain sectors. Only few adaptation measures have similar costs in different parts of the world. A good example is agriculture, where adaptation measures depend on many factors such as climate, soil and socio-economic circumstances. The assessment of costs of adaptation seems hence reasonable to be carried out at the regional scale.

As for mitigation, by contrast, the global level is more appropriate to compare benefits and costs. At the regional scale, mitigation only marginally affects the global CO_2 level. However, mitigation efforts at NUTS III level do contribute to a country’s overall mitigation strategy. Estimating the regional costs of mitigation is essential with respect to the Kyoto targets that will have to be reached by every nation committed to the protocol. Given the national budget allocated to climate policy, there is trade-off between mitigation and adaptation efforts. Thus, any higher expenses directed towards mitigation reduce the scope for national adaptation strategies.

G-3 The regional economic model

G-3.1 Methodology

There are three techniques frequently used in economic impact analysis. Each technique involves advantages and drawbacks.

Fist, in econometric modelling, statistical correlations are derived from past observations (time series). However, econometric models lack sufficient structure for complex policy analysis, since feedback effects are not comprehensively covered. This is a particular drawback if significant, non-marginal or not yet experienced changes are analysed.

Second, Input-Output analysis captures detailed structural and sectoral interdependencies of the economy. Its main advantage is its ease of use and transparency. A major limitation of this technique is the use of fixed coefficients. This implies that the marginal response of industries, resulting from e.g. the implementation of a policy, equals the relationships observed in the base year. Another limitation of the Input-Output framework is its lack of supply constraints (e.g. no constraints on the availability of labour inputs). As a consequence, prices do not act as a rationing device inducing changes in consumption and production patterns.

Third, Computable General Equilibrium (CGE) models are based on Input-Output tables. A key advantage of CGE modelling compared to Input-Output analysis is that the technological coefficients are flexible and determined by relative prices. Therefore the coefficients adjust endogenously. The quantitative results of CGE models inter alia depend on the assumed elasticities of substitution, i.e. the ease of substitution of e.g. input factors in production.

The model is first calibrated to the data of a base year, i.e. parameters are estimated such as to reproduce the observed economic data in the reference year as a model solution. There is a range of open parameters beyond, especially elasticities of substitution. These parameters are either taken from studies in the literature or they are estimated from time series or panel data. The second method generally requires comprehensive data bases. The choice of parameter values plays an important role also for the robustness of the results. From this it follows that a serious assessment should include sensitivity analysis to show the effects of alternative specifications on the results.

The present study uses CGE analysis for its impact research. CGE models include multiple sectors and multiple interacting agents whose individual behaviour is based on optimisation. Households maximise their utility given their income, firm maximise their profit given a technology. The government balances its budget so that public expenditures (e.g. social transfers) equal public revenues (e.g. taxes). Fig. G-3 presents the formulation of an equilibrium problem in CGE format. When for example a policy is implemented, CGE models depict intersectoral feedback and welfare effects. Hereby, the model solves for a set of relative prices that balances all markets. The quantitative economic analysis of regional development builds on previous multi-regional CGE model development for Austria (e.g. Koland and Steininger, 2006).

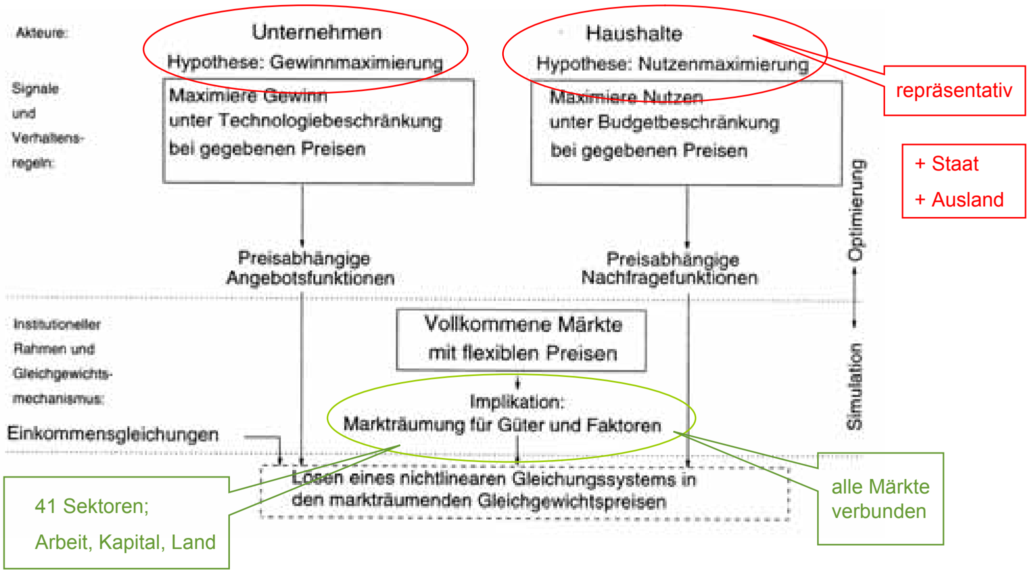

Fig. G-3 : Formulation and solution of an equilibrium problem.

Source: extended from Böhringer (1995).

G-3.2 The model structure

The present study employs a comparative static three region CGE model which is used to asses economic impacts at the macro level. The CGE model is developed within GAMS (Brooke et al., 1998) using the modelling framework MPSGE (Rutherford, 1998). It is calibrated to the year 2003 (base case).

G-3.2.1 Regions, sectors and factors of production

The analysis is applied to South Eastern (SE) Styria, comprising five political districts (Feldbach, Fuerstenfeld, Hartberg, Radkersburg, Weiz).[5] This region forms the core region (Region 1) in the three-region economic model, embedded within the rest of Styria (Region 2) and the “rest of the world” (ROW = Region 3) including the rest of Austria and abroad. While Region 1 and Region 2 are fully modelled, Region 3 is connected to them via trade flows. The allocation of regions in the economic model is illustrated in Fig. G-4.

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[5] The region of SE Styria involves an area of some 3,350 km^2 with 268,248 inhabitants (in 2006). It is among the most productive agricultural production regions in Austria, since it allows for a large variety of agricultural crops at a comparatively small regional scale. In this way, it provides a selection of adaptation options to climate change. Moreover, SE Styria is characterised by a high biomass potential and thus promising for bio-energy development. However, because of its location in the shade of the Alps, SE Styria is characterised by little precipitation.

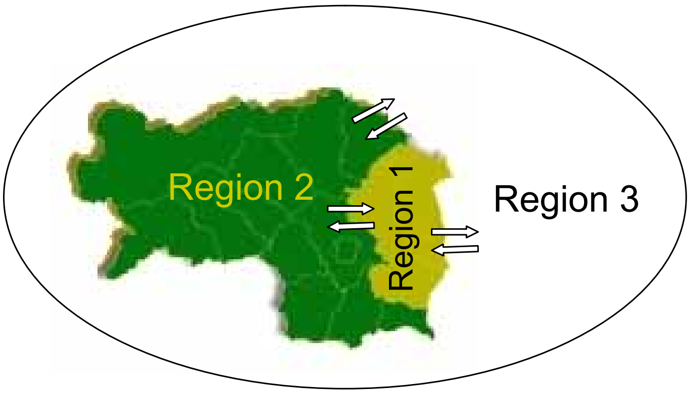

Fig. G-4 : The partition of regions in the economic model.

Region 1 is SE Styria, the core region, Region 2 the rest of Styria and Region 3 the rest of Austria and abroad ("rest of the world").

The modelled economy comprises 41 sectors, whereof six are energy producing (coal, diesel, other oil products including gasoline and fuel oil, electricity, gas), and three factors of production (labour, capital, land). Goods and services are thus produced by the use of the primary factors labour, capital and land (for agricultural crops) and by intermediate inputs from other sectors. Tab. G-16 in the Appendix presents the sectoral specification.[6]

In the biomass energy sector, the model is extended for a technological process-specific analysis. I.e. discrete biomass energy technologies are specified that allow for the substitution of fossil-based ones.

The construction of a consistent data set for the economic model, i.e. a Social Accounting Matrix (SAM), is based on regional Input-Output tables and statistical data sources (such as data from the national accounts).[7] The present CGE includes such matrices for both Region 1 and Region 2. The development of each SAM is based on regionalised Input-Output tables for SE Styria and the rest of Styria provided by Joanneum Research, Institute for Technology and Regional Policy, Graz, and developed on the basis of a regionalisation of the respective Make and Use Matrices.

The factor land is only used in agricultural production and for biomass intermediate products. It is assumed that land available for crop production is limited in each region such that producing agricultural biomass displaces the conventional agricultural sector that is scarcely able to substitute land against other productive factors.

The labour supply is exogenously given and dependent on the demographic trend in the study region. While capital and land are fully employed, the labour market does not clear, so there is unemployment. In addition, the model captures the potential labour demand shift since labour intensities vary among sectors and technologies, respectively.

Market clearance for goods implies that each good is either used as an intermediate input in production (see section G-3.2.3), is traded abroad (see section G-3.2.4) or consumed (by households or by the government) (see section G-3.2.2).

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[6] The sectoral level of aggregation is based on the ÖNACE classification (Statistics Austria, 2003), which is the Austrian version of the NACE classification (statistical classification of economic activities in the European Communities).

[7] The SAM is the economy-wide data framework for the study region and the empirical basis for the quantitative work. It is a statistical framework using double entry bookkeeping to trace transactions in the economy providing detailed information on structural links and interdependencies between sectors.

G-3.2.2 Consumption

Households demand goods and services and supply labour, capital and land. The representative household derives utility from the consumption of a bundle of n goods/services. This bundle involves private consumption, investments and stock changes. Note that a different bundle for space heating service is specified.[8] The household maximizes utility (1) subject to the budget constraint (2):

$$U = \prod_{i=1}^{n} X_i^{\alpha_i} \qquad \sum_i \alpha_i = 1 \tag{1}$$

$$Y \geq \sum_{i=1}^{n} p_i X_i \tag{2}$$

where Y represents household income and p_i the price of consumption good i, $i = 1,\dots,n$. The utility function is modelled by a Cobb Douglas function, incorporating fixed expenditure shares α_i for each good. Income is made up of wages wL (where w is the wage rate and L labour), returns on capital rK (where r is the interest rate and K capital), land rents vKL (where v is the land rent and KL agricultural crop land) and transfers T:

$$Y = wL + rK + vKL + T \tag{3}$$

The demand functions resulting from households' maximisation problem can be written as

$$X_i = \frac{\alpha_i Y}{p_i} \tag{4}$$

Expressing the households' utility as a function of income and prices yields the indirect utility function

$$U = Y \prod_i \left(\alpha_i / p_i \right)^{\alpha_i} \tag{5}$$

Secondly, there is final demand for goods and services by the government. Public revenues accrue from taxes from households and firms on goods and factors (e.g. income tax, value-added tax, land tax). These revenues are spent on public demand or investment, or they are passed on to households via social transfer payments T (e.g. unemployment benefit).

G-3.2.3 Production

Firms produce goods and services and demand intermediate products from each other. They are assumed to maximise profits. Production in each sector follows a nested CES (constant elasticity of substitution) structure and involves primary inputs (labor, capital, land) and intermediate inputs from other sectors. On the top level of the production structure, as shown in the left illustration of Fig. G-5, intermediate inputs (ID) are combined with an aggregate of land, labour, capital and energy (KL-L-K-EN), involving fixed input coefficients (i.e. the elasticity of substitution is $s = 0$). One level below, the small elasticity between land and other inputs, taking a value of 0.1, highlights the importance of the factor land in agricultural production. In the lower nesting levels, the respective elasticites are in the range of those from Wissema and Dellink (2007) and Rutherford and Paltsev (2000).

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[8] This allows for the substitution of biomass technologies for fossil heating systems. The consumer demands heat services rather than just energy for the production of heat.

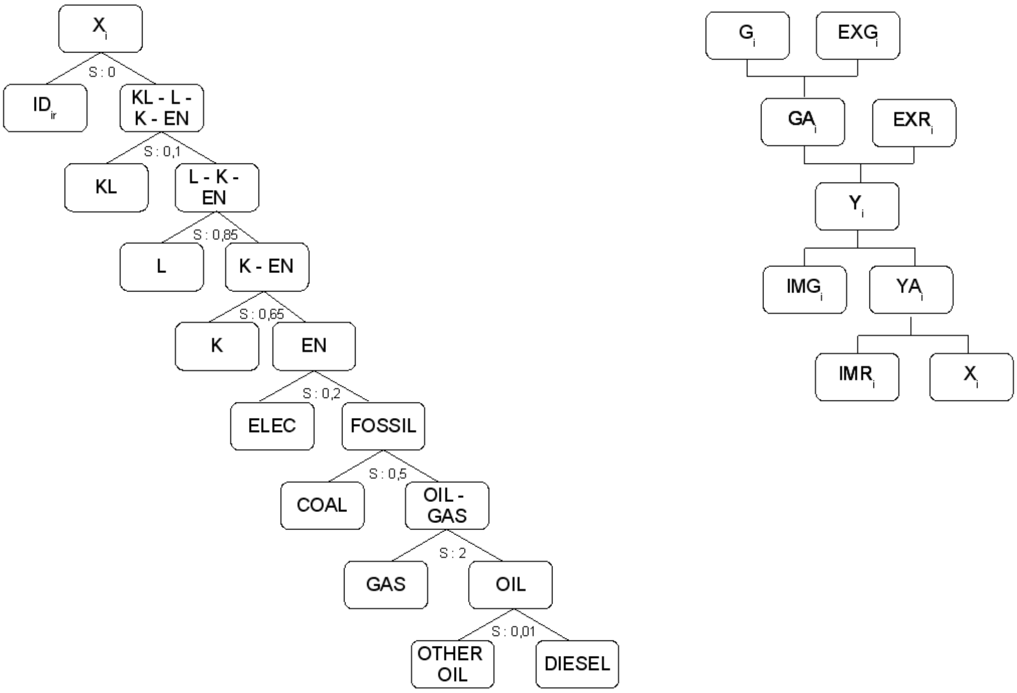

Fig. G-5 : The nesting structure of the production function (left) and the structure of foreign trade under the Armington assumption (right).

In particular, heat services can be either provided by fossil technologies or by biomass energy. Another possibility is found in improving the thermal efficiency of buildings through investments, modelled by a given level of the reconstruction rate.[9]

G-3.2.4 Trade

Commodities can be traded across the three regions (see Fig. G-4), modelled under the assumption of Armington trade.[10] Fig. G-5 illustrates how trade is modelled: Domesticly produced commodities (X_i) in Region 1 combined with imports from Region 2 (IMR_i) and imports from the ROW (IMG_i) constitute the total available commodities in Region 1. These are either consumed locally or exported to Region 2 (EXR_i) or ROW (EXG_i). G_i therefore denotes commodities which can be consumed or used as intermediate input in Region 1. The same structure holds for Region 2. In sum, EXR_i for Region 1 must equal IMR_i for Region 2 and vice versa. The quantities traded depend on the relative price of domestic and foreign goods and on trade elasticities of substitution (for exact values see Tab. G-17 in the Appendix). In particular, higher preferences for goods produced regionally within Styria are reflected by higher elasticities for regional trade flows, i.e. i.e. trade between Region 1 and Region 2, than for global one, i.e. flows to and from Region 3.

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[9] The higher the reconstruction rate, the higher the demand for insulation material and the lower the demand for heat products.

[10] According to the Armington assumption of product heterogeneity (Armington, 1969) an otherwise identical good produced in a different region is by definition not identical. By contrast, they are imperfect substitutes. Goods are thus differentiated by region of origin. The Armington assumption explains why consumers demand the output of all "identical" industries located in different regions, even if output prices differ. So, seemingly identical goods are not exclusively produced in the regions with the lowest output price.

G-4 Data and coupling of models

The present project establishes an interface between a regional climate scenario, sectoral analyses for agriculture and energy and a three-region CGE model. The model coupling is illustrated in Fig. G-6. On the one hand, the regional climate scenario is used to estimate climate-crop yield relationships. On the other hand, it serves as a basis to calculate the change in the number of heating degree days (HDDs) and cooling degree days (CDDs). The results of linking the climate model with the energy model and the agricultural model serve as inputs for the CGE model, which quantifies the relevant economic effects of local climate change for the selected region. Sections G-4.1, G-4.2 and G-4.3 report on each of these submodels, while simulations of the CGE model and their quantitative effects are described in sections G-5 and G-6.

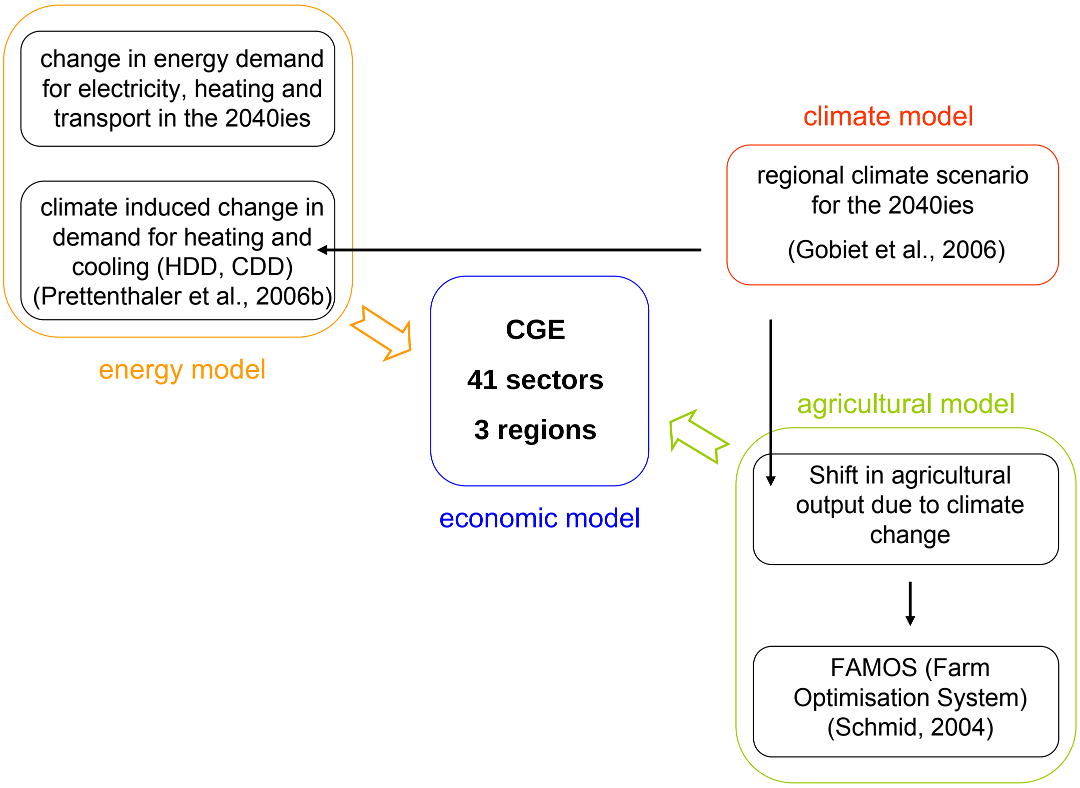

Fig. G-6 : The coupling of models in STERN.AT.

G-4.1 Regional climate scenario

The climatological data basis for STERN.AT is given by a climate scenario for the study region which covers the period 2041-2050 and is corrected for model errors by combining observational data of the ZAMG (Austrian Central Institute for Meteorology and Geodynamics, Vienna) and regional climate model information. The scenario builds on a regional climate model (MM5, Dudhia et al., 2004) which is nested into a global climate model based on the emission scenario IS92a. The simulation is conducted on a 10 km lattice which allows for the spatial detail required by STERN.AT. It covers the entire Alpine region and the period 2014-2050 (Gobiet et al., 2006) and was developed within the Austrian project reclip:more (http://systemsresearch.arcs.ac.at/projects/climate).

For the present project, monthly climate change calculated as the difference between monthly climatologies of the scenario (2040s) and the control (1980s) periods are produced for the parameters temperature and precipitation. Considering temperature, these differences are further smoothed via a three month moving average centred over the focused month in order to filter out unrealistic model variability. In case of precipitation a relative climate change signal is taken into account due to the parameter's strictly non-negative probability distribution. In doing so, the three month moving average filter is previously applied to the monthly mean climatologies of the respective periods before the relative signal is obtained from the smoothed climatologies. Fig. G-7 shows the this way obtained signals.

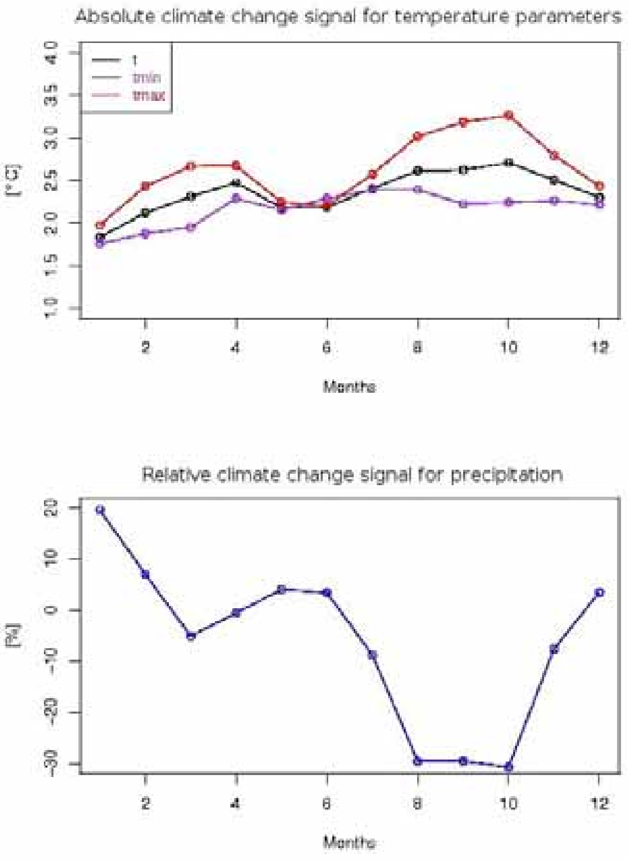

Fig. G-7 : Climate change signals for mean temperature (t), maximum temperature (tmax), minimum temperature (tmin) and precipitation in the STERN.AT study region.

Regarding Fig. G-7 a considerable warming in the mean as well as in the extreme temperature parameters can be seen throughout the year with maxima in autumn and minima in the winter season. Also precipitation shows drastic changes with reduced amounts mainly in autumn whereas this scenario also results in increasing winter precipitation.

Attention should be given to the fact that this climate change signal is based on differences in the mean climatologies and thus do not contain information about extreme indices. Further, this scenario represents only one possible realization of future climate out of a range of other possibilities. It qualitatively corresponds well with coarser scale European climate scenarios (e.g. Christensen and Christensen, 2007), which strengthens the confidence in these results, but the uncertainty range of such a scenario (interpreted local scale) is not reliably quantified so far.

In order to create scenarios of actual temperature and precipitation these "climate change signals" are added to observational data. This approach is commonly referred to as "delta-approach" and is a simple method of correcting systematic climate model errors. For each of the five districts of the study region a representative climate station is selected from the ZAMG network.[11] All stations are located in one rather homogenous climate region of Styria, the so called Vorland. This region is characterised by a rather continental climate due to its protected location in the South-Eastern foreland of the Alps. It features low annual precipitation sums (about 900 mm per year) compared to the rest of Styria and higher monthly sums in summer than in winter. Furthermore, weak winds cause an increased fog and inversion probability (Wakonigg, 1970; Kabas, 2005). On the local scale various climate factors (such as position on the valley bottom, hill slope or ridge, exposition and vegetation) modify the regional climate characteristics. It follows that site specific meteorological data shall be used.

Tab. G-1 gives an overview of the climate stations selected for STERN.AT for each political district. For the district Feldbach the most suitable observational station would be Feldbach or Bad Gleichenberg, yet both suffer from considerable drawbacks.[12] As a consequence, a regional mean for the main climatic parameters, comprising the stations Gleisdorf, Lassnitzhoehe, Fuerstenfeld and Bad Radkersburg, is used to represent this district. The list in Tab. G-1 thus includes the stations Gleisdorf and Lassnitizhoehe, as they enter the calculation for the Feldbach district mean time series. Equally, for reasons of data availability, for the district Hartberg the station Altenberg/Hartberg is chosen (instead of the climate station Hartberg). Moreover, correlations between agricultural output in the district Hartberg and climate data from the ZAMG station Altenberg/Hartberg turn out to be higher than those when using the ZAMG station Hartberg.

Tab. G-1 : The selection of climate stations in SE Styria.

The stations are taken from the ZAMG network. The geographical data (longitude, latitude, height) is given in degrees, minutes and seconds.

political district	political no.	climate station	station no.	longitude	latitude	height
Feldbach	604	Feldbach district mean				
		Gleisdorf	16500	154239	470648	375
		Lassnitzhoehe	16511	153537	470426	524
Fuerstenfeld	605	Fuerstenfeld	16600	160454	470152	271
Hartberg	607	Altenberg/Hartberg	13600	160153	471524	429
Radkersburg	615	Bad Radkersburg	20902	155851	464109	208
Weiz	617	Weiz	16520	153808	471307	465

The climate change signals are finally applied to daily observed data from the 1980s either as additive offsets (absolute signal) or as multiplicative factor (relative signal) resulting in daily scenarios on the station scale of the 2040s. This approach can be regarded as a first order bias correction of the model scenario which could be improved in further projects using additional statistical techniques (e.g., Local scaling (Schmidli et al., 2006), Quantile Mapping (Dettinger et al., 2004).

G-4.2 Sectoral analysis: Agriculture

G-4.2.1 Data in agriculture

Data for the agricultural output for different crops are available from Statistics Austria. At district level this data is available for the period 1995-2006. For a longer period (1964-2005) there is data

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[11] The data provided by the ZAMG are checked for quality but not homogenised. However, any relocation of the stations considered in STERN.AT between 1981 and 2006 has not exceeded more than 25 m in height.

[12] In particular, Feldbach started its measurements in November 1998, but time series from 1981 to 2006 are needed. Bad Gleichenberg contains a gap of nearly three years between 2001 and 2003 (including the striking heat and drought conditions in summer 2003).

only of corn and wine output and solely for 3 districts out of 5 in the study region (Feldbach, Fuerstenfeld and Weiz).

The present study analyses 6 crops which cover 60% of the agricultural land in SE Styria (comprising arable land and grass land). These crops include (i) grain maize, (ii) green maize and silage maize, (iii) soft wheat, (iv) winter barley, (v) meadows mown several times and (vi) oil squash.

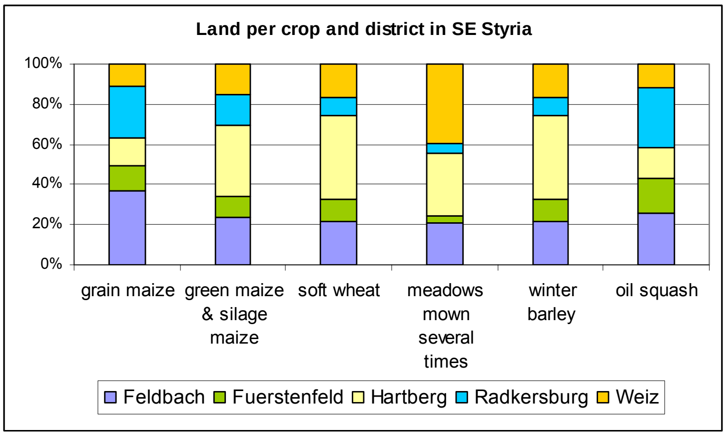

Fig. G-8 : The allocation of land among districts for the main crops in SE Styria.

Source: own construction based on ÖPUL (2006).

Tab. G-2 : Number of farms in SE Styria by size and district.

	number of farms						
size [ha]	Feldbach	Fuerstenfeld	Hartberg	Radkersburg	Weiz	total	[%]
0 – 5	2354	420	1167	725	1331	5997	44%
5 – 10	1104	252	855	346	1066	3623	27%
10 – 20	648	173	657	263	985	2726	20%
20 – 30	175	60	173	102	262	772	6%
20-200	161	67	96	117	108	549	4%
total	4442	972	2948	1553	3752	13667	100%
[%]	33%	7%	22%	11%	27%	100%	

G-4.2.2 The estimation of crop yields from regional climate data

The correlation between the meteorological parameters temperature and precipitation and the agricultural output for barley, wheat, grain maize and grassland was modelled for the year 2003 on field and district level in the StartClim2004.C project (Soja et al., 2005).[13]

In the present project, the aim is to correlate climate parameters with crop yields for the reference period 1997-2006 and to estimate future yields in the period 2041-50. The correlation between the meteorological parameters temperature and precipitation and the agricultural output are de-

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[13] The spatial analysis of Soja et al. (2005) showed that in some districts low precipitation sums were compensated by an optimal distribution of rain and low temperatures. The statistical analysis showed the existence of crop-specific time windows with high sensitivity to drought and high temperatures. Furthermore, it pointed out that it is of high importance for some crops whether the precipitation occurs in spring or in summer. Except for maize, all crop yields were more sensitive to high temperatures than to low precipitation sums, especially in the eastern part of Austria. The study shows the importance of the fact that high temperatures and drought stress often are combined. Moreover, the developed multiple linear regression models and neural networks (ANN) show the advantages and limitations of models which are based only on meteorological parameters. Through the application of agrometeorological models some of these limitations could be removed, as the results at the field scale confirm.

rived via multi-linear regressions. In particular, a growing period of several months is specified for each crop as shown in Tab. G-3.

Tab. G-3 : Growing periods for the main crops in SE Styria.

Source: Soja et al., 2005; Heinrich, 2008; personal communication with Arno Mayer, Agricultural Chamber of Styria, October 2007.

crop-specific growing period		source
grain maize	June to August	Soja et al. (2005)
green maize & silage maize	June to August	Soja et al. (2005)
soft wheat	May to July	Soja et al. (2005); Heinrich (2007)
winter barley	May to July	Soja et al. (2005); Heinrich (2007)
meadows mown several times	May to September	Heinrich (2007)
oil squash	May to July	personal communication with Arno Mayer

This specification results in a set of crop-specific climate parameters, which enter the regression analysis (mean temperatures and precipitation sums in the given periods). Then, the output changes for each agricultural crop in the 2040ies relative to the reference period are derived from a regional climate scenario for the target period in the future (for the climate scenario see section G-4.1). The results are shown in Tab. G-4.

Tab. G-4 : Estimation of physical output shift in agriculture for each crop (for 2045 relative to 2003).

Source: own calculation on the basis of Statistics Austria (for agricultural data) and ZAMG (on meteorological information for the regional climate scenario).

change in output [dt/ha]					
grain maize	green maize & silage maize	soft wheat	winter barley	meadows mown several times	oil squash
-4.5%	-6.6%	-3.4%	-3.1%	-31.0%	+11.0%

Though a range of meteorological parameters are available for the reference period (e.g. temperature maxima and minima, relative humidity, freezing days, radiation, sunshine duration, wind), the parameters used for the regression include temperature (mean) and precipitation (mean) to simplify matters. However, to check the resulting changes in agricultural output, the mean values for temperature and precipitation could be replaced by drought indices based on the work of Heinrich (2008)[14.]

G-4.2.3 *Managerial optimisation by farmers facing climate change*

Based on the calculations from section G-4.2.2, the agricultural model FAMOS (Farm Optimisation System) (Schmid, 2004) estimates the farmers' operating income, production level and input structure (machines, fertilisers and plant protection, labour, land) by Mathematical Programming. The values are given by Tab. G-5. In FAMOS, typical farms for Austria are derived with respect to a set of regional and structural criteria. The model can be employed to quantify effects of e.g. a policy at farm level. For STERN.AT, typical farms for SE Styria are extracted and analysed for the

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[14] Heinrich (2008) calculates correlations between drought indices (which are based on the core parameters temperature and precipitation) and agricultural output based on a 1995 to 2006 data set on district level. The meteorological data stems from the 14 ZAMG stations in Styria. Three districts of the present core region SE Styria belong to the climate region Vorland, two of them to Randgebirge. Overall, the correlation analysis shows that for the Southern climate regions agricultural output is more sensitive to fluctuations in drought indices. This implies that the South of Styria has to envisage more drought in the future especially during the growth period of maize, summer barley and grassland and thus to experience output reductions for these crops.

effects of climate change. Progress in plant breeding at firm level, structural change and change in agro-political instruments are not considered.

Tab. G-5 : Change in farmers' operating income, production level and input structure at firm level for each district in SE Styria (in 2045 compared to 2003).

Source: own calculation with FAMOS (Schmid, 2004).

	operating income	**production level**	**machines**	**fertilizers & plant protection**	**labour**	**land**
	[Euro]	[Euro]	[Euro]	[Euro]	[labour unit hours]	[Euro] - shadow price
Feldbach	-4.6%	-3.3%	-5.0%	-21.2%	+0.5%	-7.3%
Fuerstenfeld	-0.2%	-0.2%	+0.4%	-5.2%	-0.4%	-0.1%
Hartberg	-4.8%	-2.8%	-9.1%	-25.9%	-2.0%	-6.0%
Radkersburg	+0.5%	+1.3%	-2.9%	-12.9%	-0.3%	-2.7%
Weiz	-5.3%	-2.6%	-9.8%	-25.7%	-1.7%	-4.4%

Thus, farmers are assumed to maximise their welfare facing changes in physical output. In doing so, they adapt to altered climatic conditions in 2045. For SE Styria, Tab. G-5 shows a reduction in farmers' operating income and in the agricultural production level. The value of inputs (machines, fertilisers) falls due to altered land use patterns. Farmers will cultivate less arable land and switch to grass land and woods instead. Moreover, farmers will adapt to the new environment by producing more extensively. Consequently, the shadow price of land is falling, too, which corresponds to a decrease in "efficiency land" – a concept introduced in analogy to "efficiency labour" as in Buiter (1988).[15]

G-4.2.4 Responses of agricultural crops to elevated CO_2 concentration

The factors determining the output of agroecosystems are twofold: firstly climate factors (such as higher temperatures, altered precipitation regimes or extreme weather events) and secondly global change components such as atmospheric CO_2 concentration or ozone. The present study addresses this issue in the present section by quantifying the crop yield responses to increased CO_2 levels for the plants which are currently investigated.

Plenty of studies confirm that plant biomass and yield tend to increase as CO_2 concentrations rise above current levels. This is the so called CO_2 fertilisation effect. CO_2 stimulates photosynthesis, leading to increased plant productivity and modified water and nutrient cycles (e.g. Kimball et al., 2002; Nowak et al., 2004). However, this cannot be directly translated into increased yield. Crop yield increase is generally lower than the photosynthetic response (Tubiello et al., 2007). On the other hand, Fangmeier et al. (2000) found that in barley elevated CO_2 increased the nitrogen sink capacity of the grains in combination with accelerated flag leaf senescence, which in turn reduced the length of the period of photosynthesis and thus lowered yields.

Effects of elevated CO_2 per crop are usually differentiated for C3 and C4 crops.[16] As for the crops analysed in STERN.AT, winter soft wheat and barley are C3 plants, whereas grain maize, silage maize and green maize are C4 plants. No classification is assumed for meadows mown several times and for oil squash.

Under experimental conditions, with non-limited supply of nutrients and water, average yield stimulation for C3 crops with a doubling of CO_2 have been estimated at 30%, but estimates from

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[15] Efficiency land is defined as land measured in efficiency units, or expressed differently, as efficiency units per acre of land.

[16] C3 plants are e.g. wheat, rice, potato, soya, sunflower and sugar beet. C4 plants are maize, sorghum, miscanthus and sugarcane.

field scale experiments have been lower (Fuhrer, 2003). Kimball et al. (2002) estimated elevated CO_2 stimulated biomass in C3 grasses by an average of 12% and grain yield in wheat by 10 to 15%. The increase of grain yield in C4 crops due to CO_2 increases is much lower. Under limiting nutrient supply in FACE (free-air CO_2 enrichment) experiments yields rose by some 7% and experienced a higher stimulation under water-limited conditions. Other studies find that with an increase in CO_2 by 45% crop yields rise in the range of 10 to 20% for C3 plants and 0 to 10% for C4 plants (Gifford, 2004; Long et al., 2004; Ainsworth and Long, 2005). These values are summarised in Tab. G-6.

The impact of a CO_2 increase on grasslands is ambiguous. In a FACE project (Hebeisen et al., 1997), for example, the yields of perennial ryegrasses increase up to 30% after 3 years. The response of grasses depends, however, strongly on the nitrogen fertilisation. Nowak et al (2004) and Ainsworth and Long (2005) report on observed increases of above-ground production in C3 pasture grasses and legumes of some 10 to 20%. Other studies show that elevated CO_2 concentration may dampen the grassland yields. Shaw et al. (2002) for example found that elevated CO_2 increased net primary production (NNP) of grassland as a single-factor treatment (i.e. in the presence of ambient levels of temperature, precipitation and nitrogen input), while it damped positive effects of increased levels of these factors. Based on these findings and on the values given in Tab. G-6, the response to increased CO_2 concentration of the crops analysed in STERN.AT are estimated as shown Tab. G-6.

Tab. G-6 : Increase in crops yield for C3 and C4 plants due to elevated CO_2 concentration and values for the crops used in STERN.AT.

The assumed rise in the CO_2 level varies among the cited studies (increase by 45% and 100%, respectively). The assumed rise in STERN.AT (30%) is taken from the IS92a scenario (for the period 2003 to 2045). For C3 plants Kimball et al. (2002) find an increase by 12% for C3 grasses and 10 to 15% for wheat. For C4 plants they report 7% with limited nutrient supply and above that level with limited water supply. Moreover, the findings from the literature for grasslands correspond to the effects for meadows mown several times in STERN.AT.

	increase in crop yields [for elevation of CO_2 level]			
	Kimball et al. (2002)	Gifford (2004), Long et al. (2004), Ainsworth and Long (2005)	STERN.AT	
increas in CO_2	[+100%]	[+45%]		[+30%]
C3 plants	10-15%	10-20%	soft wheat	6.88%
			winter barley	6.88%
C4 plants	7 % and above	0-10%	grain maize	2.87%
			green maize & silage maize	2.87%
other			meadows mown several times	0%
			oil squash	0%

Taking into consideration the CO_2 fertilisation effect, the changes in agricultural output for the 6 crops analysed in STERN.AT vary as given by Tab. G-7. Note that the first line in Tab. G-7 corresponds to the values presented in Tab. G-4. For C3 plants (wheat and barley), the additional impact of elevated CO_2 concentration compensates for the output reducing impact of changed temperature and precipitation patterns (+3.3% and +3.5%).

Tab. G-7 : Change in output for the 6 crops analysed in STERN.AT in 2045 compared to 2003 with and without consideration of the CO_2 fertilisation effect.

	change in output [dt/ha]					
	grain maize	green maize & silage maize	soft wheat	winter barley	meadows mown several times	oil squash
excluding CO_2 fertilisation	-4.5%	-6.6%	-3.4%	-3.1%	-31.0%	+11.0%
including CO_2 fertilisation	-1.7%	-3.9%	+3.3%	+3.5%	-31.0%	+11.0%

Another influencing factor is the rise in temperature. While CO_2 has positive effects on crops and weeds, including yield stimulation, many of them may be reduced with rising temperatures.[17]

Due to the fact that Eastern Styria is dominated by grassland and maize, for which the CO_2 fertilization effect is dominated by temperature and extreme events (such as droughts) the most likely size of this effect is pointed out, but not considered within the empirical economic calculations at this step of maturity of modelling. Furthermore, more recent "analysis of Long et al. (2006) showed that the high-end estimates were largely based on studies of crops grown in greenhouses or field chambers, whereas analysis of studies of crops grown in near-field conditions suggest that the benefits of carbon dioxide may be significantly less – an 8 – 15% increase in yield for a doubling of carbon dioxide for responsive species (wheat, rice, soybean) and no significant increase for non-responsive species (maize, sorghum)." (Stern, 2007, p. 82). As a result, the quantification of welfare and GDP changes (section G-6) does not include the effects from CO_2 fertilization (as they do not include the impacts of extreme events beyond those present in the reference period 1995-2006).

G-4.3 Sectoral analysis: Energy

G-4.3.1 Future household demand for energy without climate change

As a first step, the future demand by households for heat, electricity and transport is quantified to model a situation without climate change. Energy consumption is calculated based on the concept of "energy services".[18] In doing so, two energy services are analysed: housing and mobility. This procedure allows modelling the energy sector in the BAU, which will then be extended by the climate component in section G-4.3.2.1.

Tab. G-8 : Final demand for heat by households by 2045 for different reconstruction rates and under the assumption that all new dwellings are built in low energy standard.

Source: own calculations based on Statistics Austria (2004a, 2004b, 2008) and Landesstatistik Steiermark (2007).

	final heat demand (new dwellings as low energy houses) [TJ]					
reconstruction rate	2003	2013	2023	2033	2043	2045
0%	9,540	9,585	9,651	9,738	9,852	9,878
1%	9,540	9,275	9,033	8,814	8,620	8,585
1.5%	9,540	9,120	8,724	8,351	8,004	7,938
2%	9,540	8,965	8,416	7,889	7,388	7,291
3%	9,540	8,655	7,798	6,964	6,241	6,162

Firstly, based on data of the household and population census 2001 (Statistics Austria, 2004a, 2004b) and on population statistics of Statistics Austria (2007), an energy service of heated 10.6 million m^2 living space is calculated for the base year 2003. This living space implies a heat demand of 9.54 million GJ. For calculating the heat demand for the year 2045, the development of

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[17] In general, warming reduces crop yields due to accelerated plant development. A rise of only a few degrees may offset the positive effect of elevated CO_2 (Amthor, 2001). Conversely, elevated CO_2 may counteract the negative effect of higher temperatures (Wheeler et al., 1996). While higher CO_2 concentrations favour C3 over C4 plants, the opposite effect is expected under associated temperature increases. I.e. rising temperatures favour C4 weeds over C3 crops in this context (Fuhrer, 2003; Tubiello et al., 2007). Fuhrer (2003) concludes that responses of agro-ecosystems will be dominated by climate effects such as shifts in temperature and precipitation patterns rather than by CO_2 elevation per se.

[18] Energy services are „actual services for which energy is used: heating a given amount of space to a standard temperature for a period of time" (IEA, 1997, p. 35).

living space (Statistics Austria, 2008) and the projected number and size of households (Landesstatistik Steiermark, 2007) are included.[19]

Tab. G-9 : Final demand for heat by households by 2045 for different reconstruction rates and under the assumption that all new dwellings are built in passive house standard.

Source: own calculations based on Statistics Austria (2004a, 2004b, 2008) and Landesstatistik Steiermark (2007).

	final heat demand (new dwellings as passive houses) [TJ]					
reconstruction rate	2003	2013	2023	2033	2043	2045
0%	9,540	9,560	9,588	9,625	9,674	9,685
1%	9,540	9,249	8,970	8,701	8,442	8,392
1.5%	9,540	9,094	8,662	8,238	7,826	7,745
2%	9,540	8,939	8,353	7,776	7,210	7,099
3%	9,540	8,629	7,735	6,851	6,063	5,969

Four different reconstruction rates are simulated (1%, 1.5%, 2% and 3%), with 1% being the baseline. It is furthermore assumed that there are three options for households to better insulate their homes; they differ by type of insulation.[20] Depending on the insulation rate, the demand for heating energy amounts between 6.16 million GJ and 8.58 million GJ for low energy houses (see Tab. G-8) and for passive houses between 5.97 million GJ and 8.39 million GJ (see Tab. G-9).

Secondly, for electricity demand of households, the energy balance for Austria (IEA, 2007) and the population statistic from Statistics Austria (2007) are used. For households in SE Styria an electricity demand of 1.59 million GJ is calculated for the base year 2003. Future electricity demand is calculated based on historical data considering the expected population increase. It amounts to 1.29 million GJ.

Thirdly, calculations for mobility related demand are based on data of the Austrian transport forecast 2025+ (Käfer et al., 2007) and on a study on transport and the environment by the BMLFUW (1997, and forthcoming). For calculating the demand related to the energy service mobility, only person kilometres of private cars are considered. The energy demand for mobility amounts 6.76 million GJ in 2003. To assess the respective future demand, numbers of the Austrian transport forecast 2025+ (Käfer et al., 2007) up to the year 2025 are used and extrapolated to 2045. It amounts to 8.59 million GJ.

G-4.3.2 Autonomous adaptation to climate change in the energy sector

G-4.3.2.1 Climate-induced change of household energy demand

The assessment of shifts in energy demand under altered climatic conditions is based on the concept of heating and cooling degree days (HDDs and CDDs). A HDD is defined by the Austrian ÖNORM 8135 regulation, while an international definition is used to specify a CDD (see Prettenthaler et al., 2006b).

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[19] The following assumptions are made: All new buildings after 2003 fulfil low energy standard, with an energy demand not higher than 0.15 GJ per m^2. In existing buildings energy demand is reduced with insulation by 0.26 (small reconstruction) and 0.33 GJ (big reconstruction) per m^2 (see Jakob et al., 2002).

[20] A fraction of households is assumed to undertake a “big” insulation, another fraction a “small” one and a third, but relatively minor part, is assumed to change from “small” to “big”.

The energy demand of heating and cooling is calculated based on the method developed in the StartClim2006.F project (Prettenthaler et al., 2006b).[21] In doing so, the energy demand is separated into a direct weather impact, quantified by the number of HDDs and CDDs, and a general (heating or cooling) coefficient. [22] The calculation for SE Styria for the 2040ies shows that in absolute terms the HDDs decrease more (reduction of 667 days on average) than the CDDs increase (rise by 198 days). In relative terms, by contrast, the increase in CDDs (+144% on average) clearly exceeds the fall in HDDs (-20%). The same holds true for the thereby assessed climate induced demand for cooling and heating energy. Since, however, the share of cooling energy in overall energy demand is negligibly small compared to heating energy, the economic impacts from climate change are obviously dominated by the shift in heating energy demand (see also section G-6.1).

For this project medium growth rates were chosen, in the case of heating –0.403% p.a., which is based on own calculations, and in the case of cooling +2% p.a. as suggested by Adnot et al. (2003) and Wegmayr et al. (2007). The growth rate of –0.403% p.a. reflects the difference in heating energy demand between 2003 and 2045 under a constant climate as calculated in table Tab. G-8.

Tab. G-10 : Change in heating and cooling energy demand for SE Styria up to 2045 decomposed into a climate and non-climate effect.

Source: own calculations. The values for heating energy demand for a constant heating coefficient (0%) under a constant climate corresponds to final heat demand in 2003 as given in Tab. G-8 and Tab. G-9, respectively, corrected for the calculation period for HDDs (1981-90). Note the difference in units of measurement (TJ and MWh).

change in heating and cooling energy demand up to 2045 [MWh]						
	heating			cooling		
change in coefficient p.a.	0%	-0.403%		0%	2%	
year	2003	2045	change other than climate induced	2003	2045	change other than climate induced
under constant climate	2,579,101	2,177,204	-401,897	2,253	4,876	2,624
under climate change	2,067,786	1,745,566	-322,220	5,389	11,665	6,277
climate induced change	-511,315	-431,637		3,136	6,789	
total change			*-833,534*			*9,413*

Tab. G-10 shows the climate and a non-climate component of changed energy demand. In a first step, the energy demand for heating is calculated under the assumption of a constant climate, but considering the development in the building sector reflected by a decreasing heating coefficient (-0.403% p.a.). Then, the climate induced change in HDDs is taken into consideration. Instead of 2,177,204 MWh under constant climate conditions, only 1,746,566 MWh will be used for heating due to higher temperatures in winter. Therefore, the climate induced change in heating energy demand accounts to -431,637 MWh. The total demand change, i.e. comprising climate and non-

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[21] For further information on energy demand for heating and cooling see Prettenthaler and Gobiet (2008) and therein in particular Prettenthaler et al. (2008).

[22] To simplify matters it is assumed that the heating energy demand, E_{heat}, changes proportionally with the change in HDDs in a given year. This number is multiplied then with a heating coefficient, k_{heat}, which indicates how much final energy demand per HDD exists at the reference point $t = 0$; the coefficient comprises all technical and socio-economic developments in the building sector. In order to assess future demands, a change factor $1+a$ finally quantifies how much the heating coefficient changes per year t. This is done analogously for the cooling energy demand and can be written as follows:

$E_{heat} = HGT * k_{heat} * (1+a)^t$ and $E_{cool} = KGT * k_{cool} * (1+a)^t$.

climate effects, adds up to -833,534 MWh. Analogously, for cooling a climate induced change of 6,789 MWh is calculated. Together with a rising cooling coefficient (+2% p.a.), the total demand for cooling increases by 9,413 MWh.

G-4.3.2.2 *Cost of autonomous adaptation and mitigation in the building sector*

Regarding the costs of climate change in energy, the purchase of additional air conditioning is considered an autonomous adaptation measure in the building sector. On the other hand, passive houses are considered a mitigation strategy.

The assumptions to calculate the cost difference between low energy and passive houses are taken from based on personal communication with the environment department of The Austrian Institute of Economic Research (WIFO) (2007). They are listed in Tab. G-11.

Tab. G-11 : Assumptions and calculations for the costs of low energy buildings and passive houses.

Source: own calculations based on personal communication with the environment department of WIFO (2007). In order to calculate the annuity, the interest rate is assumed to be 5% and life-time of the building 30 years.

costs of low energy buildings compared to passive houses			
		low energy building	passive house
investment costs per m^2	€/m^2	2000	2200
size of an average dwelling	m^2	90	90
energy demand for heating	kWh/m^2/a	70	20
energy costs for heating	€/kWh	0.1	0.1
investment costs per dwelling	€	180,000	198,000
annuity	€/a	11,709	12,880
energy use per dwelling	kWh/a	6,300	1,800
energy costs per dwelling	€/a	630	180
total costs per dwelling	€/a	12,339	13,060
maintenance costs per m^2	€/m^2/a	137	145

Based on these sources, the construction costs for a passive house are calculated as follows: First, the difference in the annuity for a passive house and a low energy building is calculated (1171 €/a)). Then, this value is divided by the size of an average dwelling (90m^2) and by the difference in heating energy demand between a passive house and a low energy building (50 kWh/m^2/a), resulting in construction costs of 0.26 €/kWh. The maintenance costs are calculated analogously resulting in construction costs of 0.002 €/kWh (see Tab. G-12).

Tab. G-12 : Cost of a centralized air condition plant and additional cost of a passive house compared to a conventional building per economic sector.

Source: own calculations based on Simander and Rakos (2005) (for air conditioning) and on personal communication with the environment department of WIFO (2007) (for passive houses). Tab. G-12 uses ÖNACE sector classifications (see Tab. G-16 in the Appendix for a description of the ÖNACE sectors).

		costs [€/kWh]	
sector		air conditioning	passive houses
29/45	engines/ construction costs	0.13	
40	energy costs	0.06	
45	maintainance costs	0.01	
45	construction costs		0.26
40	energy costs		-0.1
45	maintainance costs		0.002
	total	0.2	0.162

On the other hand, the cost assumptions for air conditioning are taken from Simander and Rakos (2005). Having calculated this, the increased costs of rising demand for cooling energy by 2045 (as calculated in Tab. G-10) is included in the model run by implementing the additional costs for a centralised air condition plant (20 cents/kWh). Hereby, only the climate induced change is considered (i.e. an increase of 6,789 MWh). The costs for heating, on the other hand, are calculated endogenously by the CGE model. Calculations for the rest of Styria (Region 2) are based on a GDP related adjustment of the values for SE Styria (Region 1).

G-5 Simulations

The simulations include four scenarios which are described in the present section and will be compared regarding their quantitative effects in the next one: Scenario 1 (without climate change, i.e. business as usual (BAU) scenario), Scenario 2 (with climate change and autonomous adaptation, i.e. Reference scenario), Scenario 3 (Scenario 2 including policy-induced adaptation) and Scenario 4 (Scenario 2 including mitigation). Scenarios 2, 3 and 4 focus on the sectors agriculture and energy, respectively.

G-5.1 Business As Usual Scenario for 2045 (BAU – Scenario 1)

The model is initially calibrated to the year 2003. Building on this base run, the Business As Usual (BAU) scenario for the year 2045 is developed by extrapolating the macroeconomic framework data. The BAU does not include any climate change. As a first step, the exogenous parameters and initial variables are specified in order to calibrate the base run of 2003. Then, population growth, factor input growth, factor productivity, energy prices and demand for heat, electricity and transport are projected to the future. These values are given in Tab. G-13. Moreover, in the housing sector, where a reconstruction rate of 1% is assumed, all new dwellings are low energy houses. The quantities for heat demand of consumers in 2045 under these assumptions are presented in Tab. G-8.

Tab. G-13 : Parameter values and exogenous and initial values for the development of the BAU scenario 2045.

Exact values for the Armington elasticity and productivity growth per sector are given in Tab. G-17 in the Appendix. The production structure with exact values for the elasticities of substitution is given in Fig. G-5.

variable	**value**		source
	Region 1	**Region 2**	
parameter			
elasticities of substitution in production	between 0 and 0.85 (varying between nesting levels)		Wissema and Dellink (2007); Rutherford and Paltsev (2000)
Armingtion elasticitiy	between 0.2 and 2.25 (varying between sectors and between global/regional trade)		Welsch (2008)
exogenous and initial values			
growth of capital stock	0.9 % p.a.	0.9 % p.a.	EU KLEMS (2007)
change in labour force until 2045	-12.70%	-12.50%	own calculation based on ÖROK (2004)
real price change for energy	+14.5% (coal); +29% (oil products); +29% (gas); +19.3% (electricity)		Kettner et al. 2007
productivity growth	between 0.31 and 2.41 (varying between sectors)		own calculation based on EU KLEMS (2007)
reconstruction rate (initial value)	+ 1.0%	+ 1.0%	own assumption
heating demand of consumers up to 2045 (initial value)	+ 3.71%	+ 1.84%	own calculation based on Kettner et al. (2007)
fuel demand of consumers up to 2045 (initial value)	+ 16.87%	+ 26.52%	own calculation based on Kettner et al. (2007)
electricity demand of consumers up to 2045 (initial value)	-18.91%	-14.85%	own calculation based on Kettner et al. (2007)

The BAU is characterised by the economic performance presented in Tab. G-14 including GDP growth, welfare, consumption price index, level of agricultural production, factor prices for labour and capital and the agricultural price level.

Tab. G-14 : The Business as Usual scenario for 2045.

The GDP growth rates are close to the IIASA Baseline Scenario B1 (urban growth 1.76% p.a., rural growth 0.94% p.a.)

BAU 2045			
		Region 1	Region 2
Economic Performance			
GDP	[2003 = 100]	163.24	202.75
GDP growth	[% p.a.]	1.20%	1.74%
Welfare	[2003 = 100]	200.0	266.5
Welfare	[% p.a.]	1.7	2.4
Consumption price index	[2003 = 100]	90.6	95.9
Agricultural production level	[2003 = 100]	137.7	136.1
Factor prices			
Labour	[2003 = 100]	282.0	339.5
Capital	[2003 = 100]	124.9	150.4
Price level agriculture	[2003 = 100]	102.2	118.3

G-5.2 Scenario with climate change and autonomous adaptation (Reference – Scenario 2)

The Reference Scenario includes climate change impacts and autonomous adaptation by consumers and producers facing these impacts. It serves as a reference case for the implementation of political instruments (policy-induced adaptation and mitigation).

In agriculture, changed temperatures and precipitation patterns in the 2040ies directly affect the conditions of growth for many plants. Moreover, the 2040ies are characterised by altered land use patterns and by more extensive production. Thus, the Reference scenario includes changes in physical agricultural output due to future alteration in meteorological parameters and individual optimisation by farmers facing these changes. The two step approach for modelling the agricultural sector is presented in section G-4.2 (sections G-4.2.2 and G-4.2.3). Productivity growth in agriculture (such as progress in plant breeding) is modelled at the sectoral level.

A prime interface between the agricultural optimisation model FAMOS (Schmid, 2004) and the CGE model is established by weighting the future production levels from FAMOS (as given in Tab. G-5) by the number of farms per district (Tab. G-2). By this means, the overall change in the agricultural production level for SE Styria can be quantified and be included in the CGE model. The change is characterised by a decline of production by 2.27% in 2045 compared to the BAU. Moreover, the changed agricultural input structure as estimated by FAMOS serves as an input for the CGE model to simulate a scenario with climate change and autonomous adaptation (in this case extensified production).

In the energy sector, a change in the average temperature over the next decades implies a shift in energy demand for heating and cooling. While the demand for cooling energy will increase over the next decade, the demand for heating energy will fall when it gets warmer. This development is modelled in two steps as described in detail in section G-4.3. First, the future demand for energy is calculated for 2045 excluding the effect of rising temperatures (see G-4.3.1). Then, the reaction by economic agents to the warming is included (see G-4.3.2 for changed energy demand and the costs for additional air conditioning).

G-5.3 Reference Scenario and policy-induced adaptation (Scenario 3)

The mixed cultivation of two to three crops on the same lot of land might be an advanced agricultural technique under changing climatic conditions. On the one hand, this mix requires an increased amount of inputs. This is inter alia due to the high labour-intensity of the production process in both preparation and maintenance and post-processing. Expressed differently, the same amount of output, relative to conventional farming, requires an enhanced quantity of inputs.

On the other hand, mixed cultivation brings along a variety of advantages, ecological and environmental ones.

Adaptation is assumed to take place in both Region 1 and Region 2. In order to model policy-induced adaptation farmers are assumed to adapt to climate change by mixing crops in cultivation. In doing so, they face the reduced crop yields resulting from higher temperatures and altered precipitation patterns. Conversely, the choice of mixed cultivation increases and stabilises output in the agricultural sector by increasing resilience and reducing erosion. The aim of the adaptation measure is thus to avoid the damages, which are present with climate change, thereby holding the overall economic costs at least constant or, ideally, reducing them (since mixed cultivation requires more inputs than conventional farming). Stated differently, it is investigated how expensive an adaptation measure may be in order to avoid negative economic effects (i.e. a decrease in the GDP) as caused by climate change.

Policy-induced adaptation is modelled via the concept of efficiency land.[23] Productivity changes through climate change or adaptation measures, such as the mixed cultivation of crops, are modelled by a change in the availability of efficiency land.

G-5.4 Reference Scenario and mitigation (Scenario 4)

Mitigation is modelled through three channels: (i) better insulation for residential buildings, (ii) passive house standard for new dwellings and (iii) enforced use of biomass for energy production.

G-5.4.1 Insulation for residential buildings (energy)

Insulation is an essential element in terms of the energy efficiency of residential buildings. It is thus a key element to avoid energy wastage and to reduce emissions from homes. Improving the thermal insulation of a building can therefore directly reduce the amount of carbon emitted and so help to alleviate the gases contributing to climate change. In principal, colder climates demand higher levels of insulation.

The improved insulation of residential buildings is modelled by increasing the reconstruction rate from 1% to 1.5% p.a. in a first step. An additional mitigation scenario for a reconstruction rate of 3% is carried out. In particular, the improved insulation is integrated in the CGE model by replacing a fraction of heat demand (in kWh) by an alternative cost structure.

G-5.4.2 Passive house standard for new dwellings (energy)

Passive houses are low-energy houses that require little energy for space heating and therefore reduce the overall energy consumption for heating. This effect shall be modelled here. The additional decreased energy demand for cooling due to the passive house standard is excluded due to the complexity this aspect would bring along.

Analogously to the modelling of improved insulation, the increase in the number of passive houses is implemented replacing a fraction of heat demand by the cost structure for passive house standard. In doing so, the difference in energy demand between passive houses and conventional buildings is supplied by the new cost structure, which is given in Tab. G-12. By assumption, all new buildings are uniformly built in passive house standard.

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[23] For a definition of efficiency land as used in STERN.AT see section G-4.2.3.

G-5.4.3 Bio-energy (agriculture, energy)

An important mitigation element in the agricultural sector – yet with strong interdependencies with the energy sector – is the advanced use of biomass for energy production. Renewable energies such as e.g. biomass or solar power can play a major role in tackling the challenge of energy security and global warming. The reason is that they are not depletable and produce less greenhouse gas emissions than fossil fuels.

To model mitigation via the enhanced use of biomass energy, the simulation is based on the EU's effort to boost the Union's share of renewables to 20% by 2020.[24] For Austria this means an increase from 23% in 2005 to 35% in 2020. The shift towards renewables is modelled by substituting some 2700 terrajoule (TJ) of fossil effective energy demand by biomass by 2045. This amount corresponds to the required share of renewables (35%) of total energy demand in 2045 in SE Styria. A quantity of 300 TJ is supplied by the cultivation of miscanthus on set-aside land, which is now used for agricultural production for the production of miscanthus pellets. [25] The remaining 2400 TJ are assumed to be provided by forestry biomass, thereof 57% logs, 39% pellets and 4% wood chips (based on Haas et al., 2007). In addition, biomass products are assumed to be imported from world markets (Region 3) at fixed shares.

The cost structures for biomass and bio-energy for the Reference case are taken from Kettner et al. (2007). It is assumed that biomass heating systems show an average progress ratio of all other economic sectors. Moreover, new biomass heating systems (e.g. miscanthus, poplar pellets) show a decrease in the investment costs to the level of mature technologies (e.g. wood chips, pellets), which corresponds to a cost reduction of some 20% of investment costs. This is often assumed in energy models as a rule of a thumb learning rate. Thus, the rising employment of biomass technologies in the future leads to a price reduction for bio-energy production.

The cost difference between renewable and conventional energy technologies is an important factor when analysing the role of renewable energy in the future. Major concepts in this respect are technological change and cost reduction potential of energy technologies: Learning curves can be expressed as single factor learning curves, meaning that the cost reduction is only a function of experience or maturity of a technology. Alternatively, the function can include R&D or other technological factors (multifactor learning curves) influencing the degree of cost reduction. For energy technologies, the common approach is experience curves. They give a progress ratio expressing the cost decline with each doubling of production.

Many studies cover cost reduction for electricity technologies and biofuel production. Martinot et. al. (2007), for example, give an overview of global energy scenarios. They state a cost reduction until 2050 for photovoltaic from 6 to 30 cents per kWh, for onshore wind from 3.5 to 20 cents and for offshore wind from 6 to 18 cents per kWh. Furthermore, the IEA (2000) presents different cost reductions for energy technologies. While in the early stages of technologies (with low installed capacity) the costs per kWh are decreasing quite dramatically, this trend slows down as soon as technologies get increasingly mature.

On the other hand, in the literature very few estimates for learning curves for biomass systems can be found. One reason might be that the cost determination of biomass systems is more complex. Learning effects of biomass systems can be split into three components: (i) learning system for the biomass plant/system, (ii) learning system for the plant/system operation, and (iii) learning

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[24] Each member state should increase its share of renewable energies such as biomass, hydro, wind and solar power. The Commission put forward differentiated targets for each EU member state, based on the per capita GDP of each country and present shares of renewables.

[25] A set-aside agricultural area is a farmland taken out of agricultural production for a period of years. The obligation to set aside land is an instrument of the Common Agricultural Policy (CAP) of the European Union in order to steer quantities on agricultural markets.

system for the fuel supply (Junginger 2005). A second point is that their production requires fuel, which is influenced by hardly predictable market dynamics.[26] Furthermore, learning curves for single home heating biomass systems differ significantly in design and format between each other.[27]

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[26] In particular, the learning curve for fuel supply is influenced by several factors. For agricultural biomass products, for instance, the breeding progress has a major influence. There might be a high cost reduction potential in the future, especially for emerging cultures like miscanthus or poplar. One might also take into account the increase in yield as a consequence of the use of genetically modified plants. Schmitz (2003) assumes an increase in yield from 1 to 1.5 % p.a. for his investigation on biofuels.

[27] For the overall cost per kWh for single home heating systems Nitsch (2007) states that hardly any cost reduction can be expected since developments in technology will be compensated by increasing fuel costs. Fritsche et al. (2007) however calculates with a cost reduction (cent/kWh) for pellets heating systems (10 to 50 kW) between 2000 and 2030 of 19% assuming that in 2030 the amount of cumulative installed pellets systems is about the tenfold of 2000.

G-6 Quantitative Results

This section presents the quantitative results of the simulations on the economy, i.e. the regional socio-economic impacts. Results from Scenario 2 are compared to those from Scenario 1 (BAU), while Scenario 3 and Scenario 4 are analysed relative to Scenario 2 (Reference). The comparison of the scenarios delivers the following results:

- differences in regional welfare and value added, including
- price changes and labour market effects as well as
- costs of climate change and policy responses.

G-6.1 Effects from climate change and autonomous adaptation

The impacts from climate change and the effects from autonomous adaptation by consumers and producers are analysed relative to a situation excluding variations in the climate. To that end, the Reference Scenario (Scenario 2) is compared to the BAU (Scenario 1). Simulation results will be described for changes in regional welfare and changes in regional GDP growth in Scenario 2 relative to Scenario 1. Furthermore, the effects for agriculture and the energy sector are studied separately, before the overall effect is analysed.

In agriculture, with altered climatic conditions the same amount of inputs produces a lower level of output. While the shift in output varies for each crop (see Tab. G-4) – it does so even more if CO_2 fertilization effects are included (see Tab. G-7) – the overall production level for agriculture decreases. Stated differently, the production of agricultural goods gets more expensive. As a consequence, the price for food rises with the price increase for agricultural goods. Moreover, the price (i.e. revenue) of land is falling (see Tab. G-5 for reduction in the shadow price of land), which corresponds to a decrease in the productivity of the factor land. Since consumers supply the factor land, besides labour and capital, their income declines, which lowers the overall demand and hence decreases the overall production. Thus, the simulations show a decline both in welfare and GDP growth as illustrated in Fig. G-9. The figure also shows that the outcomes (both for welfare and GDP) do not differ in direction for Region 1 and Region 2, even so in magnitude. This holds equally true for the energy sector.

As for the energy sector, the arising effects are dominated by the change in HDDs, i.e. by the shift in demand for heating energy. The effect from altered cooling energy demand (i.e. air conditioning), based on a change in CDDs, is negligibly small (see also section G-4.3.2.1). Contrary to the agricultural production, the welfare effects for energy differ from the GDP effects in direction and magnitude and with respect to region specific impacts (see Fig. G-9). On the one hand, less investments in the energy sector are needed since energy demand for heating decreases. The resulting demand shock drives down the capital price and thus the GDP. A further effect, which leads to the downward trend in the GDP, is that the arising fall in consumption reduces production with e.g. a decline in the building construction sector by 6 Million Euro. A third factor driving the GDP downwards can be found in the import structure: As the import of fossil fuels from Region 3 decreases, households may import other (cheaper) commodities from abroad instead of consuming them locally. On the other hand, the same heating service[28] can be provided with reduced inputs so that the welfare of consumers rises. The price of the consumption bundle falls and households are able to buy other commodities. At the same time, since the capital price decreases, households earn less, which in turn lowers consumption and hence production. The

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[28] A heating service quantifies the amount of heat is needed to reach a certain room temperature.

GDP (and consequently the level of welfare) decrease, but the net welfare effect remains positive dominated by the cheaper provision of the heating service.

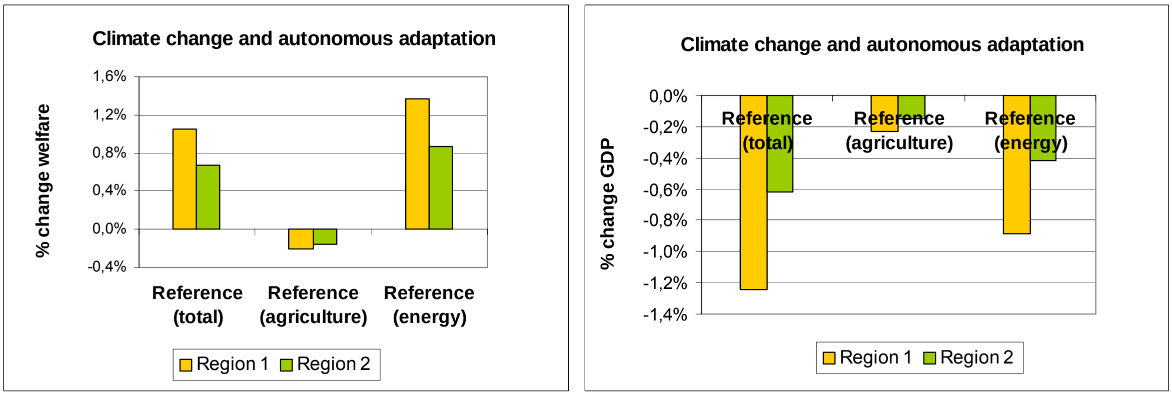


Fig. G-9 : Effects from climate change and autonomous adaptation on regional welfare (left plot) and GDP growth (right) for Region 1 and Region 2.

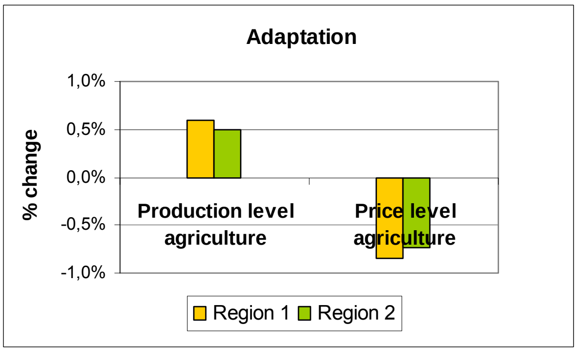
Changes are quantified for the Reference (Scenario 2) relative to the BAU (Scenario 1). Effects are analysed separately for changes in agriculture (middle graphics in each plot) and energy (right) and in total (left).

The total welfare effect, i.e. including the impacts in both sectors, is dominated by the positive effect for energy. Thus, the net effect for welfare is positive under changing climatic conditions and the respective autonomous adaptation in the two sectors under consideration. The negative trends in GDP growth for the two sectors, on the other hand, add up to an even stronger decline in regional GDP when considering the overall impact.

G-6.2 Effects from policy-induced adaptation

The effects of policy-induced adaptation in agriculture are presented as relative changes of simulated enhanced use of mixed cultivation techniques (Scenario 3) to the Reference including altered agricultural output (Scenario 2). The policy is analysed for Region 1 and Region 2. The aim of the adaptation measure is to lower damages from climate change thereby holding the overall economic costs at least constant or, ideally, reducing them (since mixed cultivation requires more inputs than conventional farming).

In order to achieve the equivalent GDP of Region 1 under climate impacts without adaptation, an alternative technology (i.e. the mixed cultivation of crops in this case) can be used, which may require additional expenditure for agricultural production up to 3.25% (in each region).



Additional expenditure for agricultural production up to x% to achieve equivalent GDP in Region 1	
Adaptation (for Regions 1 and 2)	
Region 1	Region 2
3.25%	3.25%

Fig. G-10 : Effects from policy induced adaptation on the agricultural production and price level and the additional expenditure for agricultural production for Region 1 and Region 2.

Changes are quantified for Scenario 3 relative to a newly calibrated Reference Scenario.

If adaptation leads to an increase in costs by 3.25%, the additional inputs match the otherwise present reductions in crop yields. If, on the other hand, adaptation leads to less expenditure than this threshold, the GDP decreases less (by use of a farming technique, which is more expensive than a conventional technique yet which increases the productivity of land) than it does under climate change without adapting farmers. Such a measure could therefore be recommended.

G-6.3 Effects from mitigation

The socio-economic effects caused by mitigation are presented as relative changes of simulated mitigation measures (Scenario 4) to the Reference (Scenario 2).

Energy policy represents a major economic input and is in this way connected to economy-wide feedback effects. Increasing the insulation for residential dwellings or building passive houses lowers the energy needed for heating. This can be seen in Fig. G-11, which illustrates the final household demand for heating. An increase in the reconstruction rate from 1 to 1.5% lowers energy demand for heating by some 650 TJ, whereas 2400 TJ can be saved if the reconstruction rate is raised from 1 to 3%. This reduction in energy required by households lowers their amount spent for heating. Therefore, households have more income available to purchase other goods, which stimulates the regional production of consumption goods. Since insulation and passive houses are produced regionally and are substituted mainly for imported goods (e.g. for heating oil, natural gas and coal), the regionally positive effect increases even more. Furthermore, both measures are produced by labour intensive sectors such as, for example, the building construction sector. Thus, mitigation raises the employment and reduces the amount of unemployment compensation payments spent by the government. As a consequence, the overall demand (by consumers and by the government) increases. Since government consumption (e.g. education, health service and administration) is labour intensive, too, a circular effect on employment and demand occurs.

The use of biomass for energy production has similar effects on the economy. Since most biomass technologies are cheaper compared to conventional heat production (such as heating oil), households spend less on heating when shifting to biomass heating systems. Furthermore, the production of biomass is highly labour intensive implying strongly positive employment effects.

The magnitude of the effects on welfare and GDP (see Fig. G-12) is determined by the following factors. First, the cost reduction induced by the measure, second, whether labour investments are needed or not, and, third, by the development of the factor prices. Agricultural biomass, for example, is competing with conventional agricultural production for the limited resource crop land. Therefore, an expansion of agricultural biomass production goes with a rise in crop land. Factor prices are important, because they determine the income of the households.

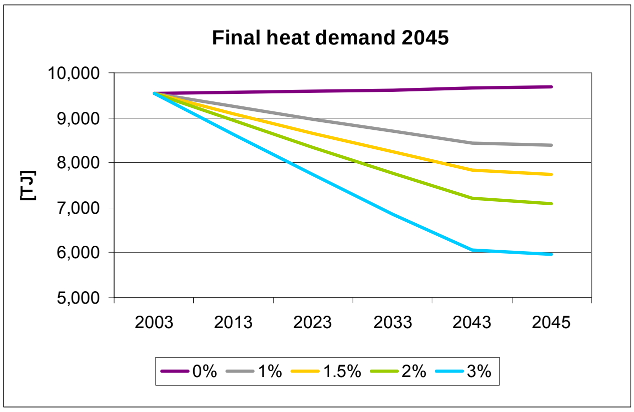


Fig. G-11 : Final heat demand by consumers by 2045 for different reconstruction rates and under the assumption that all new buildings are passive houses.

The exact numbers of this graph are shown in Tab. G-9.

As passive house standard and bio-energy are only simulated in Region 1, the effects from these measures on Region 2 (shown in Fig. G-12) can be described as spill over effects. These spill over effects are mainly triggered by the increasing government consumption in Region 1, which is to a large part supplied by Region 2. The reason is that in Region 2, since it includes the provincial capital, several governmental services are produced. The described spill over effects lead to a higher production and therefore to employment and positive GDP effects in Region 2. By contrast, insulation is implemented in both regions (Region 1 and Region 2).

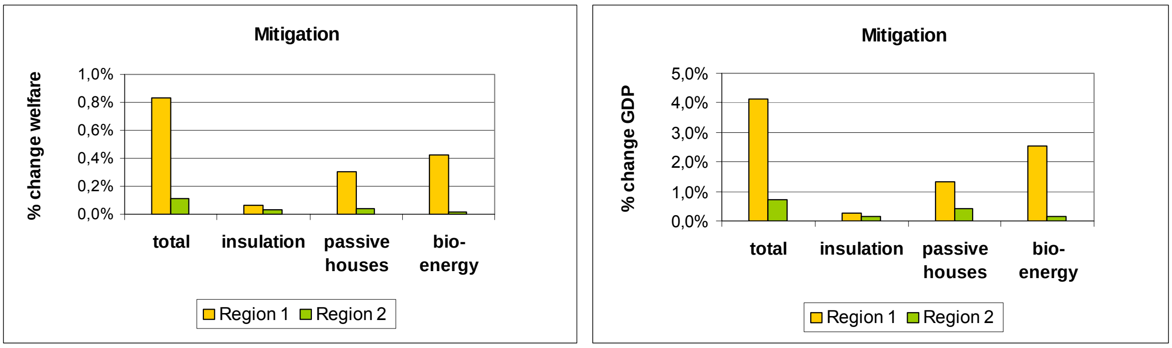


Fig. G-12 : Effects from mitigation on regional welfare (left plot) and GDP growth (right) for Region 1 and Region 2.

Changes are quantified for Scenario 4 relative to the Reference (Scenario 2). Effects are analysed for different mitigation strategies separately (insulation, passive houses, bio-energy) and in total (very left graphics in each plot).

Introducing all three measures simultaneously (with a reconstruction rate of 1.5%) results in an increase of some 4% in regional GDP. The highest contribution accounts for the bio energy (see Fig. G-12). Increasing the reconstruction rate from 1.5% to 3% leads to a total effect of some 5.5% in GDP growth (see Fig. G-13).

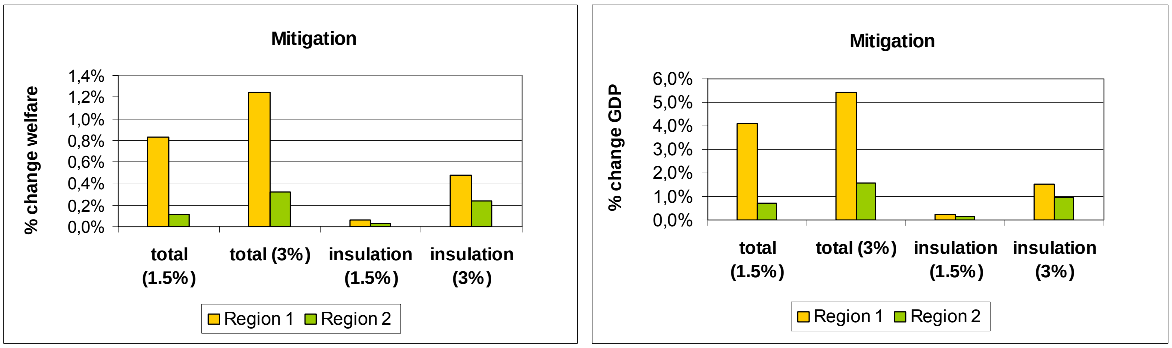


Fig. G-13 : Effects from mitigation on regional welfare (left plot) and GDP growth (right) for Region 1 and Region 2 for different reconstruction rates.

Changes are quantified for Scenario 4 relative to the Reference (Scenario 2). Effects are analysed for different assumptions on insulation (reconstruction rates of 1.5% and 3%, respectively) and in total (including also passive houses and bio-energy).

G-6.4 Sensitivity analysis

A sensitivity analysis is carried out for the following two exogenous variables:

- The Armington elasticity of substitution between home production and imports, which governs the shift in the trade balance due to changes in relative prices. The present analysis changes the elasticity in the sector agriculture. Only global trade flows are concerned.

- The import prices of energy goods, i.e. of coal, diesel, other oil products including gasoline and fuel oil, electricity and gas.

Starting from the baseline level, there is a low and high elasticity scenario and a low and high energy price scenario, respectively. The values are given in Tab. G-15.

Tab. G-15 : Variation in Armington elasticity and energy prices for sensitivity analysis.

The values listed in the “base” scenario equal those in Tab. G-13 used for the BAU.

	scenario		
	low	**base**	**high**
Armington elasticity (global trade)			
agriculture	0.3	0.9	2.7
energy prices (import prices from Region 3)			
coal	+3.05%	+14.5%	+25.95%
diesel, other oil products, gas	+16.1%	+29.0%	+41.9%
electricity	+7.37%	+19.3%	+31.23%

Fig. G-14 shows the sensitivity of changes in GDP growth for the Reference scenario. For both the Armington elasticity and energy prices, higher values lower the negative effects arising from climate change.

In particular, a higher Armington elasticity for agricultural goods allows consumers to shift to imported agricultural goods more easily when domestic goods get more expensive. Moreover, a higher value for the Armington elasticity dampens the negative climate change impact on agricultural production and price level (i.e. the level of production decreases, while prices for agricultural goods and for food rise).

Assuming higher energy prices, lowers overall economic growth. As climate change decreases the number of HDDs (see section G-4.3), the arising effect (i.e. the effect that less money needs to be spent on heating) is more significant if prices for heating are higher, however.

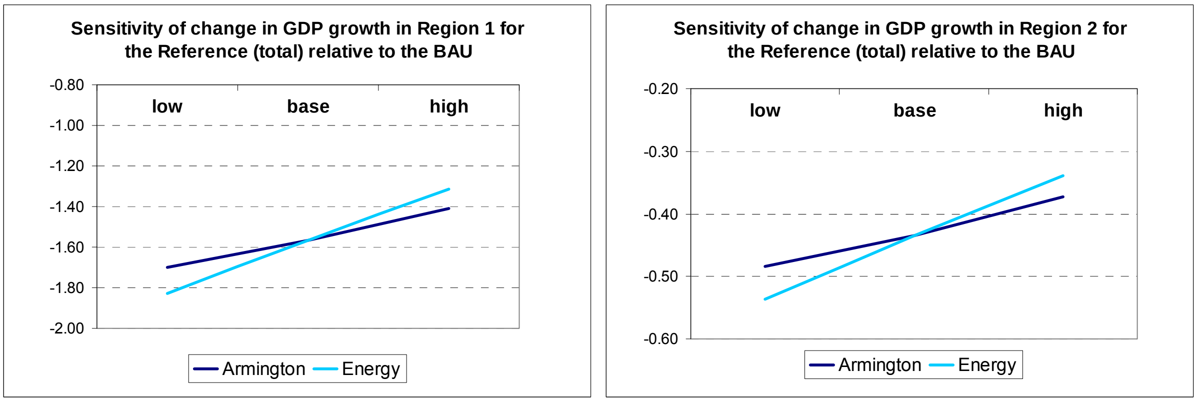


Fig. G-14 : Sensitivity of change in GDP growth for Region 1 (left plot) and Region 2 (right) for the Reference scenario (total) relative to the BAU with respect to the Armington elasticity in agriculture and energy prices.

The partial effects for the Reference (agriculture) and Reference (energy) scenario are given in the Appendix.

When comparing the results for Region 1 and 2, it can be seen that both regions are quite similarly sensitive to changes in the two variables, starting from different levels, however.[29]

The sensitivity analysis for mitigation, comprising the insulation, passive house and bio-energy measure, is shown in Fig. G-15. Almost no sensitivity is found for the Armington elasticity of agricultural goods. This happens for two reasons: First, because it is in principal only the bio-energy measure which affects the agricultural sector, and second, because most bio-energy is assumed to be produced from wooden biomass, not agricultural.

Contrarily, energy prices have a stronger impact on the results from mitigation. Each of the implemented mitigation measures tries to reduce the share of fossil fuels used for heat production. Since high energy prices reflect high prices for fossil fuels, any mitigation measure gets more profitable when energy prices are high.

Because passive house standard and further use of biomass are solely introduced in Region 1, the sensitivity results for Region 2 are mainly caused by spill over effects. In doing so, the sensitivity in Region 2 is less significant compared to Region 1 and is mainly driven by factor price developments triggered by mitigation in Region 1, which spill over to Region 2. The capital price, for instance, increases more under the low energy price assumption compared to the high energy price assumption. Since capital income is part of the households' available income, the GDP increase in Region 2 is higher if a lower energy price is assumed.

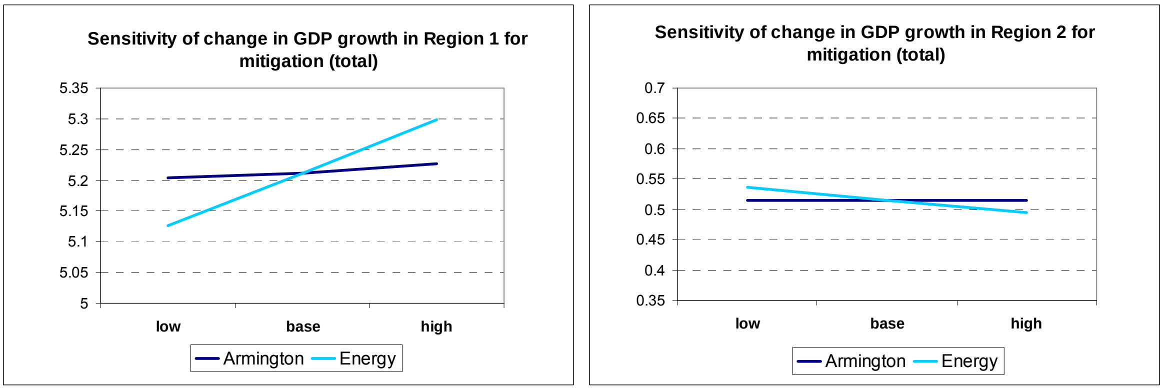


Fig. G-15 : Sensitivity of change in GDP growth for Region 1 (left plot) and Region 2 (right) for the mitigation scenario relative to the Reference with respect to the Armington elascticity in agriculture and energy prices.

The partial effects for the mitigation scenarios (insulation, passive houses, bio-energy) are given in the Appendix.

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[29] Since Region 2, for example, has a relatively smaller agricultural sector, the impacts from climate change on agriculture affect the economy of Region 2 to a smaller extent.

G-7 Conclusions and outlook

Within STERN.AT the project team sought to improve and develop methods for regional impact analysis, i.e. the regional climate downscaling, the multi-regional economic modelling and their respective integration interface. For this aim, a highly resolved climate scenario was developed and coupled with sectoral analyses for agricultural and energy production. The results of this linking served as inputs for a regional economic model, quantifying the socio-economic impacts of localised climate change for a study region in Austria.

The coupling of models (climate model, sectoral sub-models and CGE model) gave valuable insights such as direct economic effects and indirect effects via sectoral interdependencies. It assessed the sensitivity of a region with respect to climate factors relative to other factors (such as the price of oil). The modelling evaluated the direction and magnitude of effects (climate impacts, effects from mitigation and adaptation) relative to an assumed business as usual scenario, whereas no concrete forecasts were carried out.

The present study was a pre-feasibility study to reveal possible regional modelling approaches based on methods and concepts used in the Stern Report. STERN.AT assessed the methodological feasibility of such a modelling approach. At the same time this study estimated the data availability for such a modelling. On the one hand, the present project built on existing competences regarding regional assessment for e.g. energy demand for heating and cooling, while other regional forecasts (such as e.g. the biomass potential) were not available.

Moreover, the study made assumptions on future developments, both local and global such as factor productivity growth or development of energy prices. It was difficult, however, to assess the differing development of each sector (or group of sectors) in the near future and thus to find out an optimal adaptation strategy for the most vulnerable sectors of the economy modelled. In addition, difficulties arose when this sector-specific development had to be differentiated for a rural (SE Styria) and a (peri-)urban region (the rest of Styria comprising the capital Graz). Global trends such as the development of the oil price were covered by conducting a sensitivity analysis to show deviations in the results. Finally, uncertainty, such as the occurrence of future weather extremes, was not explicitly considered.

STERN.AT demonstrated how local and regional climate impacts as well as adaptation and mitigation could be modelled. The quantification of the costs of climate change is inherently a local question, because regions differ by climate impacts, vulnerability and adaptation options. An important point was to comprehensively model sectoral interdependencies – which are to a large extent left out in global models -, since (regional) climate impacts and the costs of adaptation vary considerably among economic sectors.

Initial research in climate change did often report too high damage volumes, as adaptation efforts were not taken into account. STERN.AT addressed this aspect by modelling the adaptation responses of producers and consumers. In agriculture, for example, policy-induced adaptation was modelled via the concept of “efficiency land” assuming a constant output per acre of land. Climate impact or adaptation, such as the mixed cultivation of crops, influenced the availability of efficiency land. Depending on the scope of climate change, the amount of available efficiency land varies. While efficiency land decreases with drought and high temperatures, it rises with adaptation of farmers to climate change. Thus, the assessment of impact and adaptation needs particular modelling elements for each sector, which was not obvious at the beginning of the project.

The modelling of mitigation required a tailored approach for each measure. Mitigation in the housing sector, i.e the improved insulation for dwellings or an increase in the number of passive houses, needed the specification of an alternative cost structure for the CGE model. A fraction of heat demand was hereby substituted by the new cost structure. This substitution included information on future developments in the housing sector as well as very specific assumptions on e.g. the extent and type of newly insulated homes. Similarly, the modelling of mitigation via enhanced use of biomass for heat production required the specification of cost structures for bio-energy. A fraction of heat demand was then assumed to be provided by biomass at now changed costs. Moreover, the CGE model had to be extended for a technological process-specific analysis by specifying discrete biomass energy technologies that allowed for the substitution of fossil-based one. Equally, future developments of the region such as the biomass potential had to be assessed.

A prime interface between the CGE model and the managerial optimisation model for agriculture used in STERN.AT (FAMOS) was established by assessing the agricultural production level and the corresponding input structure required for the CGE model. An improvement of this interface would be to include e.g. progress in plant breeding at firm level in the FAMOS model runs. Currently, productivity changes in agriculture are only modelled at the sectoral level with the CGE model.

Within the general discussion on the Stern Review, both on methods and results, STERN.AT pointed out the relevance of regional analysis. As there is disagreement on damage costs (with respect to the choice of the interest rate, the choice of time horizon and the assessment of future damages), it became clear that certain factors are key to different assessments of damage costs. They include, firstly, the correct characterisation of temperature changes with respect to the time period (annual, seasonal, monthly, daily) and with respect to scale (global, national, regional, local). Secondly, the assumed relationship between meteorological parameters, in particular temperature, and crop yield strongly affects results. Furthermore, local impacts will turn out significantly more pronounced as regions are diverse. Thus, climate impacts on the physical world in a country like Austria – with small scale heterogeneity of topography and land use -, should be carried out at the local scale.

STERN.AT also showed where the applied regional modelling approach could be advanced. Regarding the regional modelling of agricultural output, a more physical based model would be a useful alternative to the linear regression approach. Furthermore, the regression crop yield model could be expanded including not only mean temperature and precipitation, but e.g. a drought index and indices for extreme events. In addition, crop yields in organic farming under other management practices could be included.

Regarding the regional modelling of the energy sector under climate change, the energy supply, which was only covered by regional bio-energy supply, could be extended. This involves in particular changed precipitation and evaporation, as most of the energy in the study region is produced by small hydro power plants (SHPPs). A preliminary assessment of adaptation options for SHPPs has been done in Prettenthaler et al. (2006a). The analysis of the energy sector as in Prettenthaler et al. (2006a) could be carried out for the whole study region. Data on the output of representative SHPPs in SE Styria would be available from Small Hydro Power Austria (personal communication with Martina Prechtl, CEO of Small Hydro Power Austria, October, 2007). The required meteorological data could be provided by the ZAMG and prepared by the ReLoClim Group at the WegC. Thus, changes in energy output under future climate scenarios could be assessed.

Another extension of the modelling approach would be to assess uncertainty. This would, however, require a probabilistic distribution of the forecasted parameters temperature and precipitation, which was not available so far.

Finally, the sectors tourism and infrastructure should be included. Currently, there is only a poor database available for an analysis of these two sectors. The tourism in SE Styria is mainly a spa tourism, which is highly dependent on water supply. The main data source for economic damages in the SE Styrian tourism sector as well as adaptation is Prettenthaler and Dalla-Via (2007). An interesting research question would be to analyse the effects of weather variabilities on the number of guests in thermal baths. Moreover, regarding infrastructure there is a fairly poor database for possible climate related damages. This would therefore be an additional data gap in regional climate modelling to be filled.

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List of abbreviations

BAU	business as usual
CAP	Common Agricultural Policy of the European Union
CDD	cooling degree day
CES	constant elasticity of substitution
CGE	computable general equilibrium
FACE	free-air CO_2 enrichment
FAMOS	Farm Optimisation System (Schmid, 2004)
GDP	gross domestic product
GHG	greenhouse gases
HDD	heating degree day
IAM	integrated assessment model
IIASA	International Institute for Applied Systems Analysis, Laxenburg, Austria
IOT	Input-Output table
NACE	statistical classification of economic activities in the European Communities
NPP	net primary production
ÖNACE	Austrian version of the NACE (↑) classification
ÖNORM	Austrian standards
ÖPUL	Austrian subsidy programme for environmentally oriented agriculture
PTP rate	rate of pure time preference
R&D	Research and Development
ReLoClim	Regional and Local Climate Modeling and Analysis
ROW	rest of the world
SAM	social accounting matrix
SE Styria	South-East Styria
SCC	social cost of carbon
SHPP	small hydro power plant
STERN.AT	acronym for the present StartClim2007.G project
TJ	terrajoule (terra = 10^{12}; joule is the International System (SI) unit of energy measuring heat, electricity and mechanical work)
WegC	Wegener Centre for Climate and Global Change, University of Graz
WIFO	The Austrian Institute of Economic Research, Vienna
ZAMG	Austrian Central Institute for Meteorology and Geodynamics, Vienna

Appendix

Tab. G-16 : The 41 sectors of the economic model.

The sectors are classified by ÖNACE double-digit codes (see Statistics Austria, 2003). Two codes represent a range of subsections (e.g. 1014 for sectors 10 to 14). Italic numbers (i.e. sectors 1014, 23 and 40) show double-digit codes that have been further disaggregated to model the energy sector more comprehensively.

Sector	**Description**
01	Agriculture, hunting
0205	Forestry, fishing, fish farming
1014	*Mining and quarrying: coal*
1014	*Mining and quarrying (except of coal)*
1516	Manufacture of food products and beverages; manufacture of tabacco products
1719	Manufacture of textiles; manufacture of wearing apparel; manufacture of leather and leather products
20	Manufacture of wood and wood products (except of furniture)
21	Manufacture of pulp, paper and paper products
22	Publishing, printing and reproduction of recorded media
23	*Manufacture of coke, refined petroleum products and nuclear fuel: diesel*
23	*Manufacture of coke, refined petroleum products and nuclear fuel (except of diesel)*
24	Manufacture of chemicals and chemical products
25	Manufacture of rubber and plastic products
26	Manufacture of glass and glass products, manufacture of other non-metallic mineral products
2728	Manufacture of basic metals and basic metal products; manufacture of fabricated metal products
29	Manufacture of machinery
3033	Manufacture of office machinery and computers; manufacture of electrical and optical equipment
3435	Manufacture of motor vehicles, trailers and semi-trailers; manufacture of other transport equipment
36	Manufacture of furniture, jewellery, musical instruments, sports goods, games and toys and other
37	Recycling
40	*Energy supply: electricity*
40	*Energy supply: district heating*
40	*Energy supply: gas*
41	Water supply
45	Construction
5052	Wholesale and retail trade; maintenance and repair of motor vehicles and of personal and household goods
55	Hotels and restaurants
60	Land transport, transport via pipelines
6162	Water transport; air transport
63	Supporting and auxiliary transport activities, activities of travel agencies
64	Post and telecommunications
6567	Banking and financial intermediation; insurance and pension funding
7071	Real estate activities; renting of machinery and equipment without operator
72	Computer, data processing and data bases
7374	Research and development; other business activities
75	Public administration and defence, compulsory social security
80	Education
85	Health and social work
90	Sewage and refuse disposal, sanitation and similar activities
91	Activities of membership organizations (lobbies, religious, political and other organizations except social, cultural and sports)
9295	Recreational, cultural and sporting activities; other service activities; activities of households as employers of domestic staff

Tab. G-17 : Productivity changes and Armington elasticities per sector as assumed for the BAU scenario 2045.

Source: EU KLEMS (2007) (for productivities). Welsch (2008) (for Armington elasticities); for the service sector, a rather small elasticity of substitution is assumed (0.3 for regional and 0.2 for global trade).

sector (ÖNACE)	**change in productivity**	**Armington elasticities**	
		regional trade	global trade
01	0.9510	1.2000	0.9000
0205	0.8780	0.4465	0.2977
1014	0.8780	0.0390	0.0260
1014	0.8780	0.7995	0.5330
1516	1.2458	0.8910	0.5940
1719	1.2458	1.2000	0.8000
20	1.2458	0.5025	0.3350
21	1.2458	0.1500	0.1000
22	1.2458	0.4688	0.3125
23	1.2458	0.0390	0.0260
23	1.2458	0.0390	0.0260
24	1.2458	0.6000	0.4000
25	1.2458	2.2500	1.5000
26	1.2458	0.3365	0.2243
2728	1.3814	1.2000	0.8000
29	1.6026	1.2000	0.8000
3033	1.9365	0.2250	0.1500
3435	1.7838	0.3000	0.2000
36	1.2458	0.5025	0.3350
37	1.2458	0.3000	0.2000
40	0.8780	0.0390	0.0260
40	0.8780	0.0390	0.0260
40	0.8780	0.0390	0.0260
41	0.8780	0.3000	0.2000
45	0.8830	0.5025	0.3350
5052	1.3666	0.3000	0.2000
55	0.8382	0.3000	0.2000
60	1.3666	0.3000	0.2000
6162	1.3666	0.3000	0.2000
63	1.3666	0.3000	0.2000
64	2.4100	0.3000	0.2000
6567	2.0798	0.3000	0.2000
7071	2.0798	0.3000	0.2000
72	2.0798	0.3000	0.2000
7374	2.0798	0.3000	0.2000
75	0.8321	1.8000	0.2000
80	0.5770	1.8000	0.2000
85	1.3387	1.8000	0.2000
90	0.4383	0.3000	0.2000
91	0.4383	0.3000	0.2000
9295	0.3140	0.3000	0.2000

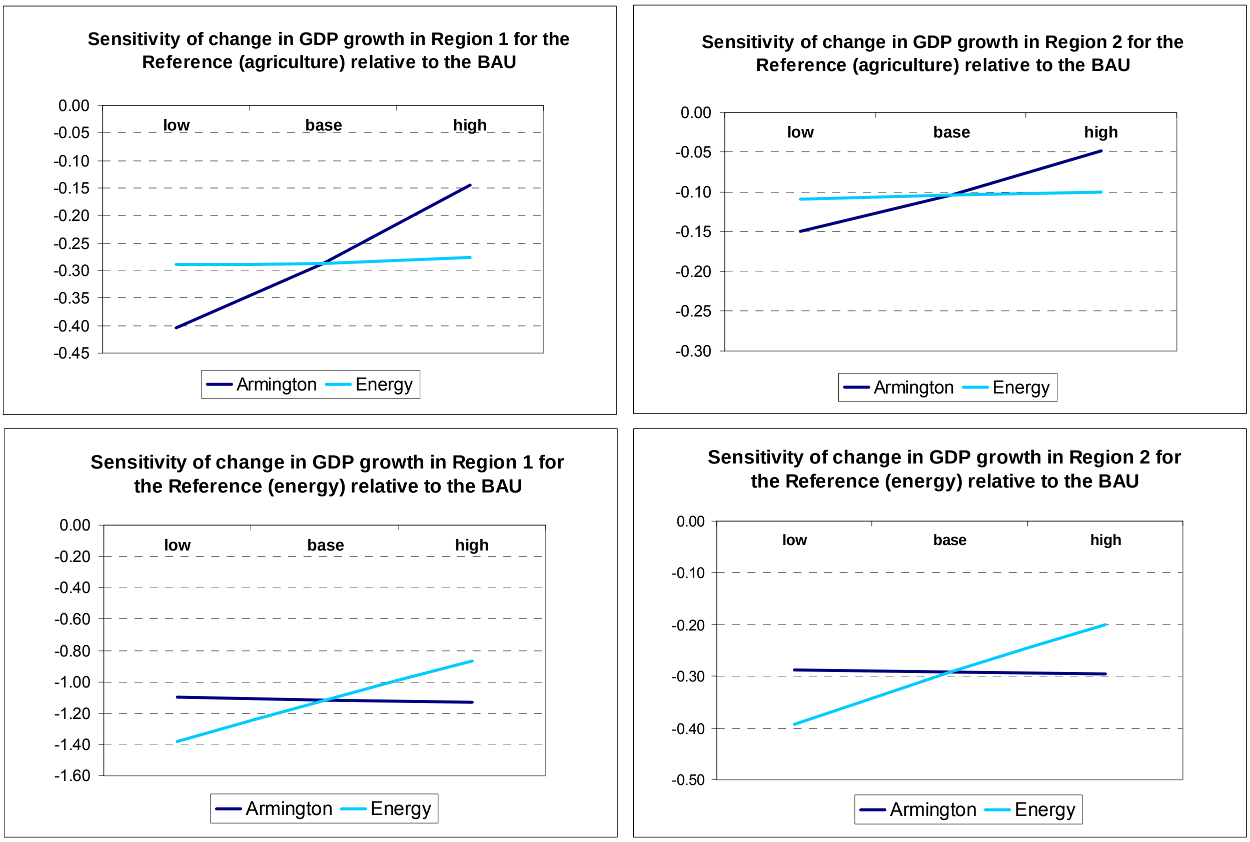
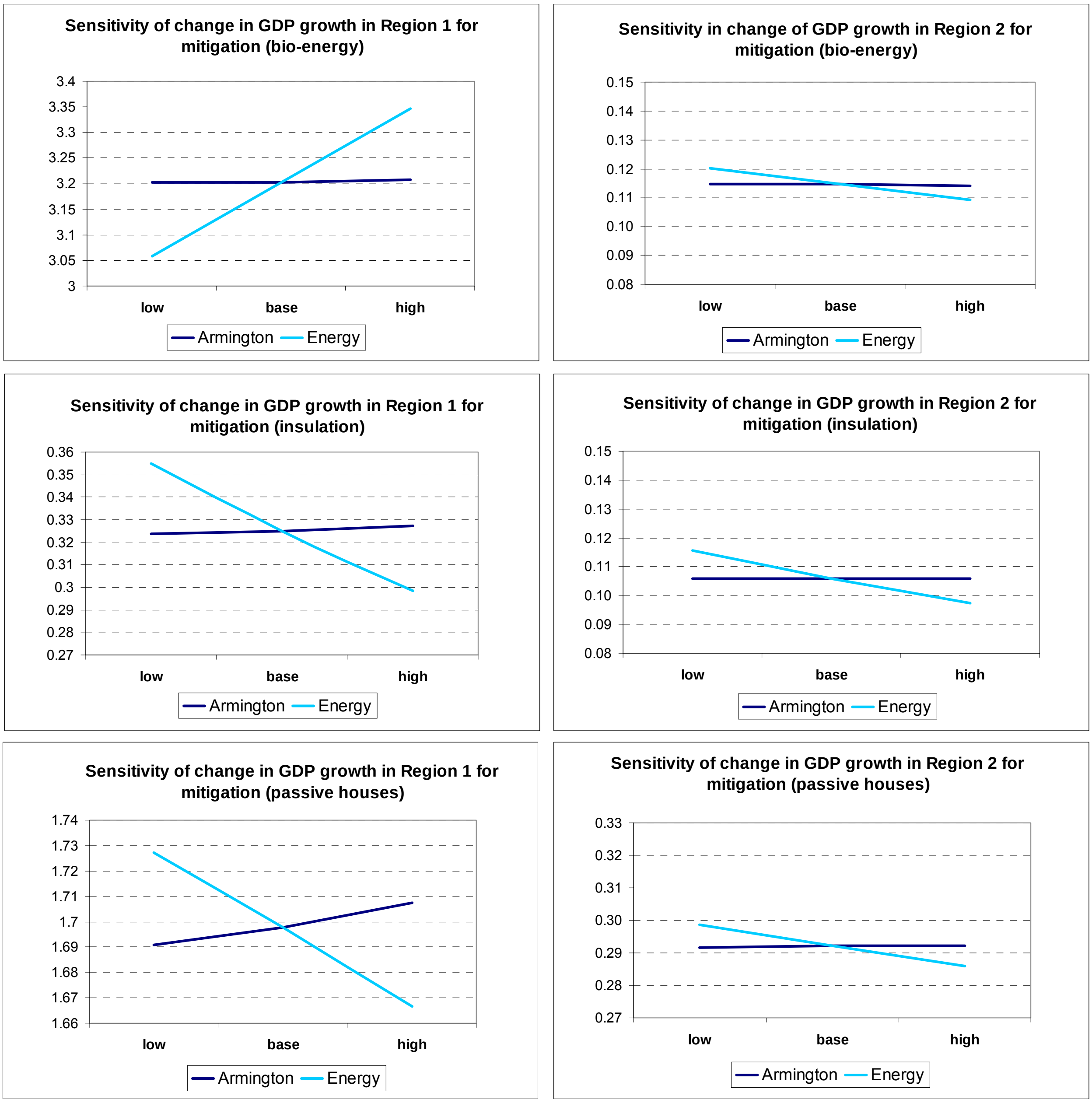


Fig. G-16 : Sensitivity of change in GDP growth for Region 1 (left plot) and Region 2 (right) for the Reference (agriculture) and Reference (energy) scenario relative to the BAU with respect to the Armington elascticity in agriculture and energy prices.



Sensitivity of change in GDP growth in Region 1 for mitigation (bio-energy)

Sensitivity in change of GDP growth in Region 2 for mitigation (bio-energy)

Sensitivity of change in GDP growth in Region 1 for mitigation (insulation)

Sensitivity of change in GDP growth in Region 2 for mitigation (insulation)

Sensitivity of change in GDP growth in Region 1 for mitigation (passive houses)

Sensitivity of change in GDP growth in Region 2 for mitigation (passive houses)

Fig. G-17 : Sensitivity of change in GDP growth for Region 1 (left plot) and Region 2 (right) for the mitigation scenarios (bio-energy, insulation, passive houses) relative to the Reference with respect to the Armington elasticity in agriculture and energy prices.