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Adequacy of Mitigation and Adaptation Options for a Case Study Region in Austria
The Case for Agriculture and Forestry

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Outline

Executive Summary

In this research project a scheme of mitigation and adaptation strategies for a case study region in Austria is developed and quantitatively assessed. In particular, the project aims to analyze the relationship between mitigation and adaptation strategies in a regional context, i.e. economic impacts from viable climate response strategies shall be assessed. Concerning mitigation the focus is on fostering the use of biomass as energy carrier in order to substitute fossil energy resources in heat production. Mitigation is also considered in terms of better manure management and consequently reduced amounts of commercial fertilizers used in agricultural production. Adaptation strategies are considered in the agricultural sector by using new crop varieties and technologies in order to reduce adverse impacts from climate change and thus stabilize agricultural output. The wider Feldbach region in South-Eastern Styria (at NUTS 3 level, embedded within Styria, NUTS 2 level), which is among the most productive agricultural production regions in Austria, is selected as a case study for the present regional analysis. Where necessary, the developments in the surrounding region Styria are also explored.

In section 1 mitigation and adaptation response strategies to climate change are presented. In particular, section 1.1 describes target areas, policy instruments and sectoral approaches for mitigating greenhouse gas emissions. The reduction of emissions through changes in energy use, technologies and/or behaviour are crucial for the stabilisation of atmospheric greenhouse gas concentrations and thus for limiting climate change. These measures have, however, to be analysed in a wider context. This requires that, on the one hand, the interrelations of mitigation and adaptation are taken into account (e.g. regarding land use and land use changes or agro-forestry) and, on the other hand, synergies with other policy objectives (e.g. energy security) and (long-term) ancillary benefits of mitigation measures are also considered. The preliminary, non-exhaustive description illustrates the wide range of (available) options for limiting greenhouse gas emissions from various sectors and activities. Section 1.2 gives a synoptical overview of the broadly discussed adaptation issue within a European context. The purpose of adaptation is to reduce vulnerability, thereby, enhancing the adaptative capacity and lessening many adverse impacts that may arise from climate change. The report delineates key areas to be addressed when designing adaptation strategies in the agricultural and forestry sector. These include sustainable soil and land management, sustainable water management, forestry as well as technical equipment and infrastructural issues. From here, an adaptation strategy to be modelled will be selected.

One prerequisite to develop and assess adequate adaptation options is the existence of spatially detailed information on past and expected climate change impacts. Section 2 presents a highly resolved regional climate scenario derived via downscaling techniques, which provides basic information about future climate conditions in the study region (period 2041-50). The scenario indicates e.g. monthly temperature changes, precipitation changes as well as the temporal shift in the occurrence of frost days.

Assessing the relationship between mitigation and adaptation strategies in a regional context, an attempt is made to derive the mitigative potential of regional biomass supply. I.e. the additional regional biomass potential for the future is estimated under specific assumptions on structural, legal and political conditions. Together with the regional energy demand by households for space heating, which is estimated for 2030 and 2045, the fraction of additional bioenergy in total regional energy demand is assessed. Depending on the assumed level of biomass potential (low, base, high), between 21% and 23% of regional energy demand by households are found to be supplied by additional biomass in South-Eastern Styria by 2030 (10% forestry, 13% agricultural). These values rise to some 27% to 33% by 2045 (10% forestry, 23% agricultural) (section 3).

In section 4, a cost analysis of biomass energy production and biomass home heating options is presented. It investigates the effectiveness of different single home heating systems. Given the current oil price, biomass technologies based on wood (chips, logs or pellets) are cost efficient mitigation options in the heating sector while technologies based on agro pellets (miscanthus) are not. However, systems based on agricultural biomass are only profitable with a high space heat load with investment costs being very high. Furthermore, the effectiveness of heating systems might change considerably under future conditions considering changed energy prices and technological developments.

In order to assess the options and effects of mitigating climate change and adapting to its impacts in a regional setting, a multi-regional CGE model is developed (section 5). The model is first built in stylized form and then calibrated to the selected Austrian study region in South-Eastern Styria, whereby the year 2003 is taken as a reference. A quantitative assessment of a biomass extension differentiated by technology for the reference year 2003 is carried out. GDP and employment effects strongly depend on production costs, in particular labour demand and energy intensity, infrastructure investments and – especially for agricultural based technologies – cropland requirements. Wood based heat services (logs, chips, pellets) in general show a higher combination of GDP and employment effects than agricultural based ones.

In section 6, starting from the baseline 2003, a Reference Scenario for 2045 (as representative for the 2040ies) is developed without considering climate change impacts as a first step, before also taking into account the impacts from a change in climatic conditions. Based on this Business As Usual Scenario (including climate change impacts as well as autonomous adaptation), three policy scenarios are constructed simulating different response strategies to climate change (adaptation, mitigation, and mix of both). Moreover, an analysis is carried out to explore the region's mitigative potential in terms of renewable resources. The focus of policy intervention is on the agricultural and forestry sectors with a crucial link to the energy sector in terms of altered energy provision via expanded biomass.

Section 7 presents the quantitative results from the simulations developed in section 6 in terms of economic indicators such as regional GDP, welfare and unemployment as well as in terms of sectoral effects. Importantly, results are analysed as deviations from a reference level but not understood as a forecast. Under the very specific assumptions of the regional modelling approach the following results are found for South-Eastern Styria (with negligible feedback effects for Styria): The impacts of altered climatic conditions by 2045 slightly decrease the economic performance and thus increase unemployment in the study region, since agriculture faces a productivity loss affecting also downstream sectors. Applying adaptation and mitigation measures separately, both response strategies generally increase regional GDP thereby reducing unemployment. While the analysed mitigation measure is found to raise welfare, under policy-induced adaptation the level of welfare tends to fall (as a consequence of lower net private consumption due to decreasing land rents and an elevated government consumption driving up consumer prices). A mix of mitigation and adaptation activities in the region, however, boosts the economy's GDP and employment levels. Furthermore, exploiting the region's biomass potential up to 2045, some 38% of regional household demand for heating can be supplied out of biomass, thereby enhancing GDP in the region by some 3.2 % and welfare by 1.1%.

Given these results, adaptation and mitigation strategies represent an opportunity for business to create value and employment and to improve the economic performance of the local region. At the same time, these strategies lay the foundation for a low-carbon growth and, therefore, can be judged as sustainable climate response measures (section 8).

Section 8 summarizes, concludes and outlines the path for future research based on the results obtained within this project.

Moreover, in the Appendix, two technologies (a forestry based and an agricultural based one) are tested for their sensitivity with respect to energy prices for a biomass expansion in the future. The analysis shows an improvement in economic performance (GDP, employment) for both heating systems, yet with a stronger development from the use of the agricultural based one requiring relatively less labour and diesel in production.

1 Mitigation and adaptation as response strategies to climate change

With increasing pace and severity of climate change, societies worldwide have to adapt to its impacts. A certain degree of climate change impacts is inevitable throughout this century and beyond, even if global mitigation efforts will prove successful. Adaptation, however, has its limits. Once certain climate thresholds are exceeded, climate impacts, e.g. ecological and social disruptions, are expected to become severe and irreversible. Therefore, adaptation and mitigation are indispensable complements to each other. Article 2 of the UNFCCC therefore applies: "The ultimate objective of this convention [United Framework Convention on Climate Change] ...is to achieve ... stabilisation of greenhouse gas [GHG] concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure food production is not threatened and to enable economic development to proceed in a sustainable manner" (*UNFCCC,* 1992). The majority of scientists now agree that if global warming exceeds a mean temperature rise of 2 °C above pre-industrial level, it will lead to dangerous, irreversible and unmanageable consequences for mankind. Therefore, 133 countries, including the 16 major economies and the European Union, have acknowledged the significance of this temperature limit and many follow this guardrail in their considerations of mitigation and adaption strategies towards climate change (*WBGU,* 2009a; *EEA,* 2008).

Subsequent sections draw a synopsis of the state of the art in mitigation and adaptation strategies towards climate change with a focal perspective towards the agricultural and the forestry sector.

1.1 Mitigation

The reduction of greenhouse gas emissions (mitigation[1]) in order to ensure a stabilisation of the concentration of carbon, methane and other greenhouse gases in the atmosphere and limit the progress of global warming has become a central environmental policy target on the domestic and international agendas. Emissions abatement mainly deals with decarbonising the energy system. But issues of removing sources and improving sinks of GHG emissions from land use, land use change and forestry are as well important. Mitigation can be achieved through a variety of measures that are to be applied in all areas of the economy and society. The main drivers for emissions are the level and development of economic activity, the energy intensity (energy use per unit GDP) and the carbon intensity of the energy source. Key approaches to influencing energy use and related carbon emissions hence include technological improvements and innovations as well as changes in production and consumptions patterns. Mitigation is closely interrelated with broader socio-

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[1] Anthropogenic intervention to reduce the sources of greenhouse gases or enhance their sinks.

economic policies and trends and must therefore be analysed in a wider context, taking into account other policy objectives, possible synergies and non-climate change impacts (see for example *Krupnick et al.*, 2000, *IPCC*, 2001, *Jochem – Madlehner*, 2003). These include economic issues like the security of energy supply and the reduction of the dependency on imported fossil fuels or growth and employment potentials through an ecological tax shift and the increased use of domestic renewable energy sources. Besides, other (non-monetary) ancillary benefits have been increasingly discussed in climate policy literature. These regard positive health effects and improvements in environmental quality due to the simultaneous reduction in conventional air pollutants (e.g. particulate matter), protection of forests, soils and water sheds that also serve as recreational areas or the reduction in congestion and road-use related fatalities.

1.1.1 Target areas and policy instruments for mitigation

Fig. 1 summarises the portfolio of available mitigation options for the main sources of greenhouse gas emissions from energy combustion. In 2005, industry and transport each had a share of 26% on total emissions in Austria, energy generation (electricity, heat, refineries) and heating by households and businesses each contributed around 17%[2].

The sectoral mitigation options can largely be classified in three categories:

- changes in energy inputs used (fuel switching),
- behavioural changes,
- development and deployment of efficient technologies.

One obvious mitigation option is to switch from emission intensive energy sources to low or zero carbon alternatives. Examples are the substitution of coal and oil by natural gas, the increasing use of renewable energy sources[3] for the generation of heat and electricity and also the blending of biofuels with diesel and petrol. The emissions from natural gas for example are 40% lower than those from burning coal and conversion efficiency is generally higher in gas-fired power plants (*Netherlands Environmental Assessment Agency*, 2006). This approach can generate substantial emission reductions in the short to medium term and represent a relatively low cost mitigation option until other efficiency technologies become available at competitive prices. However, natural gas is still an exhaustible resource and does not contribute to improving the security of supply as do renewable energy sources. In this context the role of biomass as a domestically produced energy source for heat, electricity and transport has been intensively discussed recently (for an economic impact analysis see *Kletzan et al.,* 2008; for an overview on the potential of biomass in the mobility sector see *Meyer – Scheffran,* 2008; *Weizsäcker,* 2008). Biomass is said to have some potentials for substituting fossil fuels and reduce emissions but still the realistic contribution has to be assessed and resources have to be used in a cost-efficient and sustainable way (*WBGU,*

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[2] The remaining 13% could be attributed mainly to agriculture and waste management.

[3] The EU has set a target to increase the share of renewables in primary energy use to 20% in 2020.

2009b). This concerns the limited availability of land and water (competition with food production), the production of biomass for energy use in an environmentally compatible way and the consideration of other environmental needs (e.g. conservation areas, biodiversity, water management etc.). Given these limitations for supply of bioenergy, resources should be distributed to cost-efficient uses. Research results (see for example *Sachverständigenrat für Umweltfragen*, 2007) suggest that the stationary use of biomass for power and heat generation (especially in co-generation plants) is preferable to its use as transport fuel as the conversion efficiency is higher and negative effects from biomass production are lower[4]. However, it is not adequate to give generalised recommendations as the production and use of bioenergy and/or biofuels is energy- und cost-efficient in some countries/regions but may not be so in other regions and under different institutional settings (*Worldwatch Institute*, 2007; *Rosillo-Calle*, 2007). Hence region-specific conditions and potentials to produce and employ biomass to generate low-carbon electricity, heat and mobility services need to be analysed in detail on a case-study basis.

The role that can be played by other renewable energy sources like hydropower, wind or solar and geothermal energy depends on which time frame is considered and which assumptions on future economic and market conditions are made. Although these renewable sources are currently still among the more expensive mitigation options, substantial reductions in costs are predicted and have already been observed (e.g. in wind turbines). The competitiveness of these energy sources also depends on the price differential with respect to fossil fuels and on research and development efforts in this technological area.

However, the resulting decline in carbon intensity of energy use through fuel switching will not be sufficient to reach the defined climate policy targets, especially if energy consumption continues to rise. Between 1990 and 2005 final energy consumption increased by 44%, with the most considerable growth in transport (+76%) which currently has the largest share in energy use of nearly one third.

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[4] For electricity and heat generation mostly wood biomass or wood waste are used. Transport fuel production in comparison is largely based on crops like rapeseed and corn that entail negative environmental effects (fertiliser use, irrigation, etc.) and are expected to compete in land for food production.

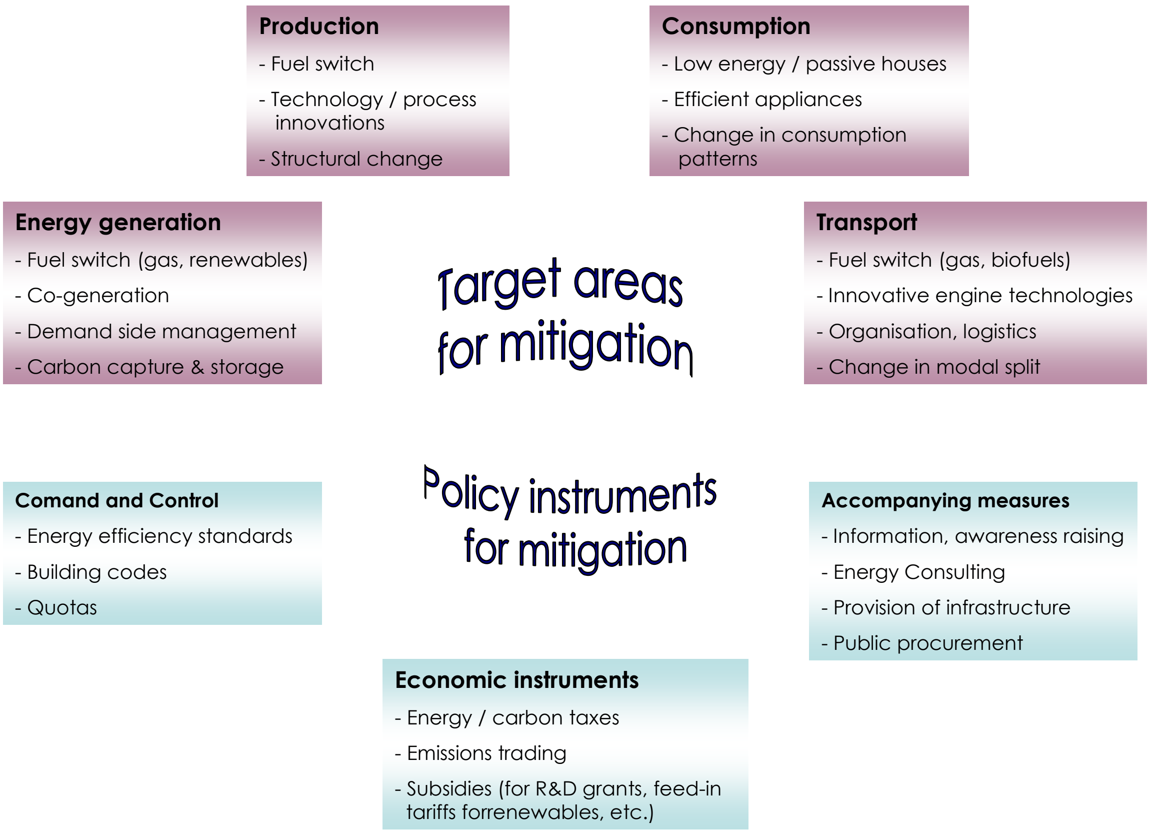

Fig. 1 : Target areas and policy instruments for mitigation measures

Thus, further interventions are needed that, on the one hand side, improve the energy efficiency of production and consumption activities and, on the other hand side, affect the level of activities or their structure. In certain areas a reduction in the activity level, i.e. in redundant energy services consumed, will be feasible. For example, in goods traffic the number of empty runs can be minimised by enhanced organisation and logistics, traffic and congestion in urban areas can be reduced by telecommuting or improved public transport. But as (voluntary) behavioural changes will presumably only bring about limited emissions reductions (*Dietz et al.*, 2009) and restricting economic activity is not a desirable mitigation option, energy efficient technologies and innovation will have to play a major role. Examples include highly efficient co-generation plants for the joint production of heat and electricity or low energy and passive houses that can reduce the energy demand for heating by as much as 90% compared to the average building stock in Austria[5]. These technologies are already available but have not yet been widely used due to their higher costs relative to conventional alternatives. Other technological mitigation options are still in the phase of research, development and demonstration. These include innovative propulsion technologies on the basis of fuel cells or electric motors, zero emission processes for industry or clean coal

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[5] The average dwelling in Austria has an energy demand for heating of around 180 kWh/m2/a. Low Energy houses require at most 40 kWh/m2/a, passive houses 15kWh/m2/a.

electricity generation with carbon capture and storage. These options are not ready for market penetration and in some cases – e.g. carbon capture and storage – connected with a high degree of uncertainty, i.e. regarding the amount of CO_2 that can be stored in reservoirs (e.g. depleted oil or gas fields), the period of storage, i.e. how long it would stay trapped or whether the CO_2 would leak to other formations. The uncertainty about leakage and environmental effects as well as the currently high costs suggest (*Newell et al.*, 2006) that carbon capture and storage might only be a medium-term option and represent a temporary storage until other means of permanent mitigation technologies are being developed.

In general, research and development in technologies that improve the efficiency of end use devices and energy conversion technologies are of great importance. As the IPCC stated already in 2001 "...*known technological options could achieve a broad range of atmospheric CO_2 stabilisation levels*...", i.e. technologies that exist in operation or pilot plant stage. But in order to affect emissions considerably not only the average efficiency of new technologies has to increase, also the diffusion of these innovations and the stock turnover has to accelerate since emissions are mainly driven by the existing stock of capital combined with the intensity of use (*Newell et al.*, 2006).

The necessary technological and behavioural changes to obtain the required substantial decrease in emissions have to be incentivised by climate policy. And as a variety of mitigation measures will have to be applied, climate change policy will be most effective if a portfolio of policy instruments is deployed.

The portfolio of national policy approaches includes economic instruments like carbon/energy taxes, tradable permits and the introduction or removal of subsidies[6]. A second category of policy instruments are command and control type instruments like technology or performance standards, zoning regulations or energy mix requirements. In addition, other approaches include information and awareness raising campaigns, energy audits, public or publicly funded research and development, the provision of infrastructure (e.g. for public transport) and the exemplary function of public procurement. Standards and regulations are widely used, but in recent years the introduction of market-based instruments like the EU emissions trading scheme or ecological taxes or tax reforms has increased. Alternative types of policy instruments will have different effects on various target groups or on the rate and direction of technological change[7]. Empirical analyses typically show that economic instruments are more efficient in providing incentives and changing behaviour than conventional regulation (*Newell et al.*, 2006). In addition, taxes and auctioned tradable permits generate revenues that can be used to lower other taxes (usually on labour) and, thus, reduce market distortions and negative tax interaction effects (*Krupnick et al.*, 2000) or can be recycled through energy efficiency or R&D subsidies. The latter offer the possibility to

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[6] For a discussion of environmentally harmful subsidies in Energy see *Kletzan and Köppl,* 2004.

[7] For an extensive discussion of climate policy instruments and their impacts see *Stern* (2007).

shape technological change in coherence with climate policy and sustainable development objectives, which can be further supported by a combination with incentives for a premature retirement of the existing capital stock in all areas of the economy (e.g. carbon pricing or regulations). A comprehensive policy approach regarding research, development and diffusion of environmental technologies can generate positive ancillary effects not only in terms of reducing energy costs and, thus, enhancing firms' competitiveness but also regarding fist-mover advantages for the innovating firms and possibilities for exporting the technologies.

1.1.2 Sectoral mitigation options

As described above, a wide variety of measures can be applied in order to abate carbon emissions in various sectors (see *Edmonds,* 2004, *Edmonds et al.,* 2004; *Pacala – Socolow,* 2004; *Metz – Van Vuuren,* 2006; *Enkvist et al.,* 2007). These measures include structural changes in the energy system, fuel switch and energy saving approaches in energy conversion and end use activities. In addition, the storage of carbon either in geological formations (carbon capture and storage) or in natural sinks (afforestation, reforestation, avoided deforestation) represents an option for emission reduction. Energy related measures regard either the improvement of efficiency of energy use or the reduction of emissions caused by the use of energy through structural changes in the energy system and the storage of emissions.

As highlighted by Pacala – Sokolow (2004) the deployment of existing technologies (grouped into seven "technology or stabilisation wedges") can lead to a stabilisation of greenhouse gas emissions over the next 50 years (as illustrated Fig. 2). After that the broad diffusion of innovative technologies is required to reach the necessary concentration goals. Each of the technology categories that are available in the short term – even if some are not yet broadly diffused and cost intensive[8] – can make a significant contribution to the mitigation of emissions. Here, a broad spectrum of measures is considered that comprises energy efficiency improvements in buildings, traffic and energy generation, a reduction of the emission intensity of energy generation (natural gas instead of coal, renewable energies, nuclear energy), carbon capture and storage as well as reforestation measures. According to Pacala – Sokolow (2004), the challenge consists in the broad application of the available technologies for one, and for another in the initiation of a large-scale, climate-relevant research and development (R&D).

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[8] Cf. *Grubb* (2004) about the cost digression as a result of learning effects for environmental technologies.

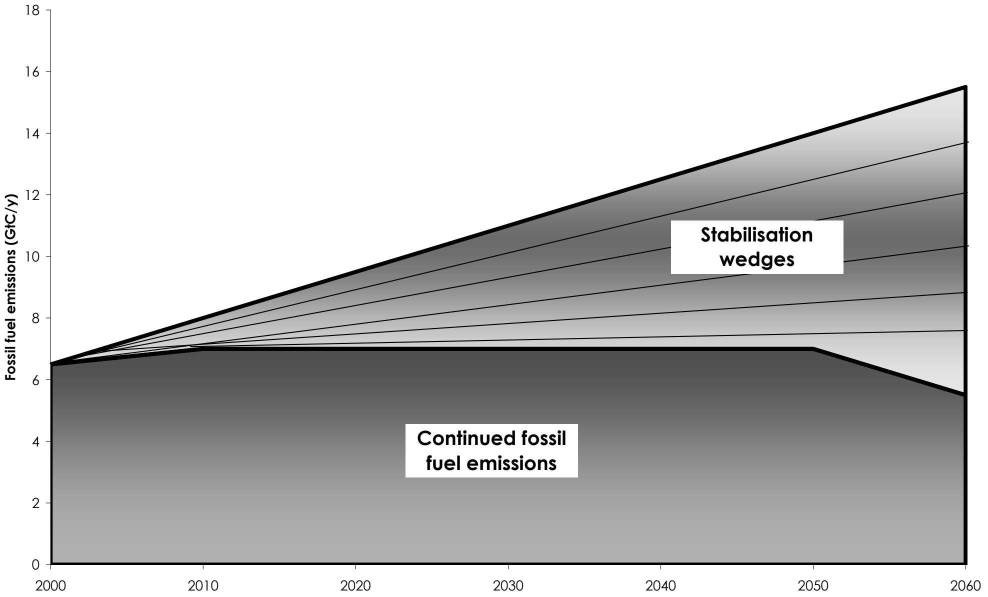

Fig. 2 : Technology wedges for greenhouse gas stabilisation

Source: *Pacala and Socolow* (2004)

In the following paragraphs[9] a selection of sectoral mitigation measures will be presented. As far as possible not only specific (groups of) emission reduction measures are identified but also the general sectoral challenges and framework conditions as well as interdependencies with other sectors and potential co-benefits are briefly discussed.

Energy supply

The challenge for the future development of energy supply will be the affordable provision of energy services given a constant or even increasing demand (if no other efficiency measures in the building or industry sectors will be applied) while minimising GHG emissions and other negative externalities (e.g. air pollution, health effects). This will require the use of a variety of energy sources and the application of efficient and innovative conversion technologies as well as integrated planning in order to satisfy the demand for heating, cooling and electricity and to identify optimal solutions for various demand structures and regions.

Fossil energy use causes about 85% of global anthropogenic CO_2 emissions. In order to reduce these emissions significantly, the use of primary energy has to shift from fossil fuels towards low- or zero-carbon sources (renewables) or highly efficient conversion technologies (including technological options to capture and store CO_2) have to be applied.

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[9] Based on IPCC (2007) if not stated otherwise.

Renewable energy systems can contribute to reducing emissions as well as maintaining the security of supply. Currently, renewable energy accounts for about 15% of global primary energy supply. Options with the highest mitigation potential in this area include:

- Hydropower: there is potential in the construction of new large hydropower plants (>10MW capacity) and the repowering of existing plants with more powerful and efficient turbines. However, such large projects, especially in developing countries, may cause negative social effects (through relocation of the local population) and ecological impacts (on river ecosystems and fisheries). Small and micro hydropower systems in contrast can provide electricity to rural or remote regions, although investment costs may be prohibitive in developing countries and may make financial support necessary.
- Wind energy: the installed capacity for electricity generation using wind power has increased largely over the past years, especially in Europe, Japan, China, USA and India and further growth is expected. In addition, technological progress has led to a continuous increase in the size of wind turbines. The fluctuating nature of wind and the requirements regarding system reliability represent a constraint for the growth of wind energy. Better forecasting methods, demand-side measures as well as the development of storage technologies can help alleviate this problem.
- Biomass and bioenergy: biomass can be used as solid fuels (firewood, pellets etc.), liquid fuels (ethanol, biodiesel), gaseous fuels in the generation of heat and power or as transport fuels. The kind of use is determined by the kind, quantity and quality of biomass available as well as the type of energy services required and the location of the consumers. A large share (around 60%) of combustible biomass is currently used in developing countries (household use) often combined with inefficient combustion technologies, but the use for cogeneration or district heating in industrialised countries also expands. Further increases are expected in connection with technological developments (e.g. second-generation biofuels, pyrolysis).
- Photovoltaic energy: the large technical potential of electricity generation with photovoltaics is currently still limited by factors as investment costs, land availability and lacking storage technologies. Expansion however continues especially in developed countries and cost reductions due to technological developments (storage, thinner cell materials, and new materials) may increase the technology's marketability.

Regarding the deployment of more efficient energy conversion technologies one main option – besides improving the efficiency of conventional plants and technologies - is the combined generation of electricity and heat (CHP). In conventional thermal power plants up to two thirds of energy used is lost in the form of heat. With cogeneration the conversion efficiency can be increased to reach more than 80% with available technologies. In addition, the reduction of transmission and distribution losses can contribute to the decrease of primary energy use and resulting GHG emissions. One option for this is the implementation of decentralised energy systems, where generation in small- to medium-sized facilities is located close to consumers and various energy services (electricity, heating/cooling) are offered.

Such approaches reduce the need for long transmission systems and losses and – given the local availability – renewable energy sources can be used.

Buildings

Energy use in buildings is related to space heating/cooling, lighting, water heating and the use of electric appliances. While the use of electricity is one driver of GHG emissions from energy supply, space and water heating largely represent direct sources of emissions from the building sector. In this case a wide range of (mature) technologies for energy efficiency and the use of renewable energy is available to reduce emissions and energy use. In addition, changes in behaviour and consumer choice can contribute to this target.

The technological options for energy-efficient buildings include building designs that reduce heating demand (insulation, low-energy and passive house, passive solar heating etc.), efficient heating and cooling systems (e.g. using ambient energy sources and heat sinks) as well as effective control strategies (building energy management. In addition, the use of efficient appliances, office equipment and lighting systems. However, the applicability and adequacy of the various technologies is largely determined by the economic and climatic conditions in a region.

New buildings can be designed in a highly efficient way (low-energy or passive houses), from the outset, using high levels of insulation, optimising the glazing area and applying efficient heating technologies (e.g. solar energy, heat pumps) in colder climates. In other climates the building envelope can be used as a filter that selectively absorbs or rejects solar radiation depending on the respective need for heating or cooling. Thus, the energy demand for heating and cooling can be reduced significantly compared to the existing building stock. The challenge for energy and emission reductions in the building sector is however posed by the large stock of existing and inefficient buildings. In order to significantly reduce energy use, the buildings have to become more energy efficient when they are renovated. Therefore additional insulation has to be added to the building shell, i.e. walls, roof, windows, doors, and the equipment as furnaces, boilers or air conditioners have to be replaced by more efficient alternatives, taking into account the reduced heating/cooling demand resulting from insulation.

Energy efficiency measures in the building sector offer a wide range of potential co-benefits. On the one hand, the renovation of buildings increases comfort and improves indoor air quality and reduces the households' expenditure for energy. On the other hand direct emissions or emissions from energy supply for the provision of heating are reduced, which also leads to a decrease of other air pollutants than GHGs. In addition, economic effects also include employment and growth effects due to the labour intensity of construction and renovation in particular as well as new business opportunities, e.g. through building energy management.

Industry

Industry is one of the major sources of GHG emissions but is also vulnerable to the impacts of climate change and especially affected by the implications of extreme weather events.

GHG emissions from industry are mostly energy related. Other sources are process emissions (from blast furnaces or cement production) and non-CO_2 GHGs (e.g. from aluminium smelting). The major part of industry's emissions stems from the energy intensive sectors iron and steel, non-ferrous metals, chemicals, petroleum refining, minerals (cement, lime, glass and ceramics) and pulp and paper. Although many installations in developed countries use new and efficient technologies there is still large potential for substituting older equipment and for increasing energy efficiency in general. This structural change is constrained by a slow rate of capital stock turnover as well as other factors as a lack of financial and technical resources, information barriers or a lack of climate change regulation.

The technological options for emissions mitigation in industry can be categorised as follows:

- Sector-wide options: these include energy efficiency measures regarding electric motors, boilers and process heaters and the switch towards less carbon intensive fuels (from coal to gas or renewable energy sources).
- Process-specific options: these include practices to use industrial waste or to recover process energy.
- Operating procedures: this area comprises the optimisation of processes and equipment size, the reduction of leaks etc.

Existing technologies can significantly contribute to reducing energy use and emissions from industrial processes. However, technological developments are a key factor for meeting medium to long term reduction targets and implementing cleaner production systems. The incentives for structural changes and technological progress are not only given by the future development of energy and carbon prices but also by climate regulation and other policy areas that determine the economic framework and R&D activities.

Agriculture and Forestry

In the areas of agriculture and forestry a variety of measures can be applied for mitigating emissions, either directly through improving management practices or indirectly through offsetting emissions from fossil fuels (bioenergy) or in capturing emissions biologically (sinks e.g soil organic carbon or trees). There are strong interdependencies between agriculture and forestry, on the one hand, and between mitigation and adaptation measures in these areas, on the other hand. The potential for mitigation depends heavily on natural and climatic conditions, thus, the extent to which a reduction of emissions in agriculture and forestry can be realised is determined by future climate change as well as adaptation measures that are taken in order to make the agricultural system more robust. Also, there are strong interdependencies of mitigation measures between forestry and agriculture. This regards primarily the production of energy crops and agro-forestry.

In particular, mitigation measures in agriculture can be categorised as follows:

- Emission reduction measures: these include more efficient management of carbon and nitrogen flows (nutrient management) in crop and livestock production. However, their effectiveness varies across site conditions (e.g. weather, soil qualities, topography) and management options (e.g. minimum tillage).

- Enhancing sequestrations: It includes any management practice that increases the carbon stocks in soil and biomass (sink function). It can be realised, for example, by agro-forestry or other perennial crops on agricultural lands, reduced or minimum tillage systems, and may involve land use changes (e.g. conversion of cropland to grassland).
- Avoiding or substituting emissions: If crops, biomass, or residues from agriculture are used as energy sources (either directly or after conversion to e.g. ethanol or biodiesel) they replace emissions caused by use of fossil fuels. The mitigation potential of bioenergy depends mainly on net-emissions of biomass production and conversion, including indirect land use changes as well as on relative prices of alternative energy sources.

In forestry mitigation options include the reduction of deforestation – the single most important source of emissions in this sector – forest management, afforestation and agro-forestry. Sustainable forest management that aims at increasing the level of carbon sequestered and providing a sustained yield of wood or energy sources can simultaneously contribute to the reduction of GHG emissions and to the target of sustainable development.

However, the increasing use of agricultural crops and residues as energy sources and the growth in agro-forestry may not be fully compatible with sustainable development. In this regard the competition with other land-uses, especially food production, has to be taken into account as well as potential impacts on biodiversity, soil and nature conservation.

1.2 Adaptation

Societies have long been adapting to the impacts of weather and climate impacts, for instance, through crop diversification, irrigation, water management, disaster risk management, markets, policies, and insurance. But anthropogenic climate change potentially leads to risks that are outside the range of experience, such as impacts related to drought, changing precipitation, heat waves, accelerated glacier retreat and hurricane intensity (*Adger et al.,* 2007). These climate related stimuli are possibly not limited to changes in average annual conditions, they include variability and associated extremes, i.e. an increasing intensity and frequency of weather extremes sometimes referred to as "climate hazards" (*Smit et al.,* 2001). These changes might result in a cascade of consequences including an increased risk of floods and droughts, losses of biodiversity, threats to human health, and damage to economic sectors such as energy, transport, forestry, agriculture, and tourism (*EEA,* 2008).

Adaptation concerns the adjustments in ecological, social, or economic systems in response to climate change and correlated impacts (*Smit et al.*, 2001). The purpose of adaptation to observed or expected changes in climate is to reduce vulnerability and to enhance resilience. Vulnerability is the state of susceptibility to harm from exposure to stresses associated with climate impacts and from the absence of capacity to adapt (*Adger,* 2006). For a conceptual overview of the interlinkages between climate change impacts, vulnerability and adaptation see Fig. 3. Resilience, by contrast, refers to the magnitude or disturbance that can be absorbed before a system (social, natural) changes to a radically different state as well as the capacity to self-organise and the capacity for adaptation to emerging circumstances.

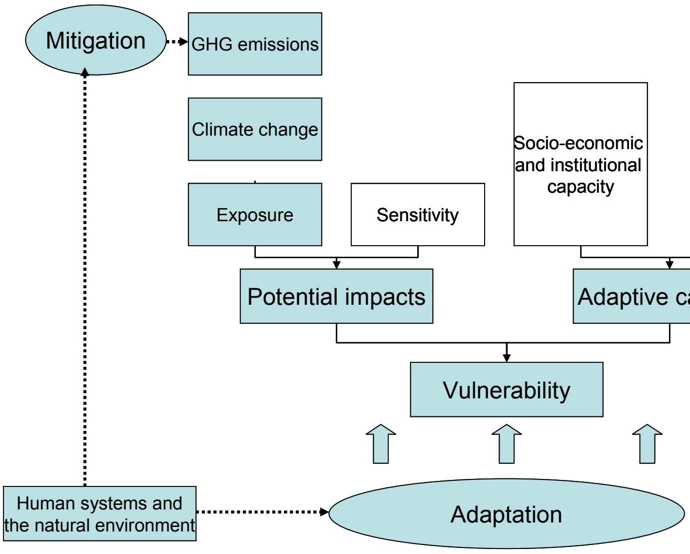

Fig. 3 : Conceptual model for climate change impacts, vulnerability and adaptation

Source: *Isoard et al.* (2008).

Adaptations are dependent upon the system in which they occur, who undertakes them, the climatic stimuli that prompts them, and their timing, functions, and effects. In natural systems, adaptation is autonomous and reactive, it is the process by which species and ecosystems respond to changed conditions (*Smit et al.,* 2001). Adaptation to climate change, yet, is mostly referred to as planned adaptation, i.e. consciously undertaken by humans with respect to actual or expected climate change and with reference to economic sectors, managed ecosystems, urban settlements, undertaken by private and public agents.

Adaptation to climate change has the potential to significantly lessen many of the adverse impacts of climate change, for example, threats to food supply, infrastructure, public health, and the availability of water resources etc. Adaptation is dependent upon the adaptive capacity of an affected system, region, or community to cope with the impacts and risks of climate change (see Fig. 3). The enhancement of adaptive capacity reduces vulnerabilities and promotes resilience. The determinants of adaptive capacity are *inter alia* economic, social, institutional, and technological conditions that facilitate or constrain the development and deployment of adaptive measures (*Smit et al.*, 2001). Fig. 3 also brings to light the close linkage between adaptation and mitigation. Mitigating GHG emissions reduces climate change impacts and, consequently, lessens the challenge of adaptation to adverse impacts of an anthropogenically induced changing climate.

Investigating adaptation in the context of climate change is important in two instances, one relating to the assessment of impacts and vulnerabilities, the other to the development and evaluation of respective response strategies (*Smit et al*., 2001).

Spatially detailed information on climate change impacts is a prerequisite for the development and assessment of adaptation strategies. In recent decades the availability of observed and projected data and information on climate change impacts has improved. However, the information flow on different impacts varies considerably between regions. There are national monitoring and data collection programmes for "Essential Climate Variables" as defined by WMO (World Meteorological Organisation) as part of the GCOS (Global Climate Observing System) as well as satellite data to track these variables. For an overview of relevant indicators see Tab. 1. Some of the data is voluntarily collected by non-governmental organisations, other data result from a limited number of local or regional and national or EU-wide research projects. But there are no regular Europe-wide monitoring programmes for many important indicators. Therefore, it would be useful to achieve a European agreement on the definition of key climate change indicators, including extreme weather events, and to define operational ways of tracking impacts through multiple sectors over a variety of time and geographic scales (*EEA*, 2008).[10]

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[10] Confer to the INSPIRE Directive of the European Parliament and the Council (*European Parliament*, 2007) that aims at improving the inter-operability, harmonisation and access to spatial information.

Tab. 1 : Essential climate variables

Source: Global Observing Systems Information Center.

Atmospheric	Ocean	Terrestrial
		River Discharge
Surface	**Surface**	Water Use
Air Temperature	Sea-Surface Temperature	Ground Water
Precipitation	Sea-Surface Salinity	Lake Levels
Air Pressure	Sea Level	Snow Cover
Surface Radiation Budget	Sea State	Glacier and Ice Caps
Wind Speed and Direction	Sea Ice	Permafrost and Seasonally Frozen Ground
Water Vapour	Current	Albedo
	Ocean Color	Land Cover (including vegetation type)
Upper Air	Carbon Dioxide Partial Pressure	Fraction of absorbed photosynthetically active radiation (FAPAR)
Earth Radiation Budget		
Upper Air Temperature	**Sub-surface**	Leaf Area Index
Wind Speed and Direction	Temperature	Biomass
Water Vapour	Salinity	Fire Disturbance
Cloud Properties	Current	Soil Moisture
	Nutrients	
Atmospheric Composition	Carbon Dioxide Partial Pressure	
Carbon Dioxide	Ocean tracers	
Methane	Phytoplankton	
Ozone		
Nitrous Oxide		
Chlorofluorocarbons (CFCs)		
Hydrochlorofluorocarbons (HCFCs)		
Hydrofluorocarbons (HFCs)		
Sulphur hexafluroide (SF_6)		
Perfluorcarbons (PFCs)		
Aerosol Properties		

Assessing adaptation options in terms of costs and benefits shall lead to a better understanding of the socio-economic and institutional requirements and potentials of adaptation measures. In the context of a cost-benefit analysis, adaptation costs are expressed in monetary terms while benefits are quantified in terms of avoided climate impacts, and expressed in monetary as well as non-monetary terms. Much of the literature on adaptation costs and benefits is focused on sea-level rise and agriculture (*Rosenzweig – Parry*, 1994; *Yohe – Schlesinger,* 1998*; Hartje et al.,* 2002). However, the literature on adaptation costs and benefits remains quite limited and fragmented in terms of sectoral and regional coverage. In addition, very few studies have assessed the effectiveness of adaptation measures over different time scales. Today's adaptation measures may, however, not be effective in future decades considering extreme weather events becoming more frequent and intense. In order to conduct coherent and comparable adaptation studies it would be useful to base adaptation assessments on climate scenarios that have been adopted on a European level and that are compatible with the IPCC climate scenarios for global development. Therefore, an institutionalised interaction between the climate modelling community and the user community that assesses impacts, vulnerability and adaptation measures is needed to develop and assess appropriate adaptation measures. Further, high-resolution climate change scenarios for the regional and local level need to be developed for the evaluation of adequate adaptation measures (*EEA*, 2008). Despite uncertainties in existing climate change scenarios, stakeholders need to make decisions which could further be improved as more detailed scenarios become available.

1.2.1 Climate change impacts in Europe and Austria

According to the EU green paper on adaptation to climate change in Europe (*CEC,* 2007)[11], the effects of climate change in Europe and the Arctic are already significant and measurable. The green paper describes the impacts of climate change in major European geographical regions as well as necessary adaptation actions and policies. For Central Europe[12] comprising eastern Austria, the following impacts must be taken into consideration when planning for adaptation: "The annual mean temperature increase is projected to be in the order of 3-4°C except for the more continental regions of Central Europe and the Black Sea Region, like Romania, where temperatures could increase by as much as 4-4.5°C. Annual mean precipitation should increase up to 10% in most regions. Precipitation would increase mainly in winter, while there would be reductions in summer precipitation in several areas. The increased risks of floods could threaten homes and infrastructure. Agriculture is expected to suffer from soil erosion, loss of soil organic matter, migration of pests and diseases, summer droughts and high temperatures, but could benefit from longer growing seasons in some regions "(*European Commission*, 2007).

Many economic sectors depend strongly on climatic conditions and will suffer from the consequences of climate change on their activities and businesses directly such as agriculture and forestry, just to mention the relevant sectors for the present analysis.[13] The agricultural sector has to be considered a key sector in adaptation because agriculture is not only central in food production but will as well become ever more important in the energy supply sector. Hence, there is a strong interrelationship between successful agricultural adaptation measures and the scope of bioenergy as a reliable mitigation and energy supply strategy. Agricultural and, thus, feedstock production for bioenergy need to take into account climate impacts and effects on water availability and quality.

Climate change may affect agriculture primarily through increasing atmospheric CO_2, rising temperatures and changing rainfall. "While moderate warming benefits crop and pasture yields in mid- to high-latitude regions, even slight warming decreases yields in seasonally dry and low-latitude regions " (*Easterling et al.,* 2007). Here below are summarised central climate change impacts and areas of concern that need to be addressed when designing and assessing appropriate adaptation measures in the agricultural sector. These topics are largely relevant for Europe as a whole but differ significantly in terms of occurrence, magnitude and impact between regions:

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[11] An EU white paper on adaptation is expected to be due in autumn 2008.

[12] The geographical zone of Central Europe comprises: Poland, Czech Republic, Slovakia, Hungary, N. Romania, S. and E. Germany, E. Austria.

[13] Other sectors negatively affected are health, buildings, transport, industrial infrastructure, energy supply as well as related financial services and the insurance sector.

Soil erosion

One of the relevant impacts of climate change on agriculture is soil erosion. Excess water due to intense or prolonged precipitation can cause tremendous damage to soil thereby destroying the capability of the soil to provide economic or environmental services (*EEA*, 2008). Studies revealed a non-linear spatial and temporal response of soil erosion to climate change with relatively large increases in erosion during wet years compared with dry years. Erosion is projected to increase with increases in precipitation amount and intensity (*EEA*, 2008).

Water retention

Water retention capacity and soil moisture content will be affected by rising temperatures and by a decline in soil organic matter due to both climate change and land-management changes. Projections show a general reduction in summer soil moisture over most of Europe. Maintaining water retention capacity is important to reducing the impacts of intense rainfall and droughts, which are projected to become more frequent and severe. Soil moisture forms a major buffer against flooding, and water capacity in subsoil is a major steering factor for plant growth. Maintaining or enhancing the water retention capacity of soils can therefore play a positive role in mitigating the impacts of more extreme rainfall intensity and more frequent and severe droughts *(EEA*, 2008).

Changing growing season for agricultural crops

Increasing air temperatures are significantly affecting the duration of the growing season over large areas of Europe mainly influenced by the increase in temperatures in spring and autumn. The impact on plants is reported mainly as a clear trend towards an earlier start of growth in spring and its prolongation into autumn. Changes in management practices such as changes in the species grown, different varieties, or adaptations of the crop calendar, can counteract the negative effects of a changing growing season like pests and capture the benefits in agricultural crop yields. More lengthening of the growing season is expected in northern and eastern areas (*EEA*, 2008).

Timing of the crop cycle

The timing of the crop cycle (agrophenology) determines the productive success of the crop. In general, a longer crop cycle is strongly correlated with higher yields as to the maximum use of the available thermal energy, solar radiation and water resources. European farmers have already adapted their practices to the changing climate by selecting suitable varieties or adapting the crop calendar, e.g. sowing or planting dates have been advanced by 5 days for potatoes in Finland, 10 days for maize and sugar beet in Germany, and 20 days for maize in France (*EEA*, 2008).

Crop yield variability

Climate change introduces new uncertainties for the future of the agricultural sector as climatic conditions are projected to become more erratic with an increase in the frequency of extreme events like floods, hurricanes, heat waves, severe droughts. Since the beginning of the 21st century, the variability of crop yields has increased as a consequence of extreme climatic events (e.g. the summer heat of 2003 and the spring drought of 2007). Biomass production of plants and, thus, crop yields are fundamentally determined by climatic conditions, i.e. the stable availability of energy and water to support growth. In addition, other environmental and anthropogenic factors such as soil fertility, crop varieties and farming practices also influence crop yields. Adaptive management is expected to continue to help reduce the risks to agricultural yields from climate change.

Water requirement

Clear trends, both positive and negative, were evident in water requirement across Europe. A significant increase in water demand occurred mainly in Mediterranean areas while large decreases were recorded mainly in northern and central European regions, e.g. the rate of increase in water demand is around 50m3/ha/year but in some cases it is more than 150-200 m3/ha/year (Italy, Greece, Maghreb, central Spain, southern France and Germany). Where reduced rainfall is predicted, the increased requirement for irrigation water can have an overall negative impact in economic and environmental terms inter alia due to increased greenhouse gas emissions. In these areas, increased water shortages are expected to increase competition for water between sectors (tourism, agriculture, energy etc.), particularly in southern Europe (*EEA*, 2008).

Austria is expected to be very vulnerable to a climatic change according to the national communication of the Austrian Federal Government (*Austrian Federal Government,* 2006). This is due to the fact that mountainous regions are highly sensitive to changing climatic patterns and 70% of Austria's surface area is situated higher than 500 m above sea level and 40% higher than 1,000 m. The report reckons that a significant climate change can already be observed, i.e. during the last 150 years, the mean annual temperature has increased by 1.8°C while the global mean temperature increase is at 0.76°C (*BMLFUW,* 2009). Further, snowfall has decreased, and glacier inventories show losses. Based on the insight that projections of climate change are difficult to obtain and rather uncertain, especially for mountain environments, the following conclusions concerning climatic changes in Austria are derived (*Austrian Federal Government,* 2006; *BMLFUW,* 2009):

The length of time that snow cover remains will be reduced due to changed precipitation regimes. This will alter the timing and amplitude of runoff from snow, increase evaporation, decrease soil moisture and groundwater recharge. Flat areas in the east of Austria will experience hydrological conditions more severe than those in the mountains. Changes in the natural water balance would have a serious impact on run-of-river power stations, which have a considerable share in electricity production in Austria. Reduced snow cover will have negative impacts on Austria's winter tourism and with that considerable socio-economic disruption in communities that have invested heavily in the skiing industry can be expected. Further, temperature increase, changes in intensity and frequency of precipitation, glacier retreat and loss of mountain permafrost could alter the frequency of natural hazards such as landslides, mudslides and avalanches. Climate change is projected to shift precipitation from summer to winter, with a slight increase in precipitation in the North and West of the Alpine divide and a decrease in the South of the Alpine divide and in the East of the country. Currently, Austrian adaptation measures are either induced by impacts of observed climate change or are serving the reduction of natural hazards, having climate change adaptation co-benefits, e.g. irrigation channels, insurance instruments in agriculture, artificial snow making, erosion and torrent control measures in forests, and risk management in flood hazards (*Sinabell – Url,* 2007).

1.2.2 Adaptation framework

Governments have a central role to play in making adaptation happen, e.g. by providing policy guidelines and economic and institutional support to the private sector and civil society (*Stern,* 2007). This is because market forces are unlikely to lead to efficient adaptation. In particular, governments shall help to provide high-quality climate information, i.e. improved regional climate predictions with respect to rainfall and storm patterns. The scale and complexity of climate information will make it unlikely that individuals and firms will undertake basic research into future changes. Therefore, high-quality information on impacts of climate change in space and time must be considered a public good. Information about climate change and its impacts should not be too complex and should provide practical pointers such that climate change will be integrated into project appraisal and decision-making by private investors and civil society (mainstreaming adaptation into general business risk management). Climate information is, thus, an important starting point for adaptation because it will drive efficient markets for adaptation.

As adaptation is complex, multilevel governance from the individual citizens and public authorities to the EU level is imperative with action being taken at the most appropriate level, i.e. supranational, national, regional or local.

Adaptation at EU level

Adaptation at the EU level is essential because in many areas climate change impacts and adaptation measures will transcend national borders, thus, requiring cross-boundary approaches, for instance in river basins and distinct bio-geographic regions such as mountainous regions like the Alps. While adaptation measures are usually location- and sector specific, the cost efficient planning and coordination of adaptation measures is appropriately assigned to upper governance levels, e.g. the EU level where many sectoral policies are largely integrated through the single market and common policies (e.g. agriculture, water, biodiversity, energy networks). The EU has formulated in its green paper on adaptation (*European Commission*, 2007) a so called "four-pronged approach" to adaptation:

1. Early action in the EU
2. Integrating adaptation into EU external actions
3. Reducing uncertainty by expanding the knowledge base through integrated climate research

4. Involving European society, business and public sector in the preparation of coordinated and comprehensive adaptation strategies

- Early action comprises the integration of adaptation measures at an early stage, i.e. when implementing and modifying existing and forthcoming legislation and policies. For example, the European agriculture[14] will face many challenges in the years to come: "international competition, further liberalisation of trade policy and population decline. Climate change will add to these pressures and will make challenges more difficult and costly" (*European Commission,* 2007).[15] The recent reforms of the Common Agricultural Policy (CAP) constitute a first adjustment towards a political support framework that steers agriculture towards a sustainable sector in the EU.
- Climate change impacts and resulting adaptation needs will have to be integrated into EU relations with third countries through dialogue, cooperation and partnership on adaptation. The EU is promoting a global market for environmental technologies that fosters trade in sustainable goods and services as well as for technological transfer between industrialised and developing countries. With regard to developing countries, adaptation should be integrated into EU strategies for poverty reduction, into existing external policies and funding instruments.
- Reducing the remaining uncertainty in favour of more accurate and detailed forecasts regarding the impacts of climate change at regional and local levels as well as concerning the costs and benefits of adaptation measures for shorter time frames such as 2020-2030 remains a central task. The EU envisages the support of integrated, cross-sectoral and holistic research approaches together with the development of methodologies to the internalisation of external costs of physical and biological system degradations, emphasising the complex interrelationship between factors and drivers of climate change and climate impacts. Research of this type is supported within the 7th Framework Programme.
- In order to stimulate adaptation in particularly weather dependent sectors, e.g. agriculture, forestry, renewable energy, water, and tourism, as well as with structures specifically exposed to climate change, e.g. industrial infrastructure, urban settlements in coastal areas, floodplains and mountains, a systematic dialogue with relevant stakeholders is needed in order to explore these challenges and support participation in the formulation and implementation of adaptation measures.

A white paper on adapting to climate change in Europe has been published presenting the framework for adaptation measures and policies to reduce the European Union's vulnerability

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[14] Adaptation strategies in other sectors like industry and services, energy and transport, health, water, ecosystems and biodiversity are briefly discussed in (*European Commission*, 2007).

[15] Adaptation is seldom undertaken due to climate change alone and is generally integrated into other cross-cutting and precautionary policies, such as coastal zone management, disaster preparedness, rural development, health services, spatial planning, ecosystems and water managements.

to the impacts of climate change (European Commission, 2009). The White Paper outlines the need to create a Clearing House Mechanism by 2011 where information on climate change risks, impacts and best practices would be exchanged between governments, agencies, and organisations working on adaptation policies. As the impacts of climate change will vary by region, with coastal and mountain areas and flood plains particularly vulnerable, adaptation measures need to be designed according to national or regional necessities. The role of the European Union is to support and complement these efforts through an integrated and coordinated approach, particularly in cross-border issues and policies which are highly integrated at EU level. Adaptation strategies will be integrated into all EU policies.

Adaptation at national, regional and local level

Comprehensive risk management strategies at the city, regional and national level have been developed.[16] While Least Developed countries are developing National Adaptation Plans of Action (NAPA)[17] some developed countries have established national adaptation policy frameworks, e.g. France, Finland, Germany, Italy, the Netherlands and the United Kingdom have worked out national strategies to adapt to climate change (*AEA*, 2007; *Adger et al.*, 2007). Austria is about to develop a national adaptation strategy. A draft policy paper "On the way to a national adaptation strategy" has been released in June 2009 (*BMLFUW*, 2009). Central approaches to reduce the vulnerability of the agricultural and forestry sector are: use of water saving irrigation systems, breeding of heat and drought resistant crops, air conditioning in livestock stables, revitalization of abandoned alpine pastures, rejuvenation of tree population and soil protection measures. In addition, risk management tools should be developed, mapping of vulnerable areas together with the types of impacts should be established and hazard assessments and forecasting should be fostered through the government in a coordinated manner in the medium term to prepare for the enhancement of adaptive capacity.

Many decisions influencing climate change adaptation are taken at the local level where there is a detailed knowledge on the local natural and human conditions available that can serve decision-making. Therefore, local authorities will have an important role to play in communicating risks from climate change and in raising the awareness regarding possible climate impacts as to promote adaptation in terms of behavioural change within societies and communities. For example, land use and land management practices could be explored together with farmers to prevent erosion, mud streams etc., taking a participatory approach to adaptation.

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[16] An interesting case of adaptation at the city level is New York where climate scenarios are being considered as part of the review of the New York water supply system.

[17] International financial and technology transfers from countries with high greehouse gas emissions to countries that are most vulnerable to present and future impacts for use in adapting to the impacts of climate change has been facilitated through development of National Adaptation Programmes of Action (NAPAs).

1.2.3 Adaptation measures in the agricultural and forestry sector

Climate change impacts will affect crop yields, e.g. by increasing variability in yields. This will put the food supply at increasing risk. The possible increase of biomass for energy production adds to the pressure on food supply. Bioenergy crops are susceptible to natural and human-caused disasters as well, including crop failures, irregular weather patterns and droughts, which could increase with climate change. Success in adaptation depends on factors such as biology, ecology, technology and management regimes. Potential adaptation strategies incorporate (*Smit et al,* 2001):

- changes in the topography of land
- the use of artificial systems to improve water use or availability
- protection schemes against soil erosion
- changed farming practices (fertilizer use, tillage methods, etc.)
- changes in the time of farm operations
- use of different crop varieties
- research into new technologies
- financial and institutional instruments and programmes.

Many of these strategies involve better resource management resulting in additional benefits other than adaptation, i.e. co-benefits or auxiliary benefits regarding the multifunctionality of agriculture such as high nature value grassland that provide habitat and assist migration for numerous species. Adaptation measures that are of key importance in the agricultural sector are related to:

Sustainable soil and land management

Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is to enhance soil organic matter. It improves and stabilizes the soil structure so that soils can absorb higher amounts of water without causing surface run off. Soil organic matter also improves the water absorption capacity of the soil acting against extended droughts (*FAO*, 2007). In order to protect the soil from excess temperatures and evaporation losses, the FAO promotes low tillage and maintenance of permanent soil cover. A no- or low-tilled soil conserves the structure of the soil for fauna and related macrospores to serve as drainage channels for excess water. Surface mulch cover can reduce crop water requirements by 30 percent (*FAO*, 2007). The FAO, therefore, encourages conservation agriculture and organic agriculture as they incorporate zero or low tillage and permanent soil cover. This practice increases soil organic carbon and reduces the need for mineral fertilizer use and, thus, induces co-benefits in terms of reduced GHG emissions from agriculture.[18] The use of hedges, vegetative buffer strips and other farm landscaping practices have crucial impacts on adaptation to drought, heavy rains and wind. Risk-coping production systems require diversified structures in space and time such as crop rotation, agroforestry, crop-livestock associations, crop-fish systems etc. (*FAO*, 2007).

Sustainable water management

Freshwater-related issues play a pivotal role among the key regional and sectoral vulnerabilities, in particular in the agricultural sector where the importance to our life support systems is widely recognised. Problems of having too much water or having too little water prevalent in agriculture may be exacerbated by climate change. The relationship between climate change and freshwater resources is, hence, of primary concern and interest.[19]

A broad range of agricultural management practices and technologies are available to spread and buffer production risks, e.g. multi-purpose reservoirs serve as an adaptation measure for both floods and droughts, and the use of resource efficient irrigation as means of maintaining cropping intensities (*IPCC*, 2008; *FAO*, 2007). Irrigation water demand may be reduced by introducing corps more suitable to the changing climate. Enhancing residual soil moisture through land conservation techniques assists significantly at the margin of dry periods while buffer strips, mulching and zero tillage help to mitigate soil erosion risk in areas where rainfall intensities increase. Competing sectoral demands for water will place more pressure on allocations to agriculture. Therefore water resource management beyond the direct agricultural interventions, i.e. for river basins and aquifers, which are often transboundary, will be necessary. In addition to measures that mainly serve the quantity management of water (availability), the quality of water will be another key concern for societies and the environment under climate change. Therefore, the protection of water courses against excessive nutrient inflow has also to be dealt with.

Forestry

Forests itself play a role in adaptation to climate change by mitigating the impacts of extreme events and the resulting threats to food security. Therefore short-rotattional trees and shrubs (including agroforestry) can play a significant role in adaptation in the agricultural sector. In addition to benefits such as the provision of wood and non-wood forest products and the conservation of biological diversity and the restoration of soil fertility, trees and forests improve the mircoclimate by buffering winds, regulating the water table, and providing shade to corps. They thus contribute to sustainable agricultural production and food security.

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[18] The agricultural sector is responsible for 60% of anthropogenic methan and 50% of anthropogenic nitrous oxide emissions, both having a much higher warming potential than carbon dioxide emissions, thereby, substantially contributing to climate change.

[19] In recognition of the importance of freshwater and potential adverse climate change impacts, the IPCC published a special report on climate change and water (*IPCC*, 2008).

Compared to agriculture, decisions taken today for managed forests, e.g. tree species choice, remain irreversible for decades or even centuries while on the other hand, the selection of seeds and seed provenances for altered climatic conditions will require time (*FAO*, 2007).

Adaptation measures in areas such as soil and water management may further be categorised employing the methodology used by AEA (*2007*):

Management measures

This concerns the choice of crop variety and fertilizer and pesticide management decisions that farmers make. These decisions are based on information from diverse sources such as the agrochemical industry, government services, discussions and publications in the farming press. Decisions are as well influenced and incentivised by subsidies and transfers.

Technical/equipment measures

The introduction of improved irrigation equipment may be regarded as technical measure. The decision towards the implementation of a new technical measure requires information on innovations and options that may be supplied by government agencies as commercial firms may be slow in developing these products, waiting instead to see if markets can be established. Extensive breeding and testing programmes may be necessary to identify cultivars and breeds appropriate to changing local conditions.

Infrastructural measures

Infrastructural measures require capital investments but may vary largely in scale and expense. The introduction of on-farm harvesting and storage of rainwater is one example of such a measure. Depending on the scope of measure, public financial support might be needed to realise infrastructural adaptation measures, e.g. the management of flood plains.

Adaptation measures to be quantitatively assessed in the ongoing second research year will be discussed and selected on the basis of the above delineated adaptation options in a workshop to be held in Vienna in November 2008.

2 Climate projection for the case study region wider Feldbach

In order to assess climate change impacts on the local scale, sufficiently finely resolved climate data are required. Downscaling approaches are suitable to satisfy these demands. In the project reclip:more (*Gobiet et al.,* 2006; *Loibl et al.,* 2007) a high resolution climate scenario for the alpine region was developed using this method (10 km grid). The regional differences found by Gobiet et al. (*2006*) point out the importance of climate scenarios at such a narrow scale. Regarding the change of precipitation for example, the authors demonstrate that

"… For the alpine region as a whole the annual mean change over the entire region (not shown) is small (-4 %) but seasonally and sub-regionally large changes are projected" (*Gobiet et al.* 2006).

Thus, in order to enable political instruments, such as adaptation measures, which are suitable to address the impacts of climate change, the regional level should be the focus of interest.

In doing so, a climate change scenario for the period 2041-2050 was developed for the NUTS 3 region of South-Eastern Styria (see Fig. 4). Located in the climatic region called "Vorland", the study region is climatologically rather homogeneous and characterized by a rather continental climate due to its protected location in the South-Eastern foreland of the Alps. It features low annual precipitation sums 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).

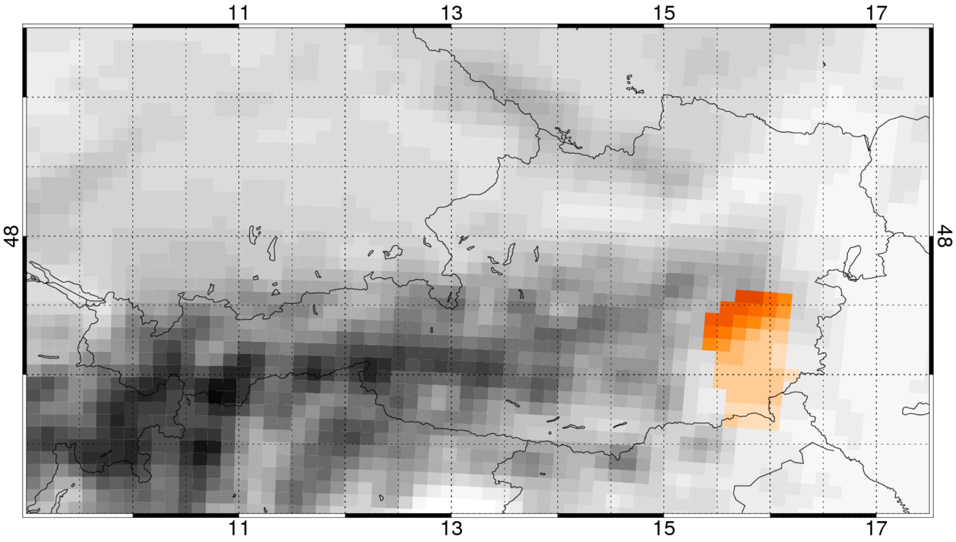

Fig. 4 : Location of the test region in Austria shown in a relief map.

The choice of meteorological parameters is based on agricultural expertise. It covers parameters which are especially important to estimate changes in the crop yields due to climate change. The full list is given in Tab. 2. In particular, *tmax* stands for the monthly average of the daily maximum temperature (similar for *tmin*), the growing degree days (*tsum*) are calculated according to AGPM (Générale des Producteurs des Mais) and DKM

(Deutsches Maiskomitee e.V.) (A. Meyer, personal communication), maximum wind speed (*vmax*) is given as the maximum daily mean windspeed per month, and precipitation (*nied*) is given as monthly mean precipitation per day [mm/day]. Frost days (*fdM1* and *fdM2*) indicate the number of days with minimum temperatures below a given temperature limit per month, and *datelastfd* represents the date of the last frost day in the respective month.

Tab. 2 : List of parameters used in the climate scenario.

parameters	
tmax	air temperature maximum [°C]
tmin	air temperature minimum [°C]
t	air temperature average [°C]
tsum	growing degree days
rel14	relatiave humidity at 14:00 [%]
v	wind speed [m/sec]
vmax	maximum wind speed [m/sec]
nied	precipitation [mm]
fdM1	frost days (tmin < -1°C)
fdM2	frost days (tmin < -2°C)
strahl	global radiation [J/m2]
datelastfdM2	date of the last frost day (tmin < -1°C) between january and july
datelastfdM1	date of the last frost day (tmin < -2°C) between january and july

Based on daily station data for the years 1981-2006 (from the network of the Austrian Central Institute for Meteorology and Geodynamics, ZAMG), monthly mean time series are calculated. These data represent the reference period, characterising the prevailing climate condition in the region. Fig. 5 shows the average cycle for the parameters temperature (*t*), minimum temperature (*tmin*), maximum temperature (*tmax*) and temperature sum (growing degree days) (*tsum*). In addition, the frost days per month are given (*fdM1*, *fdM2*) as well as the date of the last occurrence of frost days on average (9 April when defining frost day with -1°C minimum temperature (*datelastfdM1*) and 31 March when -2°C (*datelastfdM2*)).

Due to very limited resources for climate scenario construction, the future climate scenario was created by a simple, but robust approach ("Deta approach"): A "climate change signal" for each parameter in Table 2 is calculated by deriving the respective values from a future climate simulation (2041 – 2050) and from a simulation of a historical reference period (1981 – 1990) and subtracting the reference values from the scenario values. These climate change signals are added to observed data and then used as climate scenario in AMARA. This simple technique considerably improves the reliability of the climate scenario (compared to direct utilisation of climate model results) since it removes systematic model errors. The drawback is that climate variability is assumed to remain constant.

The climate change signals are derived from the results of two climate simulations (one for the reference period 1981-1990, one for the future period 2041-2050) performed in the framework of the project reclip:more (*Gobiet et al.,* 2006; *Loibl et al.,* 2007). This scenario builds on a regional climate model, the MM5 model (*Dudhia et al.,* 2004), which was used to dynamically downscale the results of a global climate model based on the IS92a emission scenario to obtain climate information on a high-resolution grid (10km, details are given in Gobiet et al. (*2006*)). The scenario simulation thus represents one possible future climate which is characteristic for the alpine region. By construction, the scenario only regards the effect of changes in monthly mean temperatures and assumes no changes in day-to-day temperature variability.

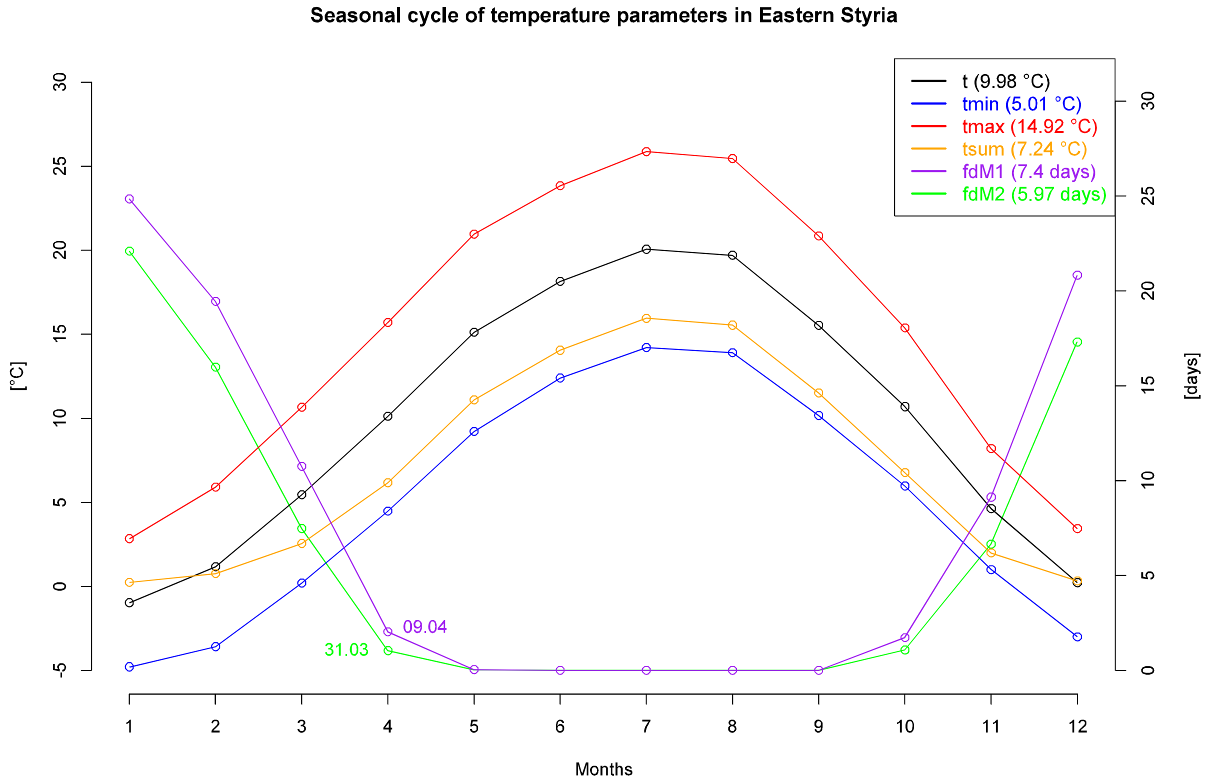

Fig. 5 : Mean annual cycle of t, tmin, tmax, tsum, fdM1 and fdM2 for the period 1981-2006 (see Tab. 2 for definitions).

Annual means are given in parentheses. Along the fdM1 and fdM2 time series, the climatological dates of the last frost day according to the -1 °C limit (datelastfdM1) and the -2 °C limit (datelastfdM2) are given.

In Tab. 3 the climate change signal on a monthly basis is given. While the absolute temperature shows an increase over the whole year with an average of 2.35 °C (increase between 1.83 and 2.71°C), precipitation increases in the winter months as well as in May and June, but decreases in the months of August, September and October, where decreases of some 30% can be observed. An interesting result, in particular for agricultural production, is the shift back of the last frost day for about 3 weeks leading to an average occurrence of the last frost day on 18 March (frost day defined with minimum temperature -1°C) or 9 March (-2°C). As a consequence, farmers can sow their seeds at an earlier point in time.

Tab. 3 : Climate change signals for South-Eastern Styria between 2040s and 1980s for the parameters *t*, *tmin*, *tmax*, *nied*, *strahl*, *v* and *rel14* (see Tab. 2 for definitions).

Values are given in absolute or relative changes as stated in the second row.

month	t [øC]	tmin [øC]	tmax [øC]	nied [mm]	nied [%]	strahl [J/cm²]	v [m/sec]	rel14 [%]
	absoulte change	absoulte change	absoulte change	absoulte change	relative change	absoulte change	relative change	absoulte change
1	1.83	1.76	1.98	0.43	19.58	1.28	-5.62	-2.9
2	2.12	1.88	2.43	0.16	7.03	10.38	-8.13	-3.61
3	2.31	1.95	2.67	-0.14	-5.11	47.63	-6.89	-3.44
4	2.47	2.29	2.67	-0.02	-0.6	12.4	-5.8	-2.8
5	2.18	2.15	2.24	0.15	4.05	16	-4.48	-1.46
6	2.19	2.29	2.2	0.13	3.42	16.02	-2.76	-0.55
7	2.41	2.39	2.57	-0.29	-8.78	63.28	-4.51	-1.76
8	2.61	2.39	3.02	-1	-29.58	117.56	-2.28	-4.61
9	2.62	2.23	3.18	-1.01	-29.52	111.15	1.23	-7.27
10	2.71	2.24	3.26	-1.05	-30.71	87.17	-1.66	-7
11	2.51	2.26	2.8	-0.23	-7.6	20.19	-2.09	-4.78
12	2.3	2.22	2.43	0.09	3.51	-10.67	-8.01	-3.19

3 The biomass potential in a regional context

3.1 The regional potential of biomass production

3.1.1 Agriculture and forestry in the study region

The wider Feldbach region in South-Eastern Styria comprises five political districts (Feldbach, Fuerstenfeld, Hartberg, Radkersburg and Weiz) as shown in Fig. 6. The study region 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, the study region is characterised by a high biomass potential and thus promising for bioenergy development. However, because of its location in the shade of the Alps, South-Eastern Styria is characterised by little precipitation.

In the study region, two thirds of agricultural area is cropland. While grassland amounts to some 43,700 ha, cropland corresponds to an area of some 86,600 ha. The main crop cultivated in South-Eastern Styria is maize, which accounts for 47% of total cropland in the region. Woody biomass used for energetic purposes in the study region is of minor importance in that the South-Eastern forest land (151,000 ha) makes up some 15% of the total Styrian forest land. Still, bioenergy based on wood plays a central role in mitigating emissions (in terms of cost-efficiency of the technology as well as economic performance and labour market effects in a regional context) as we will see in later sections of this report.

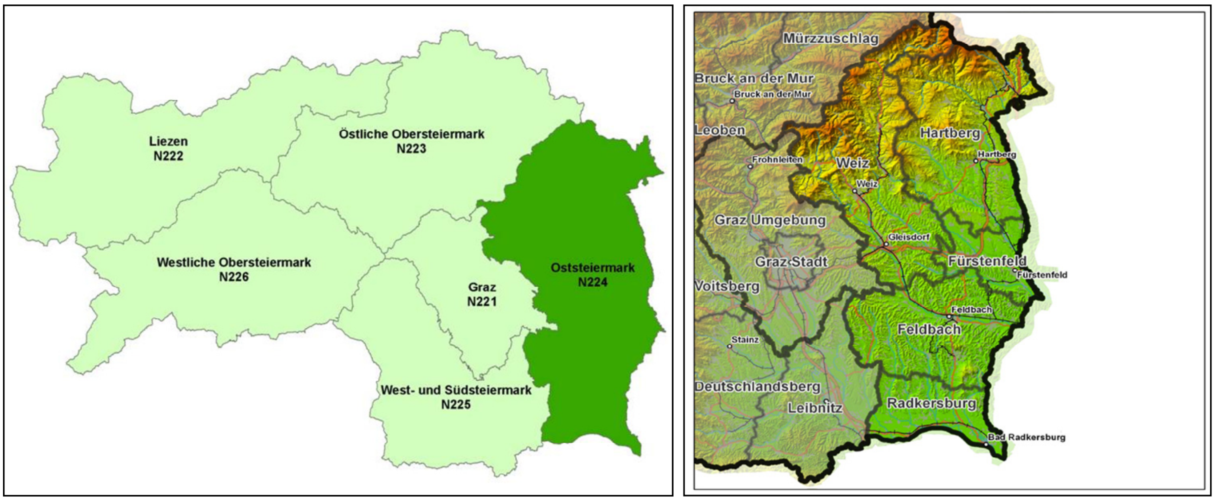

Fig. 6 : The study region in Austria.

At the federal state level of Styria, in 2007 some 5,000 ha (1.03%) of agricultural area were used for biomass production purpose. According to the Integrated Administration and Control System of the European Union (*2007*), 2,100 ha out of these 5,000 are situated in the study region, making up some 1.5% of agricultural area in this region. In terms of energy sources, mainly maize (silage maize, grain maize) is used for energy production (78%), followed by rape-seed (15%) (see Fig. 7). Principally, the study region offers 4.302 ha set-aside land that can be used for energy purposes. However, only 372 ha (8,6 %) were actually used in 2006 (452 ha in 2007). For pure energy crops such as miscanthus, short rotation poplar and willow as well as sorghum there is effort to foster their cultivation in the study region.

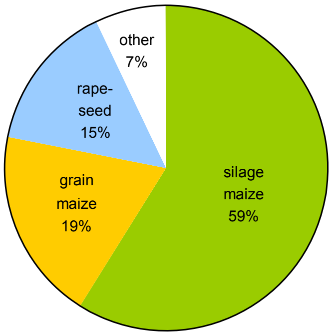

Fig. 7 : Regional energy crop production in the study region in 2007.

Other crops: miscanthus, short rotation poplar and willow, corn, sunflower, grasses, sorghum. Source: Integrated Administration and Control System of the European Union (*2007*).

3.1.2 The additional biomass potential

The additional potential of forestry based biomass in South-Eastern Styria for a time horizon of 2030 is estimated in coordination with the Styrian Agricultural Chamber and amounts to 135,638 solid cubic metres.

Agricultural based biomass includes the complete variety of crops cultivated on cropland and grassland which can be used for energetic purposes. We estimate the additional potential of agricultural biomass under consideration of the dynamics of land use change, i.e. the allocation of cropland, grassland, and woodland. Overall, a national wide decline in crop and grassland has been observed since the 1960ies. This decrease is a consequence of expanded transport infrastructure, a rising share in woodland and the increasing demand for recreational areas. In order to determine the potential of biomass production in a regional context, further factors have to be considered (*Kranzl et al.*, 2008) such as

- the Common Agricultural Policy within the European Union,
- the scope of cattle ranching and grazing land,
- subsidies for landscape preservation,
- demand for agricultural output as well as
- legal, market, and institutional conditions.

Under the very specific assumptions on structural, legal and political future conditions made here, Tab. 4 reports on a 2% reduction in cropland and a 6% reduction in grassland for South-Eastern Styria up to 2030 compared to 2006. At the same time, the relative and absolute share of energy crop production will increase.

As for future energy crop production, following Kranzl et al. (*2008*) we define three scenarios (low, medium, high) which differ by assumptions on the distribution of crops, potential area, development of livestock and the share of agricultural by-products which can be used for energetic purposes. Moreover, we take into consideration the increase in energy crop yields due to breeding progress (1% p.a.). In the high scenario, 28% of cropland and 29% of grassland are estimated to be cultivated by energy crops in 2030. In the low scenario 20% of cropland and 20% of grassland are estimated as potential energy land at that time in the future (see Tab. 4).

Tab. 4 : Estimation of additional biomass potential in the study region by 2030.
Source: own calculations based on Kranzl et al. (*2008*).

	2006 **reference**		**2030** **high scenario**	**2030** **low scenario**
***total cropland and farmland* [ha]**				
cropland	86,613		84,558	84,558
		Δ reference	*-2%*	*-2%*
grassland	43,737		41186	41186
		Δ reference	*-6%*	*-6%*
***potential energy areas* [ha]**				
cropland			23,676	16,912
		share in cropland	*28%*	*20%*
grassland			11,944	8,237
		share in grassland	*29%*	*20%*

3.2 The mitigative potential of regional biomass supply

3.2.1 Regional energy demand for space heating and cooling

In order to capture the impacts on the energy sector in the study region in terms of future conditions, we proceed in two steps: we first calculate the future (2045) demand by households for heat considering non-climate related factors such demographic trend or the insulation/reconstruction of buildings. Second, we include effects from altered climatic conditions on heating and cooling energy demand. This procedure allows modelling the energy sector for a Reference Scenario (without climate change) and a Business As Usual Scenario (including climate change) in the future (see also section 6).

As a first step, energy consumption by households is calculated using the concept of energy services, which 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). As a first step, based on data of the household and population census 2001 (*ST.AT*, 2004a, 2004b) and on population statistics of Statistics Austria (*ST.AT*, 2007a), 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 in South-Eastern Styria (NUTS 3) and of 45.38 million GJ in Styria (NUTS 2). In addition, it is assumed that all new buildings after 2003 fulfill 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). Then, in order to assess the heat demand for different points in time up to 2045, the development of living space (*ST.AT*, 2008) and the projected number and size of households (*Landesstatistik Steiermark*, 2007) are included.

Tab. 5 presents the final demand for heat by households in South-Eastern Styria for different reconstruction rates and under the assumption that all new dwellings are built in low energy house standard. Tab. 6 does the same calculation for Styria. Four different reconstruction rates are simulated (1%, 1.5%, 2% and 3%), with 1% being the baseline. Depending on the reconstruction rate, the demand for heating energy makes up between 6.16 million GJ (3%) and 8.59 million GJ (1%) for South-Eastern Styria (see Tab. 5) and between 25.1 million GJ (3%) and 38.7 million GJ (1%) for Styria (see Tab. 6) in 2045.

Tab. 5 : Final household demand for heat in Region 1 by 2030 and 2045 for different reconstruction rates (low energy house assumption).

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

	final heat demand in SE Styria (new dwellings as low energy houses) [TJ]					
reconstruction rate	2003	2010	2020	2030	2040	2045
1%	9,540	9,352	9,103	8,877	8,675	8,585
1.5%	9,540	9,243	8,841	8,461	8,105	7,938
2%	9,540	9,134	8,578	8,045	7,536	7,291
3%	9,540	8,916	8,053	7,212	6,396	6,162

Tab. 6 : Final household demand for heat in Region 2 by 2030 and 2045 for different reconstruction rates (low energy house assumption).

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

	final heat demand in Styria (new dwellings as low energy houses) [TJ]					
reconstruction rate	2003	2010	2020	2030	2040	2045
1%	45,375	44,228	42,639	41,076	39,508	38,736
1.5%	45,375	43,594	41,114	38,660	36,201	34,983
2%	45,375	42,961	39,590	36,244	32,894	31,231
3%	45,375	41,694	36,541	31,413	26,281	25,108

In a second step, we include the climate component of changed energy demand for heating and cooling based on the climate scenario described in section 2. Note that the share of cooling energy in overall energy demand is negligibly small in the agrarian study region considered here. The absolute increase in climate-induced demand for cooling energy (+24 TJ) are clearly dominated by the effects from the climate-related reduction in heating energy (-1,796 TJ) caused by higher winter temperatures (see *Koland – Steininger,* 2008).

3.2.2 Energy provision by the additional biomass potential

Once the additional regional biomass potential under future conditions (section 3.1.2) and the regional energy demand of households (section 3.2.1) are estimated, the mitigative potential in terms of bioenergy can be assessed. We will thus determine how much of the energy consumed by households in 2045 can be substituted by locally produced biomass once its output has reached the anticipated targets.

In order to assess how much of energy demand in 2045 can be supplied by the additional biomass potential, we choose a specific mix of energy crops which is cultivated on the potential cropland available for energy purposes (see Tab. 4). In particular, it is assumed that the following crops take up each 20% of the potential cropland. Their utilization and the thus produced amount of energy per hectar [TJ/ha] are as follows (see Tab. 7 for energy coefficients):

- maize (for the production of bio-gas)
- rape-seed (for bio-diesel)
- miscanthus pellets (for heat)
- whole plant corn (for heat)
- poplar pellets (for heat)

Our calculations are based on the additional agricultural and forestry biomass potential as calculated in section 3.1.2. (in the high scenario the agricultural potential amounts to 23,676 ha in South-Eastern Styria and to 40,544 ha in Styria, in the low scenario this potential makes up 16,912 ha in South-Eastern Styria and 28,960 in Styria in 2030). Since estimates are getting increasingly uncertain in the further future, we assume the same values for the year 2045.

As for forestry biomass, it is assumed that the additional potential is used in the following manner (see Tab. 7 for energy coefficients):

- 10% wood chips
- 50% wood logs
- 40% wood pellets

Tab. 7 : Production of energy per hectare of biomass crops.

Energy coefficients per hectar biomass crops		
agricultural biomass		[TJ/1000 ha]
maize		75.94
rape-seed		32.52
miscanthus pellets		166.70
whole plant corn		103.91
poplar pellets		151.55
forestry biomass	[rm] (1)	[TJ/1000 ha]
wood chips	13563.8	6.40
wood logs	67819.0	7.26
wood pellets	54255.2	6.40

[1] solid cubic metre

We calculate with an additional forestry potential of 135,638 solid cubic meters in South-Eastern Styria and of 900,000 solid cubic meters in Styria in both the low and the high scenario in 2030.

Moreover, for the future energy demand by households, we take the assumption of new houses to be built uniformly in low energy standard. Thus, under a reconstruction rate of 1%, for example, the demand for heating energy makes up 8.9 million GJ in 2030 and 8.6 million GJ in 2045 for South-Eastern Styria; the demand for Styria amounts to 41.1 million GJ in 2030 and 38.7 million GJ in 2045.

In order to guarantee that the regional biomass potential can be fully exploited, those technologies, which are not able to compete with the reference technology (oil), are assumed to be subsidized or implemented according to a legal ordinance.

We are now in the position to show the increase in the households' future energy demand for space heating that can be served by exploiting the region's biomass potential. The fraction of additional bioenergy is calculated for 2030 and 2045. Fig. 8 shows the results for South-Eastern Styria and for the whole region of Styria. What can be seen as well is the different initial shares in agricultural and forestry biomass in both regions, with forestry biomass dominating in Styria and vice versa in its South-Eastern part.

Depending on the assumed biomass potential (low, base, high), some 21% to 23% of regional energy demand by households can be supplied by additional biomass in South-Eastern Styria by 2030 (10% forestry, 13% agricultural). These values rise to some 27% to 33% by 2045 (10% forestry, 23% agricultural). In Styria some additional 18% of Styria's energy demand can be produced by 2030 by the additional biomass potential (14% forestry, 4% agricultural), increasing to some 20 to 22% by 2045 (13% forestry, 9% agricultural).

These shares can be increased when insulation measures are expanded. With a reconstruction rate of for example 1%, the fraction of additional bioenergy in total regional energy demand can be increased by up to 5% for South-Eastern Styria by 2045 and up to 4% for the region of Styria (both values for the high scenario).

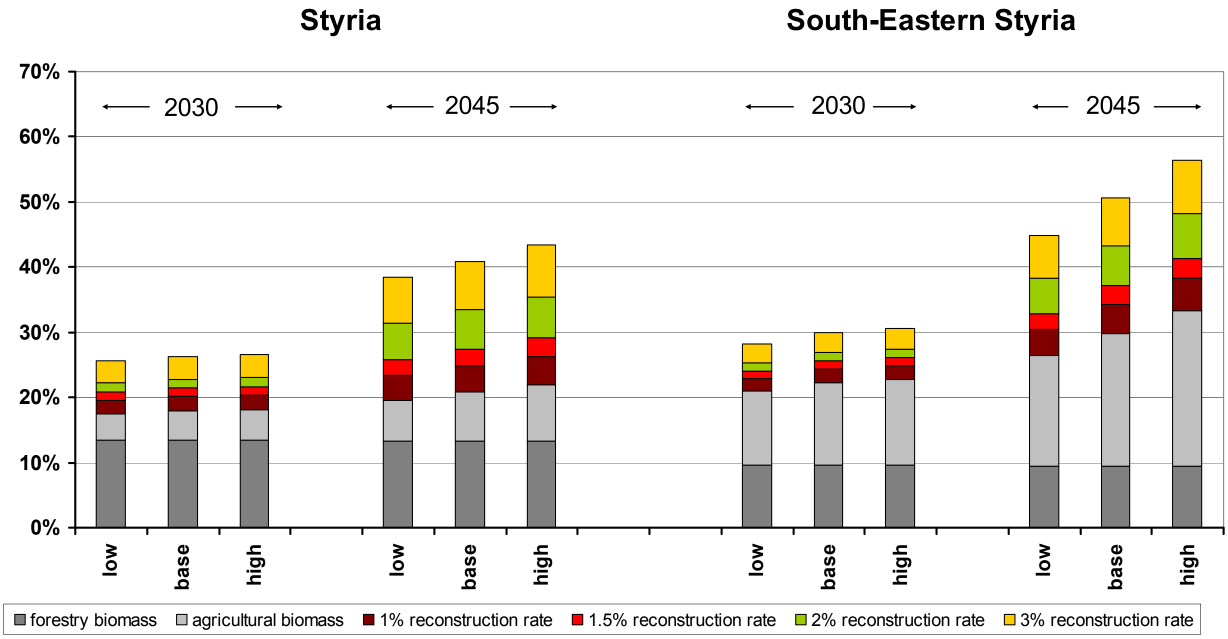

Fig. 8 : Fraction of additional bioenergy in total regional energy demand by households under different reconstruction rates by 2030 and 2045.

4 Cost analysis of biomass energy production by technology

4.1 Cost factors in biomass energy production

The cost efficiency of biomass technologies is a decisive factor that determines to what extent energy services are provided from biomass resources. Bentzen et al. (*1997*), for example, show that although wood based heating systems are generally cheaper than the fossil alternative, the substitution process of biomass for fossil fuels is slow. High investment and low operating costs, e.g. cheap fuel costs, imply that a high level of energy consumption is necessary to make biomass technologies profitable. Furthermore, risk aversion of consumers might be a barrier in that it prevents investments in biomass based heating systems.

The costs of energy services provided by the use of biomass are determined by various factors. In general, total expenditures can be split up into single expense factors such as fuel costs (i.e. the cost of biomass products), costs of capital and costs of operation and maintenance. In the present approach, land use rent is only considered for agricultural crops. Moreover, the calculations include the cost of processing and transporting. For the case of pellets, namely agro pellets or wood pellets, given biomass production costs have to be adjusted by adding costs of producing pellets.

4.1.1 Costs of energy crop production

Fuel costs, i.e. the costs of biomass pre-products, form the basis for an estimation of energy supply costs. Fuel costs are predominantly determined by yearly energy costs (such as costs for oil, pellets or wood chips). They include additional costs of heat and electricity that occur in system operation. The costs of electricity are included by taking conventional household prices (16 Cents per kWh) (*E-Control,* 2007) into account. In order to guarantee the comparability of results, agricultural and other subsidies are not included. Since here fuel costs equal regional production costs, the calculated costs of biomass pre-products used for energetic purpose could possibly differ from current market prices. Tab. 8 compares the fuel costs of biomass supply by biomass pre-product for different solid biomass resources.

Tab. 8 : Fuel cost of biomass supply by biomass pre-product (2006).

Biomass energy pre-product	unit	**fuel costs [€]**
solid biomass resources		
wood chips	Srm[1]	20.17
wood logs	rm[2]	54.90
wood pellets	kg	0.19
poplar pellets	kg	0.30
Miscanthuspellets	kg	0.34
grain pellets	kg	0.33
straw pellets	kg	0.14
Miscanthus (whole plant)	Srm	16.10
energy corn (whole plant)	kg	0.19

[1] amount of a cube full of loosely poured wood chips with a side length of one metre

[2] cubic metre

The costs of energy crops (miscanthus, straw, grain, poplar, energy corn) are calculated by using a full cost accounting method (for details on the method see *Steininger et al.*, 2008). This approach is designed for the medium and long-term perspective and considers both variable costs (seeds, labour, fertilizer, pest management, insurance, variable costs of machinery, harvesting, transport, drying) and fixed costs (lease, fixed costs of machinery).

4.1.2 Capital costs and costs of operation & maintenance

The costs of capital per year are calculated by using the method used by Kaltschmitt – Hartmann (*2002*). It splits up total costs of ownership and allocates them to single years of the assumed service life of the heating system (the planning horizon covers 20 years). This results in the annuity, which can be interpreted as yearly payment for redemption of capital. Thus, total yearly costs of capital are calculated by adding all required capital investments split up according to the method used here.

The costs of operation and maintenance per year include the costs for repair, service and maintenance. It is assumed that the yearly costs of maintenance vary between 0.5% and 1% of total capital expenditure. Furthermore, the costs of operation and maintenance take account of administrative costs, risk costs, costs of insurance and labour costs. With heating systems that have a capacity range below 100 kW, theses costs can be neglected, however.

4.1.3 Costs of production and distribution of pellets

The usage of pellets is quite convenient and therefore very popular in private households. Hence, if heating systems are based on pellets, given costs structures have to be adjusted by the costs of producing and distributing pellets to final consumers.

The cost structure shown in Tab. 9 is based on the work of Eder (*2007*) and estimates costs for the production of 10,000 t pellets per year. The costs of resource inputs (agricultural crops, wood) are excluded here. Both agro pellets (pellets made of agricultural crops) and wood pellets are considered.

Wood pellets are currently widely used inputs in single home heating systems. Although the production of agro pellets is – from a technological point of view – feasible and cost-efficient, there is no widely spread usage of agro pellets as energy input. One reason for this development can be found in the negative combustion features of agro pellets, namely the high emissions of nitrogen oxides and particular matter, the high ash content and the low fusibility of fuel ash which occur to their usage in heating systems.

Tab. 9 : Costs of pellets production and distribution (2006).

Calculations excluding resource cost and considering a yearly production of 10,000 t. Source: own calculations based on Eder (2007).

Costs of pellets production and distribution	agro pellets	wood pellets
costs of capital	172,764 €	194,422 €
fuel costs	640,000 €	506,396 €
costs of operation and maintenance	291,825 €	291,825 €
total costs	1,104,589 €	992,643 €
total investement costs	1,570,000 €	1,753,000 €
costs of pelleting	76 € per t	64 € per t
costs of distribution (incl. risk loading)	3 € per t	34 € per t

4.2 Cost effectiveness of biomass technologies

This section compares the cost effectiveness of selected biomass technologies. The overall cost calculation for biomass energy supply is based on the method as in Steininger et al. (*2008*). It considers the demand for heat, which is calculated by the building's space heat load and the yearly full load hours (1500 h/a). More specifically, the technologies analysed here are single home heating systems with a space heat load of 15 kW. Considering the net-energy demand and taking into account grid losses as well as specific fuel characteristics, the yearly demand for fuel is calculated. Including system costs of effective energy supply and taking into account a service life of 20 years, yields total annual mean costs by technology as well as total costs per kilowatt hour. Moreover, the calculations are based on real values, i.e. costs and prices are adjusted for differences in price levels over a specific period of time (inflation). Here we assume that investments of private households are subject to a real interest rate of 2.2%.[1]

Summing up over all cost factors mentioned above (section 4.1), Tab. 10 gives an overview of the cost of biomass energy production for nine different single home heating options. In particular, the single home heating systems given in Tab. 10 are based on wood chips, wood logs, wood pellets, poplar pellets, miscanthus pellets, grain pellets, straw pellets, miscanthus (whole plant) and energy corn (whole plant). In addition, the single home heating system based on oil is listed as a reference fossil fuel technology.

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[1] The real interest rate of 2.2% is calculated by the inflation-adjusted geometric mean of the Secondary Market Yield between the years 1997 and 2006 in Austria (*Austrian Central Bank*, 2007, *ST.AT*, 2007b).

Tab. 10 : The cost of biomass energy supply by technology (2006).

Technology	**Supply costs [€/MWh heat]**
single home heating systems (15 kW)	
wood chips	10.6
wood logs	8.5
wood pellets	9.9
poplar pellets	9.8
agro pellets (Miscanthus)	12.0
agro pellets (grain)	14.2
agro pellets (straw)	12.3
Miscanthus (whole plant)	11.3
energy corn (whole plant)	14.3
fuel oil[1]	11.7

[1] assumption: fuel oil price of 69 Cents per litre (mean price in 2006 excl. tax)

The calculations in Tab. 10 show that using current oil prices as reference, biomass technologies based on wood (chips, logs or pellets) are cost efficient. We find cost savings between € 1.1 (chips) and € 3.2 (logs). More specifically, heat services produced with wood logs have the lowest production costs per kWh since they do not involve any refinement of biomass. Further technologies showing lower costs than the fossil fuel system are those based on miscanthus (whole plant). On the other hand, costs of heating systems based on agro pellets exceed fossil fuel costs between € 0.3 (miscanthus) and € 2.5 (grain) per megawatt hour. The costs of a heating system based on energy corn do so by € 2.6.

Altogether, heating systems based on wood biomass are generally cost efficient relative to the fossil alternative. While wood based heating systems are cost efficient in buildings with a low space heat load, systems based on agricultural biomass are only profitable with high levels of energy consumption (i.e. with a space heat load beyond 30 kW) due to high investment costs.

When analysing the costs of biomass energy supply by technology under future conditions, however, we have to consider price changes (e.g. for energy prices or wages) as well as technological developments over time. Whereas fossil based technologies are expected to rise sharply in cost per kWh (due to rising energy prices), costs of heat produced from biomass might just slightly increase. Hereby, the change in costs for biomass technologies inter alia depends on how much energy they need in production. Altogether, on future markets the cost of bioenergy will be getting relatively cheaper compared to the conventional (fossil fuel) technology.

5 The regional economic model

5.1 Model structure

5.1.1 The basic set-up

The present project employs a comparative static three region CGE model, which is developed within GAMS (*Brooke et al.*, 1998) using the modelling framework MPSGE (*Rutherford*, 1998). The core region, Region 1, is fully embedded within Region 2, and both Region 1 and 2 are surrounded by Region 3 (see Fig. 9).

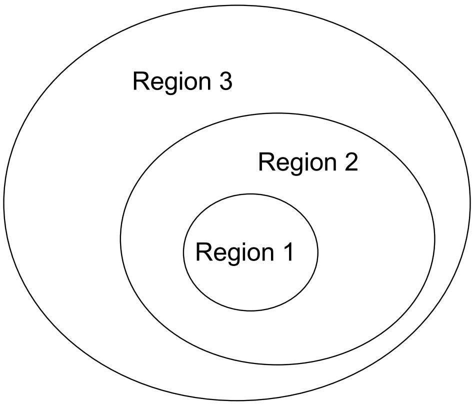

Fig. 9 : The three stylized regions of the model.

In terms of empirical implementation, South-Eastern Styria 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" (Region 3) including the rest of Austria and abroad. While Region 1 and Region 2 are fully modelled, the model is closed by connecting Region 3 via trade flows.

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.

Furthermore, 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 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.

5.1.2 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 and services. This bundle involves private consumption, investments and stock changes. 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, $i = 1,...,n$. 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 cropland) 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

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

Note that a different bundle for space heating service is specified. 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.

Furthermore, 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).

5.1.3 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 (labour, capital, land) and intermediate inputs from other sectors. On the top level of the production structure intermediate inputs are combined with an aggregate of land, labour, capital and energy, involving fixed input coefficients (i.e. the elasticity of substitution equals zero). One level below, a small elasticity between land and other inputs is assumed to highlight the importance of the factor land in agricultural production. The exact values for the respective production elasticities are given in Tab. 11.

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. In particular, the higher the reconstruction rate, the higher the demand for insulation material and the lower the demand for heat products.

5.1.4 Trade

Commodities can be traded across the three regions, modelled under the Armington assumption (see Fig. 10).

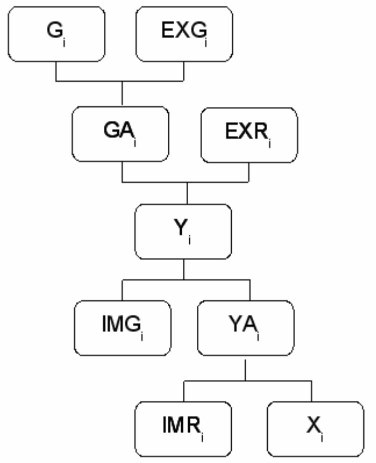

Fig. 10 : The structure of foreign trade under the Armington assumption.

Domestically 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. 12).

5.2 Calibration

The model is calibrated to the year 2003. As a first step, the exogenous parameters and initial variables are specified in order to calibrate the reference equilibrium, thereby reproducing the economic data of 2003. This specification is the model's baseline in 2003.

The elasticities of substitution in production and the trade elasticities of substitution, i.e. the Armington elasticities, are listed in Tab. 11 and Tab. 12. The Armington elasticities vary between sectors and by kind of trade, i.e. regional or global trade. In particular, higher preferences for goods produced regionally within Region 2 are reflected by higher elasticities for regional trade flows, i.e. trade between Region 1 and Region 2, than for global ones, i.e. flows to and from Region 3.

Tab. 11 : Elasticities of substitution in production.

Elasticities start from the highest nesting level. Source: own assumptions for the two upper levels; in the lower nesting levels, the elasticities are in the range of those from Wissema and Dellink (2007); Rutherford and Paltsev (2000).

elasticities of substitution in production	value
between intermediate inputs and aggregate land-labour-capital-energy	0.00
between land and other inputs (labour, capital, energy)	0.10
between labour and aggregate capital-energy	0.85
between capital and energy	0.65
between elecricity and fossil fuels	0.20
between coal and aggregate oil-gas	0.50
between gas and oil	2.00
between other oil products and diesel	0.01

Tab. 12 : Armington elasticities per sector.

Source: Welsh (2008). For sector classifications see the Appendix.

Armington elasticities per sector	value	
	regional trade	**global trade**
ÖNACE sector		
01	1.200	0.900
0205	0.447	0.298
1014	0.039	0.026
1014	0.800	0.533
1516	0.891	0.594
1719	1.200	0.800
20	0.503	0.335
21	0.150	0.100
22	0.469	0.313
23	0.039	0.026
24	0.600	0.400
25	2.250	1.500
26	0.337	0.224
2729	1.200	0.800
3033	0.225	0.150
3435	0.300	0.200
36	0.503	0.335
37	0.300	0.200
40	0.039	0.026
41	0.300	0.200
45	0.503	0.335
5052, 55, 6067, 7074	0.300	0.200
57, 80, 85	1.800	0.200
9095	0.300	0.200

The regional Social Accounting Matrices our model employs are estimated by biproportional adjustment based on regional Make and Use tables (most recently available for the year 2003). As these tables do not focus on energy or environment, they had to be adjusted for our purposes using the data of the regional energy balance calculations provided by Statistics Austria (*ST.AT*, 2006a). Tax statistics (*ST.AT,* 2006b) and the regional statistics handbook for Styria (*Arbeiterkammer*, 2007) served as database for the macroeconomic framework data (unemployment, transfers, taxes).

5.3 Quantitative assessment of a biomass expansion by technology

In this section we seek to compare various biomass technologies in their effect on macroeconomic indicators once their use is expanded. We do so for the baseline of 2003 as developed in section 5.2. Note that, for the moment, we do not consider changes in economic values over time such as e.g. future price changes or technological improvements. Taking into consideration these developments as well may alter some of the results obtained in this section. We will discuss them briefly at the end of this section.

5.3.1 CGE implementation of biomass technologies

For a comparative evaluation of the different biomass heat technologies we choose a uniform expansion in terms of energy content across technologies. In particular, we analyse a substitution of 2000 TJ use energy supplied by fossil fuel heating systems by each of the different biomass heating systems introduced in section 4. This represents about 20% of total energy demand for space heating in the study region (Region 1), as estimated in section 3.2. We take account of the subsidies already in place. For those technologies that – even with present subsidies – are more expensive than the fossil ones, households are assumed to take the extra costs.

In biomass foreign trade we assume import quotas which determine the proportion of biomass imported from Region 3 (rest of Austria and rest of the world), as given in Tab. 13. The quotas are 0% for pellets, for which domestic national supply exceeds demand (*IEA*, 2007), 10% for wood bases biomass products (*Federal Ministry of Agriculture, Forestry, Environment and Water Management*, 2006), such that national targets can be achieved, and the status quo (8%) for agricultural biomass products (*Eurostat*, 2007). For each import quota we assume the regional import quota to be in line with the national one. As we are interested in regional effects and their spill over to neighbouring regions, we implement the biomass expansion only in Region 1, and analyse impacts on both Region 1 and Region 2.

5.3.2 Regional macroeconomic effects by technology

From an expanded biomass production based on forestry biomass (see Fig. 11), we find positive regional effects on employment and GDP. For wood based biomass (wood pellets, wood logs and wood chip), it is principally three factors that govern the regional macroeconomic results: labour demand, demand for heating system infrastructure, and production costs.

In particular, heat services produced with wood logs show the highest combination of GDP and employment effects. Effects are similarly positive for the case of wood chips, where significant investments in infrastructure (e.g. storage construction) are necessary for installing this technology. These investments generate demand in the building and construction sector, both being characterised by a high labour intensity.

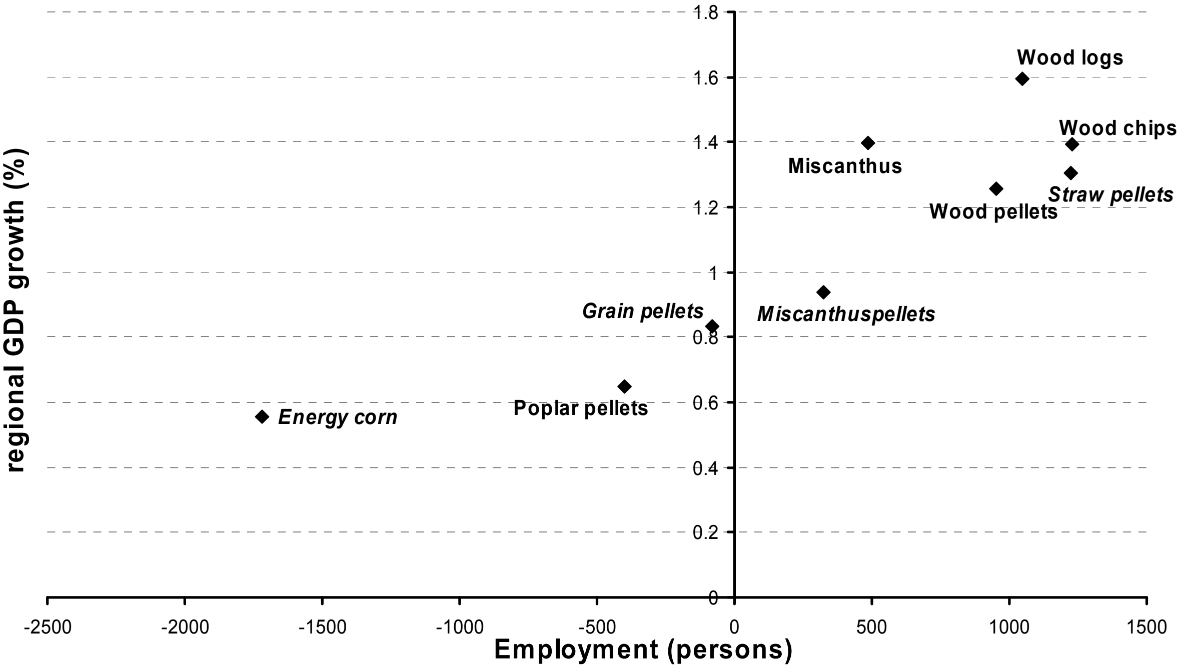

Fig. 11 : Economic performance and employment effects through expanded biomass use in Region 1.

Regarding heat produced with agricultural biomass, on the other hand, results diverge more significantly across technologies. In addition to the three factors mentioned above (labour intensity, production costs, and of less importance here, infrastructure investment), agricultural biomass crucially depends on cropland requirements. This factor has a significant impact on the production level of the agricultural sector, since conventional agricultural production is crowded out by the competition for cropland for biomass usage. Furthermore, a decrease in conventional agricultural production implies a decline in food production.

In analysing the agricultural biomass technologies in detail, heat produced from poplar pellets requires both a low amount of labour and almost no investments in infrastructure or machinery, resulting in a weak net employment effect and a moderate GDP effect. For miscanthus (whole plant), miscanthus pellets and grain pellets, significant investments in infrastructure and machinery are needed (both representing labour intensive intermediate supplies). Moreover, these three technologies do involve different production costs, but also different state-paid subsidy rates. A higher subsidy rate (as for e.g. grain pellets) reduces labour intensive government consumption. The highest employment effects are found for straw pellets. This is because straw is a residual product and therefore no extra cropland is needed, which would otherwise place it in competition with the conventional agricultural sector. By contrast, energy corn combines the characteristics of highest cost and lowest area yield rate, resulting in the lowest GDP growth rate and highest loss in employment.

Note that both the labour intensity and the land intensity differ notably across biomass products. Concerning labour intensity, forestry products show higher values (between 0.51 and 0.56) than agricultural conventional products (0.28), but agricultural biomass products still show a lower one (between 0.08 and 0.22)[2]. These values result from the fact that biomass products require more advanced machinery rather than labour input. Thus, when land intensive products such as agricultural biomass products are crowding out conventional agricultural activities, they reduce overall labour demand.

Moreover, a biomass expansion in Region 1 involves spill-over effects to the surrounding Region 2, which are highly correlated to the employment effects observed in Region 1. A rise in household consumption and income together with the thus arisen increase in government consumption in Region 1 (due to a reduction in unemployment benefit payments), stimulates the demand for goods and services produced in Region 2. This effect is crucial for the sectors health services, education and public services, which are characterised by a high labour intensity. It triggers a circular effect enhancing again an increase in employment and therefore an increase in consumption by households and the government in Region 2. Stated more generally, peripheral (or rural) regions in their growth cause increased demand for services, which such regions usually import from neighbouring central regions. Tab. 13 summarises the effects on GDP and employment for both regions.

Tab. 13 : Effects by technology on regional GDP and employment through biomass energy expansion in the baseline 2003.

	import quota[1]	regional GDP		Employment	
		Region 1	Region 2	Region 1	Region 2
		change in %		persons	
single home heating systems (15 kW)					
wood chips	10%	1.39	0.06	1226	178
wood logs	10%	1.59	0.04	1047	167
wood pellets	0%	1.26	0.05	951	194
poplar pellets	8%	0.65	-0.02	-399	-152
agro pellets (Miscanthus)	8%	0.94	0.05	322	112
agro pellets (grain)	8%	0.84	0.02	-81	-5
agro pellets (straw)	8%	1.30	0.11	1222	364
Miscanthus (whole plant)	8%	1.40	0.04	484	81
energy corn (whole plant)	8%	0.56	-0.11	-1721	-581

[1] percentage of biomass pre-products (e.g. rapeseed) imported from global markets

5.3.3 *Sensitivity of results*

We first test for the sensitivity of our results (on GDP and employment) with respect to changes in various parameters. These include energy prices, the interest rate and the global trade elasticity for agricultural commodities. First, higher energy prices favour the usage of biomass

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[2] These values for the labour intensity refer to the share in production costs, i.e. a value of e.g. 0.22 indicates that 22% of production costs are wage payments.

since biomass production becomes more attractive. In quantitative terms, some 50% higher energy prices results in some 40% increase in regional GDP. Second, the level of the real interest rate determines the capital cost of investments. Compared to conventional (fossil fuel) heating systems, biomass technologies show a very high capital commitment and thus high investment costs. The real interest rate strongly influences capital costs and therefore affects the competitiveness of biomass technologies. It follows that low interest rates favour the use of biomass technologies, whereas high interest rates hinder energy production from biomass due to high capital costs. Third, assumptions on the global trade elasticity only affect results concerning agricultural based technologies. In particular, a higher elasticity increases the amount of agricultural imports, because prices for agricultural commodities from biomass production become relatively high. Another effect of high trade elasticities is observed on the development of land prices (e.g. the increase in land prices is slowed down by11% with an elasticity raised by the factor 3).

6 Scenario Development

6.1 Stakeholder Dialogue and Scenario Construction

Based on the analysis of the potential biomass production and its economic impacts, the research team discussed apriori scenarios with respect to future mitigation and adaptation strategies in the agricultural sector of South-Eastern Styria. This was done in a workshop with all project participants at WIFO in November 2008.

In order to discuss the developed adaptation scenarios with experts from professional associations and industry, a stakeholder-dialogue was held in January 2009 at the Wegener Center in Graz. Representatives from the chamber of agriculture of Styria were invited to participate in the discussion of options and challenges of adaptation in South-Eastern Styria in the forest and agricultural sector. The dialogue was aiming at two major objectives: first, local knowledge regarding adaptation options for livestock and crop production in the light of climate impacts such as drought, heat and increased extreme events should be elicited and, second, representatives from industry and professional associations should be integrated into the process of scenario development in order to share knowledge and drive research results more application oriented.

It was concluded to investigate three alternative mitigation and adaptation scenarios in order to isolate the respective adaptation and mitigation impacts in the corollary of the project. Thus, starting from the Reference Scenario for 2045 (without climate change), we construct three specific scenarios on the likely development of the economy under climate change by 2045 as well as of its response strategies in order to mitigate emissions and/or to adapt to an altered environment (see Tab. 14).

- The Business As Usual (BAU) Scenario starts from the Reference case (without climate change) and includes impacts due to climatic variations as well as spontaneous reactions by consumers and producers to climate change.
- The two policy scenarios, on the other hand, build on the BAU Scenario and introduce mitigation and adaptation activities.

Adaption strategies are organized along the dichotomy of spontaneous or autonomous versus planned adaptation (*Smit – Skinner,* 2002). Furthermore, we conduct a fourth simulation, which combines the scenarios of mitigation and adaptation. It is important to mention that the scenarios are not understood as a forecast. In fact, we will compare the effects of the different response strategies calculated as deviations from the BAU Scenario, thus serving as a benchmark.

Tab. 14 : Overview of the scenarios.

scenario	time horizon	climate change	autonomous adaptation	policy
Reference	2045	no	no	no policy
Business as Usual (BAU) *(based on Reference)*	2045	yes	yes	no policy
Policy induced Adaptation *(based on BAU)*	2045	yes	yes	research subsidisation for breeding and cultivation of resistant plants
Mitigation (*based on BAU)*	2045	yes	yes	bio-energy expansion (biomass premium) and intraregional trade of organic fertilizers

6.2 Scenario without climate change (Reference Scenario)

Building on the base run for the year 2003 (as in section 5.2) the Reference Scenario for the year 2045 is developed by extrapolating the macroeconomic framework data for the study region. The Reference Scenario does not include any climate change. Then, population growth, factor input growth, factor productivity, energy prices and demand for heat, electricity and transport are projected into the future. These values are given in Tab. 15. 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. 5.

Tab. 15 : Parameter values and exogenous and initial values for the development of the Reference Scenario 2045.

exogenous and initial values	value		source
	Region 1	**Region 2**	
growth of capital stock	0.6 % p.a.	0.6 % p.a.	EU KLEMS (2007)
change in labour force until 2045	-11.78%	-7.99%	own calculation based on ST.AT (2006c)
global real price change for energy	+14.5% (coal); +29% (oil products); +29% (gas); +19.3% (electricity)		own calculation
productivity growth (initial value)	between 0.31% and 2.41% p.a. (varying between sectors)		own calculation based on EU KLEMS (2007)
reconstruction rate (initial value)	1.0 % p.a.	1.0 % p.a.	assumption
consumer demand of heat up to 2045 (initial value)	+ 3.71%	+ 1.84%	own calculation
consumer demand of fuel up to 2045 (initial value)	+ 16.87%	+ 26.52%	own calculation
consumer demand of electricity up to 2045 (initial value)	-18.91%	-14.85%	own calculation

Moreover, in agriculture and forestry, the Reference Scenario anticipates policy changes by the 2040ies according to the expected Common Agricultural Policy (CAP) developments and market adjustments. Furthermore, price trends and changing costs over the next decades are based on latest OECD-FAO projections, which are linearly extrapolated to 2045. The policy changes include

- abolishment of milk quota by 2015
- further decoupling of direct payments and changing from individual single farm payments to regionally based farm payments
- towards regionally homogeneous per hectar premiums
- reduction of direct payments (first pillar of the CAP) by 50%
- no change in level and design of payments within the program of rural development (second pillar of the CAP)
- no set-aside obligations for cropland (Stilllegungsverpflichtung) for 2015 and 2040
- net reduction in overall land used in agriculture and forestry (stronger reduction in crop- and grassland and relative increase in forest lands)
- change in total livestock housing capacities
- no intra- and interregional trade for livestock manure

Under these assumptions, the Reference Scenario for 2045 is characterised by the economic performance (nominal quantities) presented in Tab. 16, including GDP, welfare[3], consumption price index, level of agricultural production, factor prices for labour and capital and agricultural price level.

Tab. 16 : Reference Scenario for 2045 (future scenario without climate change).

Reference Scenario 2045			
		Region 1	Region 2
Economic Performance			
GDP	[2003 = 100]	163.99	208.25
GDP growth	[% p.a.]	1.21	1.81
Welfare	[2003 = 100]	199.3	274.3
Welfare growth	[% p.a.]	1.70	2.49
Unemployment rate	[%] [2003: Region 1: 3.6 Region 2: 4.0]	2.68	3.42
Consumption price index	[2003 = 100]	90.7	95.9
Agricultural production level	[2003 = 100]	111.0	109.3
Factor prices			
Labour	[2003 = 100]	278.0	329.0
Capital	[2003 = 100]	124.8	156.1
Price level agriculture	[2003 = 100]	124.4	143.6

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[3] The welfare index in the present model corresponds to a Hicksian Equivalent Variation index.

6.3 Scenario with climate change (Business as Usual Scenario)

The BAU Scenario comprises, contrary to the Reference Scenario, physical and economic impacts from climate change on agriculture and energy, including also autonomous adaptation in these sectors. In particular, spontaneous adaptation by consumers and producers is modelled on the supply side for agriculture (expressed by a shift in the production function), while modelled on the demand side for energy (corresponding to a shift in energy demand for heating by households).

An agricultural and forestry production and land use model is used to analyse the impacts of climate change on agricultural and forestry sectors in the regions. The model is a bottom-up, recursive dynamic, quadratic programming model consisting of all major production and land use activities as well as management options in the Austrian agricultural and forestry sectors (based on the static model as in *Schmid – Sinabell*, 2007). The model is calibrated to historic production and land use activities using the Positive Mathementical Programming (PMP) method and allows integrating of new and alternative production and management options. The model is structured with respect to time periods, regions, farm sizes, farming systems (i.e. organic and conventional farming), land categories and land uses, crop management measures (e.g. winter cover crops), tillage systems (e.g. minimum, reduced, and conventional tillage), livestock categories as well as livestock housing and manuring systems. Consequently, farm structural changes (i.e. larger farms) are endogenously modelled. All major CAP instruments – market organisations and programme for rural development - are integrated in the model.

In this analysis, the model is calibrated to the BAU scenario, which already anticipates autonomous adaptation to climate, policy and price changes. The effects of additional mitigation and adaptation measures are modelled by changes in policies (e.g. biomass premium), reduced negative crop yield impacts due to better adopted crops, and better infrastructure for surplus manure trading in within and between regions. These options are modelled separately and simultaneously as well as with different degrees of intensity.

In agriculture, climate change can cause positive or negative shifts in crop yields since temperature and precipitation patterns change according to the climate scenario for the study region (see section 2). For the six major crops of the study region, the estimated crop yield changes between current levels and projected levels in 2040s are -4.5% for grain maize, -6.6% for silage maize, -3.4% for soft wheat, -3.1% for winter barley, -31% for meadows and +11% for oil pumpkin (for method and calculations see *Koland – Steininger*, 2008).

Major results of the BAU Scenario from the agricultural production and land use model are reported in Tab. 17. The figures represent percentage changes between 2045 and 2006 model results. The model results anticipate changes - as described before - in crop yields, prices, costs, and CAP policies as well as an exogenous trend in agricultural and forestry land cover. It is expected that crop yields are decreasing due to climate change, 1st pillar budget is cut by 50%, and commodity prices and production costs are increasing, which lead to positive total net return changes for Fuerstenfeld, Radkersburg, and Feldbach and to negative ones for Hartberg and Weiz. The positive changes are mainly due to increased livestock production and increased farm structural changes. The negative changes are mainly consequences of extensification in production and increased agricultural land abandonment in these regions. The model also reports that land for short rotational poplar and willow plantations is already increasing in the BAU Scenario, because it is expected that climate change impacts are not as severe as for meadows and crops. Furthermore, the share of organic farming is increasing in all regions but mainly in Feldbach and Radkersburg, however, assuming that the commodity price wedges between conventional and organic products remain. The consequences of intensification and extensification in agricultural production are also captured in the other figures of Tab. 17. Commercial fertilizers are less purchased due to increased livestock and therefore manure production as well as to extensifications in land use management. Labour and intermediate inputs (e.g. feeds) are more required, because of increased livestock production and land is marginally devalued due to more extensified land uses and aforestations.

Tab. 17 : Changes in net returns, production level and operating input structure at farm level for each district in the study region (2045 compared to 2006).

	total net returns	**production level**	**intermediate inputs**	**machines**	**fertilizers**	**labour**	**land**
Fuerstenfeld	+6.8%	+20.1%	+39.5%	+3.9%	-33.9%	+24.4%	+0.3%
Radkersburg	+3.0%	+4.1%	+5.5%	-2.0%	-72.0%	+7.8%	-2.5%
Feldbach	+8.6%	+27.0%	+47.0%	+4.7%	-58.2%	+34.2%	-4.8%
Hartberg	-12.1%	-6.3%	+2.6%	+0.3%	-56.1%	+8.1%	-19.5%
Weiz	-7.7%	-5.1%	-1.2%	+0.8%	-48.8%	+16.3%	-18.9%
Region 1 (South-Eastern Styria)	-1.94%	7.33%	19.70%	1.59%	-53.27%	19.36%	-7.98%

Climate related economic impacts on crop yields are modelled in the CGE model via a shift in “efficiency land”, a modelling concept for climate impact analysis first introduced in *Koland – Steininger* (2008). I.e. the productivity of land alters when temperatures rise and precipitation patterns change. In doing so, the amount of land, which is measured in terms of efficiency units, decreases if climate conditions cause damages on crop yields.

As a second step, we explore the behavioural consequences of agents due to climate change in the energy sector. Again, based on the future climate scenario for the study region, which shows an increase in the average temperature over the next decades (see Tab. 3), we quantify the shift in energy demand by households for heating and cooling (autonomous adaptation by consumers). The climate component of changed energy demand (in contrast to technical and socio-economic developments in the building sector that affect energy demand – as e.g. indicated by Tab. 5 for the case of heating energy) is indicated by a shift in the number of heating and cooling degree days. The calculations show that, in absolute terms, the climate induced increase in demand for cooling energy (+24 TJ) is clearly dominated by the reduction in heating energy (-1,796 TJ) caused by the warming (for method and calculations see *Koland – Steininger*, 2008)

6.4 Policy induced Adaptation Scenario

In contrast to the BAU Scenario, where farmers adapt autonomously to the shift in climatic conditions, here adaptation takes the form of a policy-induced response strategy, i.e. political intervention takes place with the overall aim to reduce vulnerability of impacted regions and increase the adaptive capacity of farmers. There are two options in general (*Smit – Skinner,* 2002). Policies may either be implemented in order to directly support farmers by developing governmental subsidy and insurances programs (e.g. insurance and income stabilization programs), or they may foster technological developments, e.g. by supporting research efforts on breeding of heat and drought tolerant plant varieties, or on the development of new management practices and pest strategies towards invasive species. The second option thus aims at mitigating the physical impacts of climate change on the agricultural resources (e.g. soil) as well as the economic impacts in terms of quantitative and qualitative crop yield losses. It is seen as important political objective in order to balance disruptions in worldwide food production due to human induced climate change (*Battisti – Naylor,* 2009). However, such political intervention needs to take into account that crop breeding today is organized privately on a large scale. Policy design therefore should refrain from replacing private investments into plant breeding.

Consequently, we conduct three simulations on adaptation that differ by the ability of newly available farming practices to combat climate change impacts on agricultural output (damage reduction by 20% in the low scenario, 30% in the medium scenario and 50% in the high scenario relative to the BAU). These scenarios are based on the assumptions that improvements of crop varieties, as observed in the past, can be prolonged into the future and that dissemination of new technologies is sufficiently achieved.

As in the BAU Scenario, the CGE modelling of planned adaptation implies that climate change shifts the amount of "efficieny land" (see section 6.3) such that the productivity of land is declining. However, the cultivation of drought resistant crops is able to counteract the decline in land productivity caused by the warming, again increasing the efficiency land available for producers and consumers. By the use of adapted practices, farmers thus avoid the (extent of) damages otherwise caused by a changing climate.

6.5 Mitigation Scenarios

With respect to mitigation we first conduct a Mitigation Scenario including a realistic scope of biomass energy expansion in the study region as well as trade of surplus manure. Second, we seek to analyse the region's mitigative capacity by exploiting its overall biomass potential.

The Mitigation Scenario comprises two mitigative aspects: First, we integrate the effect of an expanded use of biomass for energy production in the study region, since renewable energies such as biomass generally produce less greenhouse gas emissions than fossil fuels. Second, we consider the mitigative potential of intra- and interregional trade of surplus manure. By letting trade regulate oversupply of some farms in terms of manure and undersupply of others, an emission reduction (in particular with respect to N_2O) can be attained. This measure also reduces the demand for commercial fertilizers.

Regarding the choice of biomass technologies, the use of poplar and willow pellets as well as forest wood pellets for energy supply would be cost-efficient, as their costs do not exceed fossil fuel costs. These technologies are thus principally profitable and could be chosen by farmers and foresters (see Tab. 10 for cost efficiency of technologies).[4] However, local stakeholders consider the cultivation of poplars for the production of pellets as the most suitable (first choice) response strategy for the study region of South-Eastern Styria.

Following this expertise, we construct a mitigation scenario (at three different stringency levels) based on a biomass expansion by poplar pellets which are assumed to be subject to a biomass premium. The three simulations differ in the size of the premium varying from 100 €/ha (low scenario), to 200 €/ha (medium) and €/ha 300 (high) for short rotational poplar production. Thereby, land currently set aside or used for forage production (clover, alfalfa etc.) are assumed to be likely substituted by biomass production. The model results show that up to 7,400 hectars are used for short rotational poplar production in 2045 (premium of 300€/ha). The shares of intra- and interregional trade of manure are assumed to vary between 20% (low scenario), 50% (medium), and 80% (high).

Furthermore, we are interested in the consequences of exploiting the study region's total potential in terms of biomass based energy production. In particular, based on the biomass potential analysis conducted in section 3, we explore the regional economic effects of a biomass expansion over the total estimated potential bio-energy area of the study region. Since we assume that the expansion level of cultivated biomass plants is determined by law, no biomass premium accrues. Starting from the high mitigation scenario (enhanced production of poplar pellets on an area of 7,400 ha), we assume that the remaining cropland is taken up each 25% by maize, rape-seed, miscanthus and whole plant. The potential forestland is used for wood logs, wood chips and wood pellets with shares as in section 3.2.2.

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[4] Note that although wood logs are ranked first in Tab. 10, they are not chosen as a technology. This is because the future costs per kWh heat will be different from those now since prices will have changed. For the case of wood logs, in particular, labour will have got more expensive by the 2040ies and thus will increase production costs according to the high labour intensity of its technolgy.

7 Model simulations and results

Section 7 summarises the quantitative simulation results, i.e. the regional economic effects in the study region. First, the economic impacts of climate change are illustrated. Second, we separately depict the economic effects of adaptation and mitigation as response strategies to climate change. Third, the economic effects of combined adaptation and mitigation measures are presented. Finally, we conduct a potential analysis towards regional energy provision from biomass in the study region. Overall, the results are reported in terms of macroeconomic parameters such as regional GDP, welfare and unemployment. We also report separately on results for the core study region of South-Eastern Styria (Region 1, NUTS 3 level) and its surrounding region Styria (Region 2, NUTS 2 level).

7.1 Effects of climate change

The climate-induced effects on consumers and producers (BAU Scenario) are analysed relative to the case excluding variations in the climate (Reference Scenario). The economic effects of climate change can then be interpreted as the relative change between these two scenarios (see Tab. 18).

Tab. 18 : Effects of climate change on selected economic parameters.

BAU Scenario 2045					
		Region 1		Region 2	
		BAU Scenario 2045	Difference to Reference	BAU Scenario 2045	Difference to Reference
Economic Performance					
GDP	[2003 = 100]	163.71	*-0.28*	207.97	*-0.29*
GDP growth	[% p.a.]	1.209		1.802	
Welfare	[2003 = 100]	201.2	*1.89*	275.6	*1.28*
Welfare growth	[% p.a.]	1.72		2.50	
Unemployment rate	[%]	2.95	*0.28*	3.50	*0.09*
Consumption price index	[2003 = 100]	89.8	*-0.89*	95.3	*-0.55*
Agricultural production level	[2003 = 100]	107.3	*-3.73*	106.2	*-3.13*
Factor prices					
Labour	[2003 = 100]	278.0	*0.00*	329.0	*0.00*
Capital	[2003 = 100]	123.4	*-1.30*	155.8	*-0.29*
Price level agriculture	[2003 = 100]	153.0	*28.56*	167.8	*24.17*

We find climate change to slow down regional GDP growth by -0.28% (Region 1) and by -0.29% (Region 2) by 2045 (also see Fig. 12 and Tab. 19). The negative GDP effects mainly stem from the development in agricultural markets for two reasons:

First, agriculture faces a productivity loss because of altered climatic conditions. I.e. the same amount of input now produces less output. Thus, the production of agricultural goods gets more expensive, resulting in higher price levels (+28.26% in Region 1; +24.17% in Region 2) and lower production levels (-3.73% in Region 1; -3.13% in Region 2) in agriculture (see Tab. 18). This, in turn, leads to indirect production cost increases in those sectors, which strongly depend on agricultural goods as intermediate inputs (such as food or textiles). In these sectors output is therefore reduced as well.

Tab. 19 : Effects of climate change on regional GDP, welfare and unemployment rate.

Effects from climate change		
	Region 1	Region 2
	[changes compared to Reference]	
GDP	- 0.28%	- 0.29%
Welfare	+ 1.89%	+ 1.28%
Unemployment rate	+ 0.28%	+ 0.09%

Second, the provision of biomass used for heat production expands under climate change, as farmers adapt autonomously to the shift in climatic conditions. I.e. the supply of biomass rises in the study region, whereas the overall level of agricultural production decreases (see above). As a result, consumers demand less heat from fossil sources relative to biomass related heat, resulting in a biomass based share of heat of 11.4% in Region 1. Negative production effects in the sectors coal (-12.6%), gas (-12.6%) and oil (-26.5%) are the consequence, which in turn tends to lower regional GDP, too. Since the remaining sectors of the economy are only marginally affected by the shift in climatic conditions[5], the decline in GDP growth can be mainly attributed to the feedback effects described above.

Moreover, climate change affects employment levels in that the decline in regional GDP leads to higher unemployment rates. By 2045, due to climate change the unemployment rate in Region 1 increases to 2.95% compared to the Reference situation (2.68%)and to 3.50% compared to the Reference rate (3.42%) in Region 2 (see Tab. 19). The negative labour market effects can be mainly explained by production decreases in labour intensive sectors[6] such as agriculture, food, coal and oil. Since marginal production increases due to expanded biomass cultivation and since heat is produced from biomass crops in less labour intensive sectors (such as biomass refinement, biomass heat production and machinery), an overall increase in unemployment is the consequence.

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[5] The feedback effects of the cost increase in agriculture are not high enough to significantly increase production costs in these sectors.

[6] These sectors are characterised by labour intensities above the average of all economic sectors

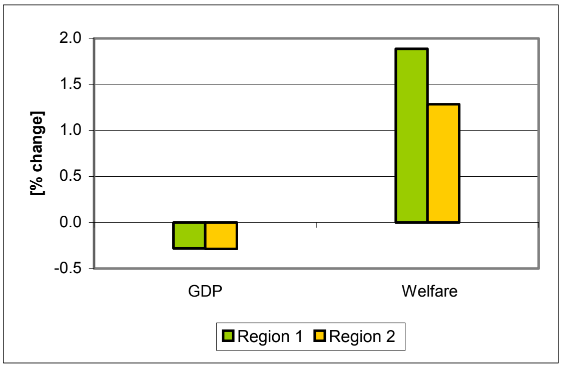

Fig. 12 : Effects of climate change on regional GDP and welfare for Region 1 and Region 2.

Inspite of GDP and labour market being negatively affected by climate change, we find a welfare increase in both Region 1 (+1.89%) and Region 2 (+1.28%). The net welfare increase results from the interference of both welfare boosting and welfare lowering effects:

On the one hand, enhanced unemployment and reduced capital income due to GDP decline decreases private demand. Also government consumption is reduced (-1% in Region 1 and -0.81% in Region 2) due to higher expenses for unemployment compensation. In addition, consumer demand is positively influenced by higher land prices because of increased production in agriculture.[7] The net effect on private demand, however, is slightly negative (-0.08% in Region 1 and -0.27% in Region 2). Given the market clearing assumption in the model, prices adjust in order to meet the lower overall consumption demand, and the price of the consumption bundle declines (-0.89% in Region 1; -0.55% in Region 2). Summing up, the government faces moderate consumption losses, while private consumption remains fairly stable now at cheaper prices. The net effect on consumer welfare remains unclear, however.

On the other hand, we find a strong factor positively affecting welfare which is due to the reduced demand for heating energy caused by climate change (see section 3.2.1). I.e. the same heating service can now be provided at lower costs. Hence, consumers are able to demand additional (or other) commodities due to the reduced expenses for heating services. A further positive effect on welfare is found in the import structure of the model, where we assume a constant trade balance: Since the import of fossil energy sources (coal, gas, oil) decreases, households may import other commodities from abroad (those cheaper than at home) instead of consuming them in the local market. Altogether, households consume less heat services allowing them to demand additional goods in the regional and global market.

We can conclude that, although private demand marginally decreases in the BAU Scenario, welfare is increased relative to the Reference Scenario for the following reasons: First, the

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[7] More land is needed in order to produce the same amount of output. Hence, the land rent increases.

regional consumption bundle price decreases enabling households to consume at cheaper prices. Second, because of reduced expenses for energy services households demand additional goods locally. Third, based on the assumption of constant trade balances, households may import goods cheaper than in the local market in order to compensate for the reduced imports of fossil fuels.

7.2 Effects of adaptation

The effects from adaptation are analysed relative to the results of the BAU Scenario. Recall that we conduct three adaptation simulations differing by the strength of reduction in climate related crop loss from using more resistant plants in Region 1 (see section 6.4).

Depending on the stringency of the adaptation measure analysed, the regional GDP is found to marginally increase (between 0.013% and 0.044% in Region 1 and with almost no effects in Region 2, see Fig. 13, left plot). The small positive effects in Region 1 are due to the augmented use of resistant plants, ensuring a higher productivity in agriculture. Two consequences are tied to this effect which impacts the regional GDP: First, the agricultural sector now produces cheaper relative to the BAU Scenario. Production increases slightly (between +1.1% and +2.86%) and the price level decreases moderately (by some -1.68% to -4.43%). Sectors using mainly agricultural products as intermediate inputs thus gain in terms of elevated production levels relative to the BAU Scenario (through indirect production cost decreases via cheaper agricultural products). Second, the fraction of biomass cultivated in Region 1 declines, because the cultivation of more resistant agricultural plants now increases crop yields. As a result, with adaptation farmers produce less heat from biomass[8]. On the one hand, this production loss negatively affects regional GDP growth. On the other hand, the decline in biomass heat production leads to a relative production level increase in the sectors oil, gas and coal.

To sum up, the net effect of the above described developments marginally increases the GDP growth in Region 1. Since we did not assume any adaptation measures in Region 2, the small GDP growth results from cheaper intermediate input goods and consumption goods imported from Region 1. However, we can conclude that under the very specific assumptions of modelling, adaptation measures in Region 1 have only very weak feedback effects on Region 2.

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[8] The share of biomass heat in the overall heat demand decreases from 11.6% in the Reference scenario to 11.25% in Adaptation Scenario 1, to 11.18% in Adaptation Scenario 2 and to 10.65% in Adaptation Scenario 3.

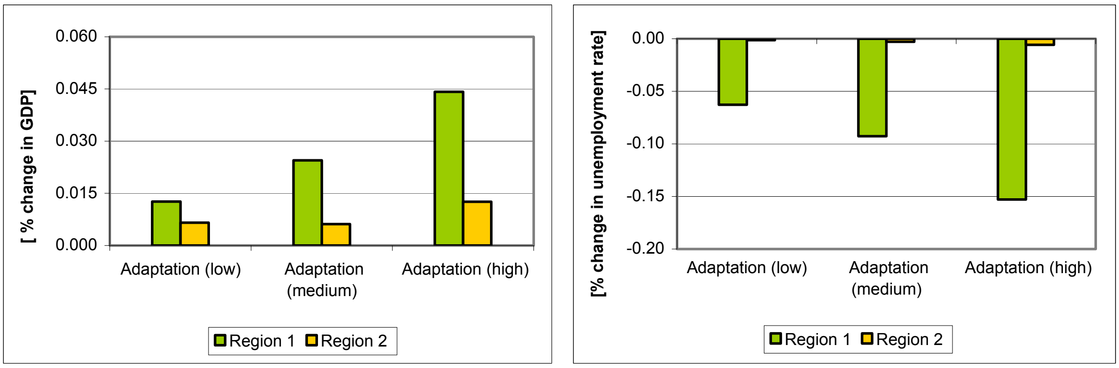

Fig. 13 : Effects of adaptation on regional GDP (left plot) and unemployment rate (right plot) for Region 1 and Region 2

The (slight) increased production of labour intense sectors (such as agriculture, food, or oil, see above) raises labour demand in Region 1. Depending on the stringency of the adaptation measure chosen, the unemployment rate is reduced between -0.06% and -0.15% in Region 1 relative to the BAU Scenario (see Fig. 13, right plot). Region 2 again experiences only a negligible benefit from farmers, who are located in Region 1 and adapt to climate change by growing more resistant crops.

Policy-induced adaptation in Region 1 has diverse effects on regional welfare. While Region 1 faces a welfare loss up to -0.08%, Region 2 experiences a welfare growth up to 0.05% (see Fig. 14). Although unemployment in Region 1 decreases relative to the BAU Scenario (enhancing private consumption demand), the land rent decreases as a result of the productivity gains in agriculture (reducing private consumption demand). Since the latter effect dominates the first one, a slightly lower net private consumption demand is the consequence (between 0.09% and -0.17%). The government, on the other hand, faces lower unemployment compensations and raises its consumption (by some +0.9% to +0.17%). The net effect of private and government consumption demand is an overall reduction of consumption demand in Region 1, thereby lowering the price of the consumption bundle. The elevated government consumption scales back part of the price decrease from the overall net reduction in demand, causing a slight decrease in welfare in Region 1. In Region 2, the slightly positive welfare effects are generated by cheaper imports from Region 1, which reduce production costs in Region 2. Marginally lower consumption bundle costs and higher private consumption demand lead to a marginal welfare increase (up to +0.05%) in Region 2.

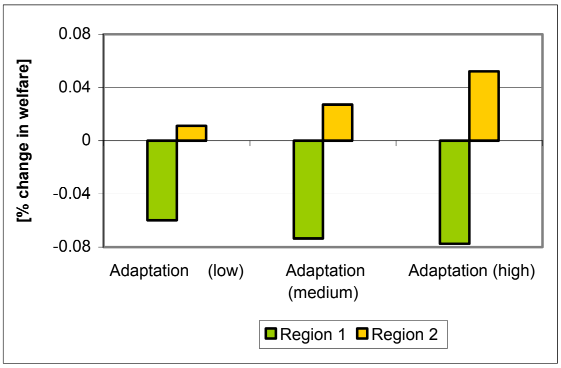

Fig. 14 : Effects of adaptation on regional welfare in Region 1 and Region 2.

7.3 Effects of mitigation

The effects of mitigation are explored as deviations of the Mitigation Scenario from the BAU Scenario. Three simulations are developed depending on the amount of the biomass premium implemented and the share of intraregional trade of fertilizers assumed in Region 1 (see section 6.5)

The regional GDP is found to rise between +0.13% and +0.19% in Region 1, while spill-over effects to Region 2 are very weak (see Fig. 15). As for GDP growth in Region 1, on the one hand, the biomass premium positively affects agricultural production in Region 1 (with an increasing production level between +1.0% and +3.1%). This development is mainly triggered by the expanded cultivation of biomass plants and their refinement, respectively, causing more biomass based heat to be produced regionally[9]. The rise in agricultural production also leads to cheaper agricultural products in Region 1, boosting production levels of agriculture intensive sectors. These developments thus tend to increase the regional GDP. On the other hand, the biomass premium dampens the production level of fossil fuel sectors such as coal (up to -1.1%), gas (up to -1.2%) and oil (up to -2.4%). Production levels decrease because more biomass is cultivated within the agriculture sector to be then used for heat production. Thus, more biomass heat is supplied and substituted for fossil fuel heat. The net effect of these two developments on the GDP is positive for Region 1. Again, the GDP effects on Region 2 are negligible.

The simulations show a lower unemployment rate in Region 1 mainly because of higher value added. The net effect of production gains in labour intensive sectors (e.g. agriculture or food) on the one hand, and production losses in less labour intensive sectors (e.g. gas), on the other hand, leads to a slightly lower unemployment rate (between -0.04% and -0.07%) in Region 1 (see Fig. 15 right plot). Unemployment in Region 2 is negligibly affected.

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[9] The share of biomass heat in the overall heat demand increases from 11.6% in the Reference scenario to 13.2% in Mitigation Scenario 1, to 13.8% in Mitigation Scenario 2 and to 15.1% in Mitigation Scenario 3

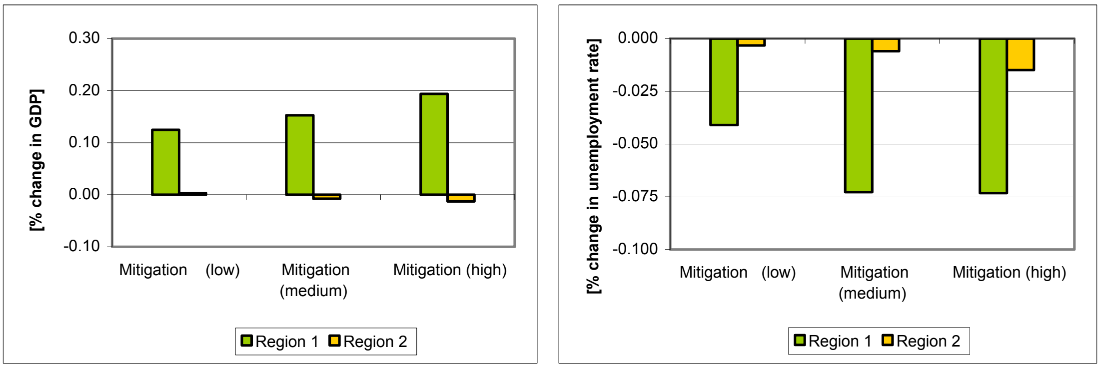

Fig. 15 : Effects of mitigation on regional GDP (left plot) and unemployment rate (right plot) for Region 1 and Region 2

The introduction of mitigation measures in Region 1 is found to increase welfare slightly by some 0.10% to 0.30% (see Fig. 16) for the following reason: Private income rises because less people are unemployed and since land rent increases. The latter effect stems from the expansion of biomass cultivation, which leads to a higher demand of land and hence to rising land prices. These two effects finally raise the private consumption level, which increases welfare in Region 1. Concerning Region 2, almost no welfare-related effects can be observed. The positive feedback effects from Region 1 are too small to significantly influence the welfare development in Region 2.

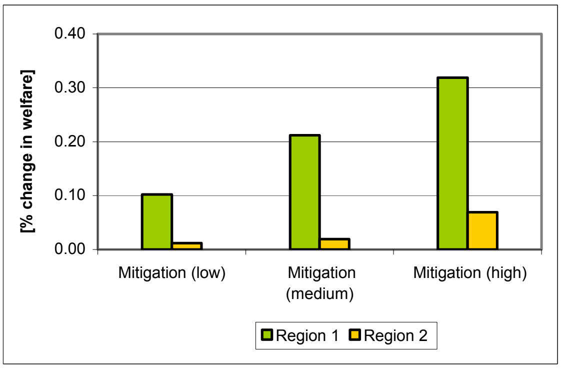

Fig. 16 : Effects of mitigation on regional welfare in Region 1 and Region 2.

7.4 Effects of exploiting the region’s mitigative potential in terms of bio-energy

The mitigative potential of the study region is explored by a biomass exploitation of the area which can be potentially used for energy purposes by 2045. They are hence analysed also relative to a situation with climate change (BAU Scenario) in Region 1. Tab. 20 presents the economic effects from exploiting the region’s biomass potential up to 2045. If the whole biomass potential in Region 1 is used to cultivate biomass plants, the following economic performance is observed: a GDP increase of +3.19%, a welfare gain of +1.11% and a reduction in the unemployment rate by -0.84%.

Tab. 20 : Mitigative potential in terms of biomass based heat production in Region 1.

Biomass potential exploitation			
Macroeconomic perfomance	[% change relative to BAU]	*Sectoral performance*	[% change in production level relative to BAU]
GDP	+ 3.19%	Agriculture	+ 13.80%
Welfare	+ 1.11%	Oil	- 31.40%
Unemployment rate	- 0.84%	Coal	- 9.80%
		Gas	- 11.25%

The positive effects on GDP growth (+3.19%) are mainly due to a higher production level in agriculture (+13.8%) (see Tab. 20). The reason for this development is, as indicated above, the increased cultivation of biomass plants as well as their refinement. Moreover, sectors which provide intermediate goods for the production of biomass refinery technologies (e.g. machineries) are positively affected by the expanded biomass cultivation and show production increases as well. Additionally, the refined biomass is used to regionally produce heat, biodiesel and electricity, boosting further the regional value added.

Concerning the overall heat demand in Region 1, 38.02% of total regional demand is now supplied by heat produced out of biomass. The higher supply of biomass related energy leads to production decreases in the regional sectors oil (-31.4%), coal (-9.8%) and gas (-11.25%), because less energy from fossil fuel sources is demanded (see Tab. 20). However, since almost all fossil fuels are imported and not produced in Region 1, these reductions only marginally affect the regional GDP growth.

The high employment effects in Region 1 generally emerge from the regional GDP increase. In particular, the moderate decrease in unemployment (-0.84%) follows from the use of highly labour intensive biomass refinement technologies. Especially the refinement of forestry biomass (wood logs, wood chips and wood pellets), which is not considered in the policy scenarios before (Mitigation, Adaptation and combined scenario) demand a high amount of additional workers. Wood pellets, for example, are characterised by a high labour intensity. The increase in the wage rate (from 2003 up to 2045) is far beyond of the increase in the price of capital as well as the price of land. Therefore, the production of wood pellets is getting relatively expensive. In addition to that, the production of wood pellets requires a higher amount of diesel, which also shows a strong price increase up to 2045.

Overall, the positive welfare effects (+1.11%) evolve from increased private consumption and production levels. Higher land rents (since land competition increases due to the expanded biomass cultivation) and a slightly increased capital income together lead to a rise in private income. Given the model's market clearing conditions, the additional income is used up for private consumption, resulting in a higher welfare level relative to the BAU.

7.5 Effects of combined adaptation and mitigation

By simultaneously introducing adaptation and mitigation (as described in sections 6.4 and 6.5) we seek to explore the interlinkage between adaptation and mitigation activities in a regional context. In doing so, we compare the results of a combined policy simulation (high scenario) with the Adaptation Scenario (high) (section 6.4) and the Mitigation Scenario (high) (section 6.5). Due to negligible effects in Region 2 (as shown in the previous sections), we particularly consider effects on Region 1.

Tab. 21 : Effects of adaptation, mitigation as well as a combined policy (high scenario each) relative to the BAU Scenario for Region 1.

Combined adaptation and mitigation			
	adaptation	mitigation	adaptation and mitigation
	[% changes compared to BAU]		
GDP	+ 0.04%	+ 0.19%	+ 0.31%
Welfare	- 0.08%	+ 0.32%	+ 0.20%
Unemployment rate	- 0.15%	- 0.07%	- 0.27%

If adaptation and mitigation measures are simultaneously introduced in Region 1, we obtain the following results: regional GDP increases by +0.31%, the unemployment rate falls by -0.15% and welfare rises by +0.2% relative to the BAU Scenario (see Tab. 21). Whereas adaptation measures show higher employment effects, mitigation measures have a higher impact on GDP as well as on welfare (see also Fig. 17). Moreover, in the combined adaptation-Mitigation Scenario (high) 14.81% of the overall heat demand in Region 1 is produced from biomass.

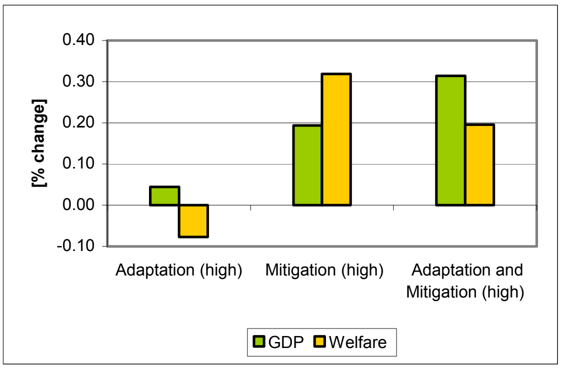

Fig. 17 : Effects of adaptation, mitigation as well as a combined adaptation-mitigation policy on GDP and welfare relative to the BAU Scenario for Region 1.

7.6 The relationship between adaption and mitigation

The simulation results show that both mitigation and adaptation measures in the agricultural and the forest sector generate positive economic impacts on the regional economy in question (region 1). Economic effects from adaptation in terms of GDP growth in region 1 are very weak, however, ranging from +0.013% to +0.044% depending on the scope of damage reduction considered from adaptation measures. Consequently, adaptation in the agricultural sector cannot compensate for potential economic losses from climate change that sum up to -0.28% GDP loss (see Tab. 19). The same holds for the unemployment rate. Adaptation cannot neutralize the loss in employment arising from climate change. This may be due to scenario settings but might as well result from economic structures at work, for instance, adaptation could be less labor intense than the forgone agricultural production. In order to validate this result, a sensitivity analyses needed to be carried out. It is left for further research.

Effects of mitigation are found to increase regional GDP between +0.13% and +0.19% and are thus more explicit than in the case of adaptation. Mitigation measures using biomass for heating, however, show a less clear potential to reduce unemployment with respect to adaptation measures, -0.04% to -0.07% in comparison to -0.06% to -0.15% with adaptation relative to BAU.

Taken the impacts of adaptation and mitigation response measures together in one model run, economic losses from climate change can be compensated by a rise in GDP of +0.31% compared to a potential loss from climate change of -0.28%. This is a remarkable result as it shows first, that a combination of adaptation and mitigation measures show a higher potential for GDP generation (and unemployment reduction) than each measure on its own, and, second, mitigating greenhouse gas emissions and adapting to climate change have the potential to generate economic benefits besides its contribution to climate protection. Thus, there is an indication that climate change does represent an important opportunity for business to generate economic growth and, at the same time, to lay the foundations for a sustainable low-carbon economy. Generating economic growth through mitigation creates additional benefits in terms of avoided GDP losses if climate change will successfully be avoided. This, however, depends on the combined mitigation efforts from other (world) regions as well.

Regarding the interrelationship of mitigation and adaptation it is important to note that some climate response measures that are viable for the agricultural sector have the potential to generate benefits in both adaptation and mitigation. This holds for instance for organic agriculture. Organic agriculture has the potential to be a considerable CO_2 sink if good farming practices such as the enhancement of soil organic matter by low tillage and maintenance of permanent soil cover are applied. This does not only conserve the structure of the soil making it more robust against adverse climate impacts such as drought and heavy rains but also creates sinks for enhanced CO_2 uptake. It reduces energy intense fertilizer production and reduces the amount of excess manure if it follows a concept of closed substance cycle (*FAO,* 2007). Assessing the beneficial effects of organic farming as climate response measure was, however, beyond the scope of the present research project and therefore remains subject to further research.

8 Conclusion

The study analyses mitigation and adaptation measures as a response strategy to climate change, setting a focus on biomass as a feedstock of energy production in Austria. Given that a certain degree of climate change cannot be avoided anymore regardless of the success of global mitigation efforts, societies need to adapt to climate change and its impacts. Adaptation in terms of adjusting practices and processes in response to the threat of climate change can significantly reduce negative impacts, e.g. on biomass production. Adaptation strategies are interrelated with mitigation strategies concerning varies instances. I.e. the potential of biomass to reduce emissions from energy use depends *inter alia* on the efficiency of adaptation measures implemented to counteract negative impacts from climate change on biomass production. And the success of adaptation measures depends on the scale of climate change impacts that depends on (global) efforts to combat climate change. Thus, impacts of adaptation and mitigation are strongly interlinked.

The model simulations show that both mitigation and adaptation response measures can generate positive economic impacts on the regional economy given the example of the agricultural and the forest sector. However, economic effects from adaptation in the analysed case are rather weak such that adaptation measures cannot compensate for economic losses from climate change impacts. This result may be due to the specific case and therefore needs further refinements in terms of economic sectors considered and selected adaptation measures. Positive economic effects from mitigation activities are found to be more explicit than in the case of adaptation. Mitigation measures using biomass for heating, however, show a lower potential to reduce unemployment with respect to adaptation measures. But welfare is increasing in the case of mitigation in contrast to the considered adaptation measures that induce the welfare index to decline. Analysing the combined effects of adaptation and mitigation response measures on the regional economy, economic losses from climate change can be compensated by a rise in GDP of +0.31% compared to a potential loss from climate change of -0.28%. This is a central research output as it shows first, that a combination of adaptation and mitigation measures show a higher potential for GDP generation (and unemployment reduction) than each measure on its own, and, second, mitigating greenhouse gas emissions has the potential to generate regional economic benefits besides its contribution to global climate protection. However, as this result is valid for the specific case analysed within this project, results cannot be transferred to cases where other economic sectors are concerned nor can they be generalized. Further research is, thus, needed to validate the synergetic potential of adaptation and mitigation measures as climate response with regard to its economic potential. With regard to the welfare index, the combined adaptation and mitigation climate response measure shows positive values that lie in between adapation (-0.08%) and mitigation (+0.32%), namely at (+0.20%).

Finally, the outcome of themodel simulations for the agricultural and the forestry sector may be interpreted as an indication for the possibility a “green economy”, i.e. mitigation and adaptation strategies represent important opportunities for business and economic growth and employment, with correlated benefits arising from mitigating climate change (if other world regions realize a similar approach). Thus, adaptation and mitigation should be integrated in terms of scientific analysis and political programme development dedicated to tackle climate change. This is because these two climate response measures potentially generate important synergies in economic terms. Other aspects, such as the economic crisis and energy security issues may as well be at the core of combined climate response measures. The project outcomes thus indicate – under the specific modeling assumption taken - that climate change adaptation and mitigation response measures may not be seen as cost drivers but as stimuli to generate green growth and employment, and as tools to pave the way for a low or zero carbon economy, thereby serving structural change and sustainable development.

Appendix

Sensitivity of results with respect to energy prices

In the recent past we observed a dramatic increase in energy prices, and their future development is very much uncertain. For this reason we explore the economic performance and employment effects of two biomass heating technologies under different assumptions on energy prices. We compare a forestry based technology, wood pellets, and an agriculturally based biomass heating technology, agro pellets based on miscanthus.

In doing so, we construct a high energy price scenario by letting the energy price increase by 20% compared to the 2045 Reference Scenario (which is therefore the low energy price scenario here). The high energy price scenario is thus characterized by an oil price about 55% above the 2003 level (real price increase). With such an assumption, the Reference Scenario changes dramatically indicating the dependence of the economy on cheap energy.

First comparing the two selected technologies in terms of cost-efficiency, the production of miscanthus is getting cheaper relative to that of wood pellets. Since wood pellets are characterized by a high labour intensity together with a large amount of diesel required in production, with a rising price of both labour (relative to capital) and diesel up to the 2040ies, agro pellets (based on miscanthus) can be produced more cheaply under future conditions.

As a second step, we explore the economic performance of heat produced with miscanthus pellets and wood pellets under diverging energy prices. We find an increase in regional GDP and in employment in the case of both heating systems, yet with a stronger development from the use of miscanthus pellets. This result stems inter alia from its relative advantage in production costs. Overall, miscanthus pellets are gaining relatively more from high energy prices than do wood pellets.

Tab. 22 : Economic performance by technology through biomass energy expansion in 2045 under different energy price assumptions.

	import quota[1]	regional GDP		Employment	
		Region 1	Region 2	Region 1	Region 2
		change in %		persons	
single home heating systems (15 kW), Year 2045					
wood pellets	0%	2.72	0.16	957	297
agro pellets (Miscanthus)	8%	3.13	0.14	464	286
single home heating systems (15 kW), Year 2045 - high energy price assumption					
wood pellets	0%	2.83	0.14	899	269
agro pellets (Miscanthus)	8%	3.29	0.13	423	261

[1] percentage of biomass pre-products (e.g. rapeseed) imported from global markets

Sectoral classification

The sectoral specification of the CGE model uses ÖNACE classifications given by Tab. 23. ÖNACE is the Austrian version of the NACE, the statistical classification of economic activities in the European Communities (see *ST.AT*, 2003).

Tab. 23 : Sectoral classification used in the CGE model.
Source: *ST.AT* (2003).

sector (ÖNACE)	
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
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

List of figures

List of tables

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