PUBLISHABLE FINAL REPORT

A) Project data

Short title:	Food Security
Full title:	Food Security Risks for Austria Caused by Climate Change
Programme:	ACRP, 3rd call
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B) Project Overview

1. Executive Summary

1.1 English Summary

The UN, US and EU have recognized food security as a threat since 2008. Climate change will influence agricultural production potential in Austria and in regions from which Austria imports food and feeding stuffs. Beyond that, the resilience of Austrian food supply could be affected by threats of political conflicts, social and political rebellions for food, feed and water as well as global competition for agricultural commodities, agricultural land and energy needed for agricultural production.

Up to now there is no common assessment available, which takes into account the effects of climate change on agricultural production in Austria and the food resilience regarding imported feed, food, energy and other inputs relevant for agricultural production. Food resilience is not only affected by the effects of climate change on global agricultural production, but also by socio-economic impacts and security policy risks. This project hopes to identify the major hazards, threats and risks that could affect agricultural production and food supply in Austria.

The aim of the project is to analyse the Austria's future food security risks in the years 2030 and 2050, taking into account climate change, political and socio-economic risks by developing scenarios. This project will conduct a risk analysis, which will offer risk management options and based upon political recommendations regarding food security, risk communication and food security risk management. Project results were derived in two stages, comprised of a forecast and a risk assessment (national resilience) in the first stage and a second risk assessment using threat scenarios generated by Monte-Carlo simulations in the second stage.

Austria is currently a net exporter of sugar, beef and veal. The country's production of wheat and pork is self-sufficient. Austria is an importer of oil crops, oil seed meals, vegetable oils, fruits, vegetables, poultry meat, eggs, butter and fish. The protein component of oil seed meals is essential to Austrian pig and poultry production. Thus the SSR for pork and poultry meat are more or less dependent on the protein supply from abroad. Most food sector imports originate from EU-member states. With SSRs of 9% for soybean, 49% for oil seed meals and for 46% vegetable oils, EU-27 has shortages of production of relevant agricultural products similar to Austria.

Most food sector imports originate from EU-member states. Beyond that, Austrian agricultural production is dependent on import of energy (crude oil, diesel, natural gas) and agricultural inputs (phosphate, potassium, pesticides, vitamins, essential amino acids) Production of nitrogen fertilizers is again dependent on energy imports. The risk analysis did not take into account short-term inputs that EU industry could substitute with its own production as well as products not necessary for food security (e.g. bananas). The supply risks of energy and inputs were assessed by taking into account the national resilience (NR), expressed by social resilience (SR) and political resilience (PR), of the countries from which Austria imports.

Food security risks for Austria in 2030 and 2050 are addressed by establishing two simple (non-economic) simulation models based on forecast data (base line scenario). Each simulation model was calculated for four scenarios: "baseline, best case, most probable and worst case scenario". The scenarios take into account seven groups of risk identified by the project team.

Major risks identified in this project that would affect agricultural production and food supply in Austria:

1) Climate change: Changing climatic and extreme weather conditions will affect agricultural production in Austria/Europe. Effects on yields are limited in general until 2050.
2) Import of energy: Austria is dependent on imports of crude oil, diesel, natural gas, and nitrogen fertilizer produced by natural gas (Haber-Bosch-process).
3) Import of inputs (phosphate fertilizer): Austrian agriculture is dependent on imports of phosphates.
4) Import of high-protein feedingstuffs: Austrian life stock production is dependent on imports of soybean meal and vegetable oils.
5) Suspicion of technical progress: Public suspicion of technical progress (e.g. biotechnology in agriculture) may hinder potential increases in yields or plant and animal health.
6) Biofuels and biofibres: Uncontrolled expansion of areas farmed for biofuels and biofibres may limit the area needed for food and feed production.
7) Agricultural policy: Political efforts towards a low input agricultural policy may reduce production potential.

The impacts of climate change on Austrian agricultural production were addressed equally in all potential scenarios, including technical progress and supply risks (shortages of phosphorus (P-) fertilizer, lacking imports of protein feeding stuffs). In the worst-case scenario, a shortage of energy supply resp. excessive energy prices were expressed by an uncontrolled expansion of area used for bioenergy and fibres. All scenarios presume certain political prejudices. The best-case scenario accounts for sustainable intensification of agricultural production. The worst-case scenario presumes extensive agricultural production all over the country. The most-probable-case scenario follows more or less the current political trend towards more ecology in agriculture.

Best-case scenario: Food security risks for Austria can be decreased if all the possibilities of technical progress offers—including biotechnology—are implemented. This means increasing the intensity level of inputs and reaching higher productivity in agriculture. Political measures have to be taken so that no shortages of energy, inputs and import feedstuffs arise. The area used for biofuels and biofibres can be increased to up to 10% of the arable area without affecting food markets. Current levels of meat consumption can remain at present levels. The simulation results of this scenario show that the required acreage decreases by -19% (-191,000 ha) in 2030 and by -29% (– 297,000 ha) in 2050, relative to 2015 (model 1). SSRs increase by up to 52 percentage points in 2050 (model 2).

Most probable scenario: Food security risks for Austria can be tackled by achieving a medium input level in agricultural production. Technical progress must then also be accepted to a certain extent. Shortages of phosphate and high-protein feedstuffs are also taken into account. In this scenario up to 12% of the arable area could be used for biofuel and biofibres. More area is devoted to more extensive farming (e.g. more area farmed organically). The most-probable-case scenario mirrors more or less current political prerogatives. In this scenario the required acreage increases by +1% (+10,000 ha) in 2030 and decreases by -6% (-60,000 ha) in 2050. Changes in SSRs vary between -15 %age points and +27 %age points.

Worst-case scenario: Food security risks for Austria will increase drastically if agricultural production swings to a general low input level (e.g. 100% organic agriculture) and shortages of fossil energy, phosphate fertilizers and high-protein feedstuffs occur simultaneously. In this scenario we assumed an uncontrollable increase in the demand of biofuel and biofibres - up to 40% of the arable area - due to shortages and price rises of fossil energy. The required acreage increases by +99% (+1,025,000 ha) in 2030 and by +109% (+1,128,000 ha) in 2050. SSRs decrease by up to -67 percentage points.

Following the assumptions the largest positive changes in yields are due to technical progress. The largest negative changes in yields are generally due to lower intensity levels of inputs (as a result of input supply shortages or political presumptions).

Summarizing the models show the following: There is a scope for additional production and acreage available to substitute imports or enhanced production of biofuels and biofibres if Austrian politics faces the risks described and enables sustainable intensification of agricultural production. Food security risks and the dependence on imports could be reduced.

If policy imposes extensive agricultural production systems all over the country and does not tackle the upcoming fossil energy supply bottleneck self-supply rates will decrease and food security risk will increase dramatically already in 2030.

If the currently postulated farming policy will be continued and technological progress is permitted up to a certain degree at the same time there will be a slight scope for more acreage as well as for organic production (up to 25%) and for the production of biofuels and biofibres (up to 15%). The food security risks will increase because of slightly decreasing self-supply rates and the increasing uncertainties in exporting regions.

1.2 Deutsche Kurzfassung

Die Ernährungssicherung (Food Security) stellt eine globale Herausforderung dar. Der Klimawandel wird das landwirtschaftliche Produktionspotential sowohl in Österreich als auch in Regionen, aus denen Österreich Lebens-, Futter- und Betriebsmittel importiert, beeinflussen. Darüber hinaus wird die Versorgung Österreichs mit Lebensmitteln, etwa durch die globale Bevölkerungsentwicklung, politische Konflikte, soziale und politische Unruhen in Exportstaaten und durch den global steigenden Wettbewerb um Lebens- und Futtermittel, Land aber auch Energie und Produktionsmittel beeinflusst.

Ziel des Projektes ist es, potentielle Risiken der Ernährungssicherung zu bewerten und deren mögliche Auswirkungen auf Österreich abzuschätzen. Dazu wurde die Situation für Österreich für die Jahre 2030 und 2050 anhand zweier Simulationsmodelle auf Basis von Versorgungsbilanzen analysiert.

Das Projekt beruht auf einer mehrstufigen Risikoanalyse. Im ersten Schritt wurden die Versorgungsbilanzen und Importströme nach Österreich analysiert und die politischen und sozioökonomischen Bedrohungen für Regionen, aus denen Österreich Lebens- und Futtermittel, Energie und andere für die landwirtschaftliche Produktion relevante Betriebsmittel importiert, identifiziert und bewertet. In einem zweiten Schritt wurden die identifizierten Bedrohungen sowie weitere Einflussfaktoren der Versorgungssicherung zu Szenarien zusammengefasst und diese Szenarien (d.h. bestimmte Sets von unterschiedlichen Annahmen) mithilfe von Simulationsmodellen analysiert.

Die größten in diesem Projekt identifizierten Risiken, die die Agrarproduktion und die Nahrungsversorgung in Österreich betreffen, sind:

1) Klimawandel: Veränderte klimatische und extreme Wetterbedingungen werden die Agrarproduktion in Österreich und Europa beeinflussen. Die Auswirkungen des Klimawandels auf Erträge werden aber in Österreich bis 2050 eher gering sein.
2) Energieimporte: Österreich ist abhängig von Importen von Rohöl, Diesel, Erdgas und Stickstoffdüngern, die aus Erdgas produziert werden (Haber-Bosch-Prozess).
3) Import von Betriebsmitteln: Eine besondere Importabhängigkeit der österreichischen Landwirtschaft besteht bei Phosphatdüngern.

4) Import von stark eiweißhaltigen Futtermitteln: Die österreichische Tierproduktion ist abhängig von Importen von Sojamehl und pflanzlichen Fetten.
5) Argwohn gegenüber technischem Fortschritt: Der Argwohn der Bevölkerung gegenüber technischem Fortschritt (z.B. Biotechnologie in der Landwirtschaft) könnte das Ausnutzen von Ertragspotentialen oder Verbesserungen in der Pflanzen- und Tiergesundheit verhindern.
6) Biotreibstoffe und biogene Rohstoffe: Eine unkontrollierte Ausdehnung von Flächen für den Anbau von Biotreibstoffen und biogenen Rohstoffen könnte die Anbaufläche für die Lebens- und Futtermittelproduktion limitieren.
7) Agrarpolitik: Eine Agrarpolitik mit Schwerpunkt auf Extensivierung und Ökologisierung wird zur Nichtnutzung der Produktionspotenziale führen.

Die klimawandelbedingten Änderungen in den Simulationsmodellen beruhen auf Ertragsprognosen mithilfe von Klimamodellen für die betrachteten Produkte. In die Simulationsmodelle werden auch unterschiedliche agrarpolitische Ausrichtungen, dargestellt in Form von unterschiedlichen Intensitätsgraden (Intensivierung, Extensivierung), eingearbeitet.

Best-case-Szenario: Die österreichische Agrarpolitik setzt auf nachhaltige Intensivierung (+1% jährlicher technischer Fortschritt), der Import von Produktionsmitteln ist nur wenig beschränkt. Die Nachfrage nach biogenen Rohstoffen (energetische stoffliche Nutzung) steigt auf 10% der entsprechenden Fläche.

Most-probable-case-Szenario: Die österreichische Agrarpolitik bewegt sich entlang der gegenwärtigen politischen Diskussion (Fortschreiben der gegenwärtigen Entwicklung). Die Nachfrage nach biogenen Rohstoffen für stoffliche und energetische Nutzung steigt mittelmäßig. Es sind Versorgungsengpässe bei Eiweißfuttermitteln (-10% Importe) gegeben, rund 50% der potentiellen Ertragsrückgänge aufgrund eines Phosphormangels werden realisiert. Die Nachfrage nach biogenen Rohstoffen (energetische stoffliche Nutzung) steigt auf 12% der entsprechenden Fläche.

Worst-case-Szenario: Die österreichische Agrarpolitik setzt auf eine vollkommene Extensivierung und Ökologisierung (Ertragsniveau im Schnitt rund -30%), gleichzeitig treten Versorgungsprobleme bei Phosphatdüngern (Importe fallen weg) und Eiweißfuttermitteln auf. Aufgrund der hohen Energiepreise steigt die Nachfrage nach Bioenergie stark (40% der entsprechenden Fläche).

Die Simulationen zeigen, dass im Falle des Best-Case-Szenarios der Flächenverbrauch bis 2050 beispielsweise für die Weizenproduktion um 27 % bzw. für Futtergetreide um 34 % in Österreich bis 2050 sinken würde.

Im Falle des Worst-case-Szenarios würde hingegen der Flächenverbrauch für Weizen um 94% bzw. für Futtergetreide um 115% steigen.

In absoluten Zahlen bedeutet dies, dass bei einer Intensivierung (Best-Case-Szenario) der gesamte Flächenverbrauch um rund 240.000 Hektar gegenüber dem Most-probable-case-Szenario reduziert werden kann. Bei einer Extensivierung steigt der Flächenverbrauch um 1.213.000 Hektar gegenüber dem Most-probable-case-Szenario (Durchschnitt der Simulationsergebnisse).

Im Most-probable-case-Szenario, das sich an der gegebenen agrarpolitischen Diskussion orientiert (weitere Extensivierung, Nachfrage nach Biomasse steigt nur mäßig), bleibt der Gesamtflächenbedarf ähnlich wie jetzt.

Zusammenfassend zeigen die Modellierungen folgendes: Wenn die österreichische Politik den gefundenen Risiken proaktiv begegnet und eine (nachhaltige) Intensivierung der Landwirtschaft ermöglicht, ist über "freiwerdende" Flächen (bis zu 240.000 ha) ein erheblicher Spielraum für zusätzliche Produktionspotenziale gegeben. Damit können die Importabhängigkeit und das Ernährungssicherheitsrisiko gesenkt und/oder Flächen für energetische und stoffliche Nutzung bereitgestellt werden.

Im Falle einer flächendeckenden Extensivierung (Ökologisierung) und wenn dem Problem der Abhängigkeit von fossilen Energien nicht entgegengesteuert wird, ist schon 2030 von einer massiv steigenden Importabhängigkeit in der Lebensmittelversorgung und aufgrund einer zu erwartenden Verteuerung von insbesondere fossiler Mobilitätsenergie einem übermäßigen Anstieg des Flächenbedarfs für energetische und stoffliche Nutzungen auszugehen. Die Selbstversorgungsraten sinken stark und das Ernährungssicherheitsrisiko steigt drastisch.

Schreibt man die gegenwärtig postulierte Agrarpolitik fort und lässt technologischen Fortschritt in einem gewissen Ausmaß zu, ergibt sich sowohl ein Spielraum für extensiv/ökologisch genutzte Flächen (bis zu 25%) als auch für die energetische und stoffliche Nutzung (bis zu 15% der Flächen). Das Ernährungssicherheitsrisiko steigt ob der leicht sinkenden Selbstversorgungsraten und der steigenden Unsicherheiten in den Exportregionen.

2. Background and objectives of the project

Austria heavily depends on imports of energy, oilseeds, fruits and vegetables. Austria has a self-sufficiency rate above 100% with only sugar, wheat, beef- and veal meat, pig meat and milk. This data is partly misleading as the high sufficiency rate for meat heavily depends on imports of protein feedstuffs, particularly soybean meal, of which Austrian imports amount to 500,000 tons annually. Soybean meal is essential for pork and poultry production. Without imports of soybean meal the self-sufficiency rate for pork and poultry would shrink dramatically. Austrian agriculture is further highly dependent on imports of energy (crude oil, diesel and gas) and phosphate fertilizer for agricultural production. Phosphorus is essential for plant growth and thus for agricultural crop yields and food production. (Cooper et al 2011). It is mostly excavated in mines and processed with Nitrogen and Potassium to mineral fertilizers (Cordell et al. 2009).

It is evident that there will be risks to Austria's food security if production potentials in Austria and Central Europe are affected by climate change and other supply risks, e.g. shortfalls of crude oil, diesel, gas, phosphate fertilizers or feeding stuffs. Supply risk may be caused by political or socio-economic conflicts and by global competition for agricultural commodities, agricultural land and energy and fertilizers needed for agricultural production. Due to climate change there could be new competition for exported feed or even shortages of food in exporting countries. All of this is important to consider because Austria's food security risks have never been assessed using scientific based methods.

To ensure the future food supply – and therefore national security – some nations (China, Japan and South Korea) have already chosen different solution statements. One of these solutions is the acquisition of agricultural land in foreign countries, occasionally by private firms, formation of national organizations or use of private investors. The 4th IPCC report acknowledges the worldwide effects of climate change and reasons as well as why these effects will increase over the next decades. Measures to mitigate climate change as well as measures to adapt to changing conditions due to climate change will increase in importance in the future. For the first time in June 2008, the U.S. Military Advisory Board classified climate change's risk to U.S. national security as higher than the risk of a military conflict during the Cold War, as well as several other global risks. The European Union has also recognized climate change as a risk for food security.

In the CAP debate, post 2013 concerns about food security in a world with rapidly increasing population, a few things have arisen as key issues. Among them are good land management, the problem of climate change as well as the balanced development of rural areas. Until now, the EU Council has only identified food security risks for developing countries. The United Kingdom has already started an intensive scientific debate on national food security. Under these changed premises, the UK is the only member state to have accomplished a national food security assessment. The Austrian Lebensmittelbewirtschaftungsgesetz of 1997 provides measures to secure food supply in emergency situations in Austria. The Federal Ministry for Agriculture, Forestry, Environment and Water Management may issue the Austrian Agrarmarkt with this responsibility. Food security as a general issue is in the initial phases of political discussion. At the present moment, real data on forecasts of food security risk in Austria are unavailable.

WP 2's objectives are the identification, description and assessment of political and socio- economic threats to exporting regions relevant for Austria's feed, food and energy supply. In light of its membership in the European Union, all EU Member States exporting feed, food or energy to Austria are considered stable trading partners and therefore excluded from this analysis. Furthermore, WP 2 takes into consideration the resilience of the food and feed supply against global markets on a political and socio- economic basis.

Based on the database developed in WP 1 and significant threats to food security identified in WP 2, WP 3 aims to analyse the condition of Austrian food security in 2030 and 2050. Significant threats to food security in

Austria include the impact of climate change, possible shortages of P-fertilizer and protein feedstuffs as well as a possible limited availability of fossil fuels (in terms of a higher demand for bioenergy). The condition of food security is addressed by developing simple simulation models based on supply balances. The models simply show changes in certain positions of product-specific supply balances due to assumed changes.

Since this project aims to analyse the impact of different threats, two different simulation models were developed, each of them incorporating different threats to food security. The simulation models do not aim to forecast SSRs for Austria in 2030 and 2050. Rather, they aim to analyse the possible extent of changes in SSRs due to certain assumptions (in terms of an "if ... then"-analysis, similar to a comparative statics analysis). It is important to note that the simulation models do not account for economic considerations of, e.g., farmers or consumers: in the models, only supply balances are considered, thereby disregarding relative prices, costs, etc. Additionally, in order to account for a range of possible outcomes, assumptions on different magnitudes of threats are bundled into four different scenarios: a baseline scenario, a best-case scenario, a most-probable case scenario and a worst-case scenario.

3. Contents and results of the project

3.1 Agricultural production & supply To describe the global supply situation meeting Austrian demands three different scenarios were used to describe possible supply/demand situations in 2015, 2030 and 2050; each of them based on FAO data and respective FAO studies

- non-intensive scenario,
- intensive scenario and
- intensive scenario taking into account the effects of climate change on production.

Under non-intensive scenario conditions it will not be possible to fully answer the rising demand of the fast growing world population. This means the International Community's goal to cut the number of the world's undernourished and starving people in half cannot be reached by 2015 nor - even less possible – by 2050.

The results of these three scenarios show that it will only be possible to cover world food demand if agricultural production is intensified worldwide. Business as usual, even though higher CO2 amounts should have positive effects on yields per area unit, will not make a difference. Without intensification of production, growth rates will not be sufficient high to answer the increase in food demand.

On the other hand, the 2013 IPCC Report warns that climate change will lead to more intensive and disastrous weather incidents, which may impact local production regions with worldwide consequences for the supply situation. This has already happened 2008, 2009 and 2010.

Another factor of growing importance will be wars, civil as well as worldwide financial and economic crises. The latter will influence dietary habits and enormous migration and may lead to destabilization even in countries that are presently quite stable.

Current dietary habits and non-intensive agricultural production methods are risks for undernourishment. Losses of potential yields in agricultural production (potentially reaching up to 40% of possible production) and waste of food will exacerbate food supply risks particularly in countries with low purchasing power. Taking the IPCC - study under consideration, climate change will hit developing countries first, although most of its causes were produced in developed countries over the last 70 years.

The International Community should commit itself to help developing agriculture in the most endangered developing countries by:

- improving agricultural innovation systems
- building capacities and
- setting priorities to strengthen the capacity of small farmers to farm more efficiently and sustainably.

Small and medium sized agricultural companies are important investors in the rural areas of developing countries. There also represent nearly the only investors in the least developed countries. Therefore, to increase and stabilize the supply for local people, it seems essential to provide favourable conditions for them, enabling them to invest more and at reduced risk and financing their costs.

The supply situation in EU-27

OECD-FAO-forecasts for 2015 show a 10%-increase for wheat production based both on a moderate enlargement of area and higher expected yield progress, going along with increased consumption and resulting in almost equal SSR of some 109%. In 2015 a light SSR reduction to 99% is expected for coarse grains with small growth rates in both production and consumption. Oil seeds show a continuing and remarkable rise in production and consumption since 2000, mainly due to larger cultivation areas especially of winter rapeseed. SSRs are increasing higher for oil seeds (66%, +8% to 2000-2010) and oil seed meals (49%, +2%) but not for vegetable oils (56%, -8%), because of the steeply rising demand for bio oils. In EU-27 soybean area is small with some 0.40 million and larger acreages in the time period from 2010 to 2012 (FAOSTAT, 2013)[1]. The very low Soybean-SSR is thus expected to rise slightly from 6% to 9%. EU-27 imports of soybean dropped in recent years, as did other sources for vegetable oil available for the food sector. The increasing prevalence of oilseed meals from rapeseed and sunflower reduce growth rates of soybean meal demand from EU-abroad (USDA, 2012; OECD, 2011)[2)3)].

EU sugar production declined by about 20% due to EU sugar regime in 2006. In 2015 a sugar SSR of 95% can be expected in EU-27 (OECD, 2013)[4]. As for starch crops in the EU-27, more than 99% are potatoes, a crop steadily shrinking in area, production and even more in consumption. The SSR has thus increased during 2000-2010 from below 90% to 100%. A decrease in SSR from 85% to 77% is given for fruits and a very slight fall from 101% to 99% is shown for vegetables during the first 2000-decade, in both cases due to a stronger reduction in production than in consumption. The EU-SSRs for meats are near 100% or higher. Beef and veal production is shrinking faster than consumption thus lowering the SSR to for 4% to 95% in 2015, whereas pig and poultry meats are growing in both production and demand with almost unchanged SSRs. High SSRs are also given for milk and milk products. For fish there exists a 50%-dependency on supply from outside of EU-27.

The supply situation in Austria for 2015

The Austrian population is expected to follow a rather linear growth course during the next two decades with some 30,000 additional inhabitants a year reaching 9.00 Mio people in 2030 and 9.33 Mio in 2050. Austrian nutrition habits, especially for meat consumption, are largely similar to those in EU-27. Since 2000, Austrian per capita consumption of wheat, coarse grains poultry meat (though on a smaller scale) has increased, whereas consumption of sugar and red meats has slightly declined. However, the total per capita demand of meat for purely human consumption is 66.6 kg per year in Austria (2015), (EU-27: 63.0 kg). The global per capita consumption of meat is much lower and lies at some 33.8 kg (OECD, 2011a). Furthermore, Austria's whole domestic use of meat per capita, including bones, losses and meat used for pet feed, has been up to 100 kg per capita since the middle of the 1990-thies (Elmadfa, 2012)[5].

Actually arable land has been up to 1,371 Mio hectares with an annual decline of about 2,500 hectares or -1.8% since the 1990s due to land sealing or other land consuming projects and plans. Following the trend, 1,350 Mio hectares are expected in 2015: Wheat (20%) and coarse grains (36%) will hold the largest area shares, followed

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[1] FAOSTAT (2013): FAO Statistics Division, http://faostat.fao.org/site/368/default.aspx#ancor, (downloaded Sept 2013)

[2] OECD/FAO (2011): OECD-FAO-Agricultural Outlook 2011-2000, OECD Publishing and FAO. http://dx.doi.org/10.1787/agr_outlook-2011-en)

[3] USDA, Foreign Agricultural Service, 2012: Oilseeds: World markets and trade, Circular Series, FOP 06-12, http://usda01.library.cornell.edu/usda/fas/oilseed-trade//2010s/2012/oilseed-trade-06-12-2012.pdf

[4] OECD (2013): OECD-FAO-agricultural outlook database. http://www.oecd.org/site/oecd-faoagriculturaloutlook/database-oecd-faoagriculturaloutlook.htm

[5] Elmadfa, I. (2012): Österreichischer Ernährungsbericht 2012. 1. Auflage, Im Auftrag des BMG. Institut für Ernährungswissenschaften. Universität Wien.

by other oil crops (8%), sugar beet (4%), soybean (3%) and potatoes (23%). The rest comes from forages, other crops (20%) and fallow land (3%).

Wheat area and production volume is expected to increase in comparison to the 2000-2010 mean by some 10%. Coarse grains are dominated by maize (around 45%) with its yield progresses resulting in a relevant higher production volume in 2015 at an almost unchanged acreage. Since 2000, spring barley area has been reduced by half, mainly in supporting corn area.

Higher domestic demand of wheat is caused by continuously growing food use and substantially higher industrial usage of bioethanol since 2008 (annual capacity up to 620,000 t cereals, mainly maize and wheat but also triticale) and for wheat starch production from June 2013 on (250,000 t a year) (Simak, 2013)[6]. The domestic use of coarse grains has also been accelerated by the extended capacities of maize starch as well as those of bioethanol production and derived products. The industrial use of maize is already more than 1.1 million tons a year (AMA, 2013)[7] or 40 to 50% of the annual production. Canola has established on a growing level of 50,000-60,000 ha since 2005. Since 2007, soybeans have shown an annually increasing cultivation rate due to higher outlets in food production. Despite doubled area, soybeans account for only 3.0% of the arable land. Further protein crops in Austria such as peas and fava beans are cultivated to an even lower extent due to yield risks and lack of market position.

Factoring in food, feed, seed, industrial use and losses, Austrian consumption of wheat soybean, other oil crops and vegetable oils has increased sharply during the last decade. The national demand of oilseeds and vegetable oils was rising significantly from 2000 to 2010, mainly due to increasing food use, especially industrial use for bio fuels. Production of biodiesel was 122,000 t in 2006 and has already risen above 250,000 t since 2008. Furthermore the whole production capacity of 14 Austrian production sites is nearly up to 650,000 tons (ARGE Biokraft, 2012)[8] However, Austrian consumption of sugar and potatoes remained comparatively unchanged during this period. For fruits and vegetables, slightly higher consumption levels can be expected. Taken in context with the higher needs of these commodities for industry, SSRs of wheat, other oil crops and vegetable oils will decrease in 2015. Supply rates of sugar will remain very high. Similarly, no remarkable changes are expected for the supply rates of Austrian potatoes, fruits and vegetables.

Data for meat products refers to gross production of slaughter weight; imports and exports of living animals intended for slaughter are not included. Consumption data is comprised of food use, pet feed, losses and waste. Shares of direct human food vary between 60% and 70%, depending on the kind of meat (supply balances, Statistics Austria, 2012a).

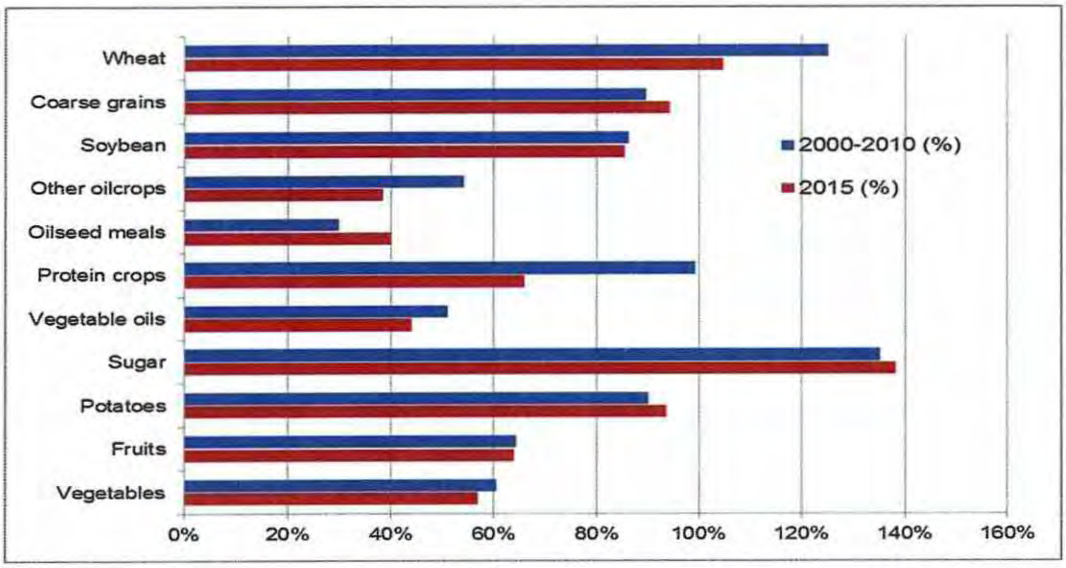
Small decreases in beef and veal production and a more marked decline in consumption are expected in 2015, thus raising the SSR even further up to 153%. Exports of beef and veal have already doubled from 2000 to 2010, though cattle numbers of bulls and cows are slightly shrinking. Other meat species and animal products figures mostly show a similar increase in production and consumption for 2015, especially poultry meat, eggs and cheese, thus the supply rates remain almost unchanged. The increase in butter consumption is covered by higher imports, resulting in a lowered SSR.

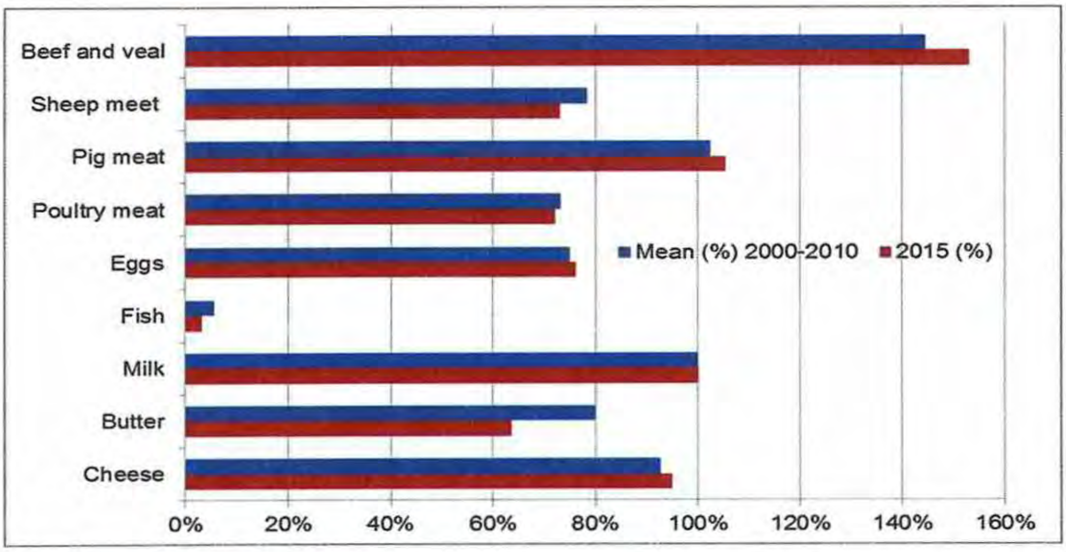
Figure 1: Self-sufficiency rates for plant and animal products mean 2000-2010 and 2015 (%)
(Statistics Austria (2012a) and 2015-forecasts), Note: SSR vegetable oils: including imports of processed oil seed lots

[6] Simak, 2013, Multliplizierte Eiffizienz in Pischelsdorf. AgroZucker-AgroStärke 3/2013, 18-19

[7] AMA - Agrarmarkt Austria (2013): Getreidebilanz 2012/2013, Wien, http://www.ama.at/Portal.Node/ama/public?gentics.rm=PCP&gentics.pm=gti_full&p.contentid=10008.128696&170_Getreidebilanz_Oesterreich_vorlaeufig_2012_2013_quartals.pdf, (downloaded 2013)

[8] ARGE Biokraft, Arbeitsgemeinschaft Flüssige Biokraftstoffe - im Fachverband der Chemischen Industrie Österreichs (2013): Biokraftstoffe - Produktionsdaten. http://www.biokraft-austria.at/DE/www.biokraft-austria.at/Biokraftstoffe/Produktionsdaten/132402de.aspx, (downloaded: Sept 2013)





3.2 Global supply resilience

Description of the current situation

Most imports in the food sector originate from EU-member states. However, some severe dependencies exist, especially in the feed, energy and fertilizer sector:

Energy:	Crude oil, diesel, natural gas
Inputs:	Phosphate, potassium, pesticides, vitamins, essential amino acids
Food:	Bananas
Feed:	Soy

A risk assessment (national resilience level) of exporting countries was carried out by project partner PLUS based on the dependencies described above. The following section gives a summary of the analysis of the exporters to Austria. This analysis is based on the following parameters:

- Social resilience (SR) and the political resilience (PR) of the countries Austria is importing from.

- Self-sufficiency rate for the respective import-dependent item in the exporting country.
- National resilience (NR). For each exporter NR is determined.[9]
- Furthermore, the possibility of military conflicts and a variety of other problems that threaten Austria's suppliers are addressed.
- Specific threats to the suppliers of agricultural products due to rising food prices and "land grabbing" are also evaluated.

Energy

Crude Oil

The main countries exporting crude oil to Austria are Kazakhstan, Libya and Nigeria.

Kazakhstan is the main supplier of crude oil to Austria. Its political and social resilience are rated 2 and 3.3, respectively. The self-sufficiency with regard to crude oil is high (NR = 3). Kazakhstan is dependent on several countries to export its oil by means of pipelines or trains to ports. Currently, there are no open conflicts with any country involved in the transit. Hence, export interruptions security threats are unlikely.

Libya is the second biggest crude oil supplier to Austria. Its PR and SR are rated 5 and 3 respectively. Its self-sufficiency with regard to crude oil is high, resulting in a national resilience of 4. Since the killing of Muamar Ghaddafi in August 2011 and the subsequent dissolution of the regular National Armed Forces, Libya faces several security threats such as civil war or invasion by neighbors. The probability of an unforeseen interruption of petroleum-based exports from Libya to Austria due to security threats is high.

Nigeria as the third important exporter of crude oil to Austria has a low PR and SR, i.e. rated at 4 and 4.5, respectively. Its self-sufficiency with regard to crude oil is high, resulting in a national resilience of 4. Nigeria faces several security threats: lawlessness in the Niger-delta, religious violence and border disputes. Unforeseen interruptions of petroleum-based exports towards Austria are likely at present.

Diesel

Due to Austria's strong dependence on crude oil imports, exporters of diesel fuel to Austria are not directly evaluated, but instead, their main suppliers of crude oil, namely Russia and Venezuela. *Russia's* PR and SR are rated 3 and 3.5, respectively. Its self-sufficiency with regard to crude oil is high, resulting in a national resilience of 3. Russia faces several security threats that could influence exports. Though, its medium level NR represents a dampening factor on this supply risk. Venezuela's PR and SR are rated 4 and 3.5, respectively. Its self-sufficiency with regard to crude oil is high, resulting in a NR of 4. The probability of a significant deterioration of the national security situation is rated high, i.e., it cannot be excluded that short-term oil exports to Austria will be interrupted, e.g., triggered by a change in the political leadership.

Natural Gas

The main exporters of natural gas to Austria are Norway and Russia. Natural gas is needed for nitrogen fertilizer production. *Norway* is the second biggest natural gas supplier to Austria. Its PR and SR are both rated 1. Its self-

[9] The lower the NR value, the higher the resistance of that country against disturbances in the supply of a given item. Values of SR, PR and NR range from 1 to 5. The resilience level (political/social) is assessed by using a combination of various indices, based on a wide spectrum of parameters. These parameters were evaluated by renowned organizations (such as the World Bank and many others) and describe the current situation in quantitative manner, using arbitrary units.

sufficiency with regard to crude oil is high, resulting in a NR of 1 of 5. Norway is not currently facing any appreciable security threats. *Russia* is the main exporter of natural gas to Austria. Similar to the "Diesel" section, Russia's SR, PR and NR are rated 3, 3.5 and 3, respectively; for security threats, see the "Diesel" section.

Inputs

Phosphate

The main exporters of phosphate are, in descending order with regard to amount, Morocco (by far the most important, >90% of total import), Syria and Jordan. They all feature relatively high values in PR and SR, indicating a rather unstable political and social situation. The NR is rated 4 in all three cases.

The world phosphate rock reserves largely consist of the reserves in Morocco and Western Sahara (5,700,000,000 t), which represents about 45% of the global reserves.[10] With a weighted average global fertilizer consumption of 17.0 metric tons per 1,000 persons[11], a further growing global population will accelerate the agricultural use of phosphate rock and thereby increase global competition for this resource.[12] Morocco will have to increase its phosphate production to meet the worldwide demand for (15% in 2010 to around 80% in 2100; Cooper et. al., 2011). In this case, the demand and the free market price are determined by a single country.

Potassium

The most important suppliers of potassium are, in descending order with regard to amount, Germany, Belarus and Russia. *Germany* as a member of the EU is considered to be a stable trading partner and therefore excluded from analysis. *Belarus'* PR and SR are rated 4 and 3.5, respectively. Together with its high self-sufficiency in regard to potassium, a NR value of 4 is assigned. Similar to section "Diesel" *Russia*'s SR, PR and NR are rated 3, 3.5 and 3, respectively.

Pesticides

The main suppliers of pesticides are EU members. However, active ingredients mainly origin from China and India. *China's* PR and SR are rated 2 and 3.8, respectively. Due to a solely medium self-sufficiency rate, the national resilience was assigned 4. *India* has higher value in PR (3) and SR (4.5). In view of its high self-sufficiency this results in national resilience of 4.

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[10] Cost less than US$ 40/tonne; FAO- Natural Resources Management and Environment Department, Use of phosphate rocks for sustainable agriculture..., World phosphate deposits, http://www.fao.org/docrep/007/y5053e/y5053e07.htm#TopOfPage (last visited: 24 January 2012).

[11] Fertilizer consumption measures the quantity of plant nutrients used per unit of arable land. Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Traditional nutrients - animal and plant manures - are not included. The time reference for fertilizer consumption is the crop year (July through June); Agriculture Statistics - Fertilizer consumption, Nationmaster, http://www.nationmaster.com/graph/agr_fer_con_met_ton_percap-consumption-metric-tons-per-capita (last visited: 24 January 2012).

[12] Cooper, J., Lombardi, R., Boardman, D., Carliell-Marquet, C.:The future distribution and production of global phosphate rock reserves; Resources, Conservation and Recycling, 2011 p. 78-86.

Vitamins and Essential Amino Acids

The most important non-EU suppliers of vitamins and essential amino acids are China, Japan and USA. All of them feature high self-sufficiency rates. NR rates for China, Japan and USA are 3, 1 and 2 respectively. Though the NR values are not alarming, there is the possibility of change in market structure due to China's dominance.

Food

Bananas

The most important suppliers of bananas are, in descending order with regard to amount, Costa Rica, Ecuador and Columbia. In all three cases the self-sufficiency rate is high. In terms of NR, Costa Rica is rated 3, Colombia and Ecuador are both rated 4. The possibility of export interruptions with Austria is considerable for Ecuador and Columbia due to internal security threats. Costa Rica is considered to be a more stable trading partner.

Feed

Soy

The most important suppliers of soy feeding stuff are, in descending order with regard to amount, Brazil, USA and Argentina. *Brazil's* PR and SR are rated 3 and 3.8, respectively. The self-sufficiency with regard to soy is high, resulting in a NR of 3. The probability of an unforeseen interruption of soy exports from Brazil to Austria due to security threats is not significantly elevated at present. *USA* was rated 2 and 1.5 with respect to PR and SR, respectively. Due to a high soy self-sufficiency rate, the NR was rated 2. Though military engagement is likely, US soy export to Austria is viewed as of not being threatened by security threats at present. *Argentina's* PR and SR are rated 3 and 3.3, respectively. The self-sufficiency in regard to soy is medium, resulting in a NR of 4. Further, Argentina is a target of land grabbing. It has not yet introduced laws to limit the area that might be purchased by foreigners. The probability of an unforeseen interruption of soy exports from Argentina to Austria due to security threats is high at present.

Assessment of potential future political, military and other security threats, as well as socio-economic threats in 2015, 2030 and 2050

Austrian imports of feed, food and energy are *inter alia* dependent on potential future political, military, socio-economic and other security threats of exporting regions relevant for the supply of these goods to Austria. In view of its membership in the European Union, all EU Member States exporting feed, food or energy to Austria are considered stable trading partners and therefore excluded from this analysis.

Crude Oil and Natural Gas

Kazakhstan can be expected to be a stable short-term oil- and gas-trading partner with Austria at least until 2050. *Libya*'s future development is highly uncertain due to the physical and political devastation caused by the regime change in 2011. Internal as well as external threats can impede the reliability of hydrocarbon exports from Libya to Austria in the next few years, possibly even over several decades. *Nigeria* will remain a highly potent, but also an uncertain, exporter of hydrocarbons to Austria until 2015 and probably beyond that. *Russia* has no imminent internal or external risk factors in the near-term and can continue to be viewed as a stable exporter of crude oil and gas for Austria until 2015. Meanwhile there will be an increasing demand from Asian parties for these commodities, i.e., Austria will have to be prepared to face increasing competition. *Norway* has extensive proven as well as newly discovered oil- and gas reserves. This will enable its industry to supply hydrocarbons to Austria with high reliability until 2050.

Phosphate

Austria is highly dependent on Morocco with regard to its phosphate supply. Though Morocco is not the only phosphate exporting country to Austria, it is by far the largest accounting for more than 90% of all phosphate imports to Austria.

2050: *Morocco* will continue to face internal and external threats to its security, and thereby to its national stability. This in turn may impede its ability to function as a reliable short- and long-term phosphate exporter of to Austria. In addition, the country will have to cope with simultaneous demographic, societal and environmental pressures over the coming decades. Together with Morocco's increasingly monopoly-like position as the world's leading phosphate supplier in the 21st century, Austria needs to consider alternatives, in case exports from Morocco do not meet the amounts needed by Austrian agriculture.

Soy

The main soy suppliers to Austria are (in descending order with respect to amount of the respective product) Brazil, USA and Argentina. Austria is heavily dependent on reliable soy exports from the Americas. *Argentina*, with its large agricultural potential, will remain a key player in the soy sector. However, internal and external security threats will remain for the next decades, unless major political advances are made domestically and in its foreign policy. *Brazil* represents an exporter with a comparatively high degree of stability. The *United States* will be able to continue to act as a highly reliable short-term exporter. Looking far into the future, the country faces significant financial, social and external security threats that may well negatively impact its ability to continue this role with the same high degree of reliability.

3.3 Risk analysis and scenarios

Taking into account supply-balance for Austria and global trends (WP1) and possible threats to food security in Austria identified in WP2, 7 major risks identified by expert assessment that would affect agricultural production and food supply in Austria (risk analysis first stage):

1) Climate change: Changing climatic and extreme weather conditions will affect agricultural production in Austria/Europe. Effects on yields are limited in general until 2050.
2) Import of energy: Austria is dependent on imports of crude oil, diesel, natural gas, and nitrogen fertilizer produced by natural gas (Haber-Bosch-process).
3) Import of inputs (phosphate fertilizer): Austrian agriculture is dependent on imports of phosphates.
4) Import of high-protein feedingstuffs: Austrian life stock production is dependent on imports of soybean meal and vegetable oils.
5) Suspicion of technical progress: Public suspicion of technical progress (e.g. biotechnology in agriculture) may hinder potential increases in yields or plant and animal health.
6) Biofuels and biofibres: Uncontrolled expansion of areas farmed for biofuels and biofibres may limit the area needed for food and feed production.
7) Agricultural policy: Political efforts towards a low input agricultural policy may reduce production potential.

The risk analysis first stage is followed by a risk analysis second stage, performed as Monte-Carlo triangle simulation.

Based on these findings of the first stage and using the database developed in WP 1, **WP 3** aims to address food security in Austria in 2030 and 2050 by developing and analyzing simple simulation models. These models simulate supply balances for 2030 and 2050. The **database** for the simulation models particularly consists of supply-balance data from 2000 to 2010 for Austria (according to Statistics Austria) and forecasts of supply-balance data from 2011 to 2020, which were estimated in WP 1. To simplify the positions of the supply balances and to allow a higher flexibility of the model structure, crop- and animal-specific feed-use coefficients were derived from feed balances and livestock data of Statistics Austria. These coefficients are used to separate total domestic use of the supply balances into two positions only: a feed-use and a non-feed-use position. Changes in stocks are considered in the trade balances.

The aim of the simulation models is to analyse different scenarios by simulating the effect of different assumptions (applied on the exogenous variables) on self-sufficiency rates and on endogenous variables.

For 2030 and 2050, respectively, we define four different scenarios: a baseline scenario, a "most-probable case" scenario with quite moderate assumptions, an optimistic scenario with rather favourably changing assumptions and likely a more positive outcome ("best case") and a pessimistic scenario ("worst case") that represent a set of rather unfavourable assumptions and would result in a more negative outcome. Applying these four scenarios for the years 2030 and 2050 and for two different models result in 16 different outcomes. It is important to note that these classifications of the scenarios ("best case", "worst case", etc.) are made for the sake of distinguishing and simplifying purposes only, but they do not aim to judge certain scenario-specific assumptions in a subjective manner.

Product-specific self-sufficiency rates in Austria will be addressed by implementing different assumptions on the impact of climate change on crop yields, on the availability of phosphorus fertilizer and of imports of protein feeding stuff, and on the demand for bioenergy. In addition, we consider technical progress in the agricultural sector as well as changes in yields due to different levels (or, intensities) of agricultural inputs. Table 1 qualitatively summarizes the scenario-specific assumptions. The following assumptions were considered in the simulation models.

Table 1: Overview of assumptions

	baseline scenario	**best-case scenario**	**most-probable case scenario**	**worst-case scenario**
impact of climate change	yes			
technical progress	as before	higher than before	as before	lower than before
input level affecting yields	as before	high input level	medium input level	low input level
phosphorus fertilizer	no shortage		medium impact of shortage	total impact of shortage
bioenergy	demand as before	low increase in demand	medium increase in demand	high increase in demand
imports of protein feeding stuff	no import restrictions		medium import restrictions	high import restrictions

Assumptions are described in detail in chapter 5.3 of this report and in chapter 6.3. of the "Full Report".

The scenarios developed can be described as follows:

1. The best-case scenario assumes a relatively high level of agricultural productivity. All possibilities offered by technical progress (including biotechnology) are used. The intensity level of inputs increases relative to 2015. There are no shortages in energy, inputs and imports of feedstuffs. Demand for biofuel and biofibres increases up to 10% of the acreage of the respective crops.

2. The most-probable-case scenario assumes a medium input level and expanded areas farmed extensively (25%). Technical progress and normal breeding efforts as well as shortages in phosphate and high-protein feedstuffs are taken into account. Demand for biofuel and biofibres increases up to 12% of the acreage of the respective crops. The scenario assumes that the share of extensive agriculture is higher. The most-probable-case scenario more or less mirrors the current political focus.

3. The worst-case scenario assumes a relatively low input level (100% organic agriculture). Shortages in fossil energy, phosphate fertilizers and high-protein feedstuffs are also taken into account. In this scenario, demand for biofuel and biofibres increases up to 40% of the acreage of the respective crops.

As mentioned before, the structure of the **simulation models** (in terms of the question, which supply-balance position is taken as given) is determined by the possible analysed threats. Besides developing the simulation models, the tasks of WP 3 included a project team agreement on possible magnitudes of these threats and their implementation in different scenarios. The simulation models refer to the years 2030 and 2050 as this is the time horizon considered in recent studies on climate change. This timely reference is particularly established via the implementation of changes in yields due to climate change (WP 1) and population forecasts from Statistics Austria. In addition, further assumptions of possible changes in crop yields include different levels of technical progress, of the availability of P-fertilizer and of the intensity level of inputs. Regarding animal yields (e.g. milk, meat), changes are possible due to technical progress and the intensity level of inputs. Besides changes in yields, the threat of shortages in fossil fuels transfers into assumptions of different levels of per-capita bioenergy demand, whereas assumptions of possible shortages in protein feeding stuff require that trade balances need to be taken as given in the models. The threats identified in WP 2 are bundled in four different **scenarios** for 2030 and 2050: a baseline scenario, a best-case scenario, a most-probable-case scenario and a worst-case scenario. To account for the given effects of climate change on agricultural production, its impact on crop yields is implemented in all scenarios at the same level. The baseline scenario assumes the impact of climate change, a continuation of the trend of technical progress, an intensity level of inputs as before, no shortages in P-fertilization and in imports of protein feed, and a per-capita use of bioenergy crops as before. Relative to that, the best-case scenario assumes a higher level of technical progress, an intensification of input levels as well as a slightly higher bioenergy use than in the baseline scenario. The most-probable-case scenario assumes technical progress as in the baseline scenario and medium levels of intensification, of availability of P-fertilizer and of import restrictions of protein feed as well as an increasing use of bioenergy. The worst-case scenario assumes low levels of technical progress, of intensification, of available P-fertilizer as well as high levels of import restrictions of protein feed and of bioenergy use. While specific numerical values are assumed for yields and population in 2030 and 2050, uncertainties regarding the level of other exogenous supply-balance components are met by **Monte-Carlo simulations** by generating a range of possible input data based on the database 2000 to 2020 and some probability function. Results of these Monte-Carlo simulations are used as data input for variables like trade balances, per-head non-feed use, areas and livestock. Scenario-specific assumptions (imports of protein feeding stuff, bioenergy use) were applied to these data.

On average Austria has been a net exporter from 2000 to 2010 as well as in 2015 regarding the crop products wheat and sugar and regarding the animal products beef and veal, pork and milk with SSRs above 100% (see also Figure 1). For the remaining products as considered in the supply balances, Austria has been a net importer with SSRs below 100%. Thus, due to import dependencies, climate change or the global availability of P-fertilizer, food security is a critical issue for the latter products with average SSRs (2000 - 2010) ranging from 99% (protein crops) to 6% (fish). Particularly, animal production relies on imports of protein feeding stuff with all SSRs of relevant crops being below 100%: protein crops (99%), soybeans (86%), other oilseeds (54%) and oilseed meals (30%). The simulation models for 2030 and 2050 show the following results:

Since some data input is based on Monte-Carlo simulations, the simulation models deliver a considerable range of results for each year (2030, 2050) and scenario. In the following presentation of results, only the average value of the total range is chosen for simplicity reasons (see Figure 2). Simulation model 1 asks for the impact of changes in consumption (consisting of feed use and non-feed use) and changes in trade on production. In this model the scenario-specific assumptions regarding changes in imports of protein feeding stuff and changes in non-feed consumption (e.g., bioenergy use) are incorporated, but the effect of changes in yields on production is not implemented. Rather, once production needs are identified, the incorporation of scenario-specific yields allows identification of the required changes in acreage and livestock. Relative to 2015 (the year chosen as a reference point) the simulation results show that changes in SSRs are quite moderate so that – qualitatively net-import or net-export positions of products remain. The difference between minimum and maximum average SSRs across time (2030, 2050) and scenarios are highest in the cases of oilseed meals (30 %age points) and "other oilseeds" (23 %age points). However, in most cases average SSRs in 2030 and 2050 are higher than in 2015. This result is due to generally higher production needs as a consequence of the assumptions on imports of protein feed and/or on per-capita bioenergy demand. In addition, changes in total demand (for feed and non-feed) are due to changes in the population and per-capita non-feed use (representing various scenarios on bioenergy uses which are derived from Monte-Carlo simulations), which implies changes in the necessary livestock and, consequently, in the feed use (and acreage) of certain crop products. Increases in average SSRs relative to 2015 are particularly high in the cases of "other oilseeds" (up to +31 percentage points in the worst-case scenario in 2050) and protein crops (up to +25 percentage points in the worst-case scenario in 2030 and 2050). Differences between scenario results of crop products are mainly due to different assumptions on trade balances and per-head non-feed use as well as changing livestock and feed use.

The model results show that necessary increases in average livestock are highest for sheep (up to +42% in the worst-case scenario in 2050, relative to 2015). On average, necessary increases are about +5% for other livestock categories in the most-probable case scenario or about +17% in the worst-case scenario. In the best-case scenario, average livestock numbers decrease relative to 2015 (except for sheep). Referring to acreage, changes in the average total area of crops considered in the simulation model ranges from -29% (best-case scenario in 2050) to +109% (worst-case scenario in 2050), relative to 2015. Thus, the required acreage is more than twice as high in the worst-case scenario. Most acreage is cultivated with coarse grains (47% of the total area considered in 2015) and wheat (31%). Hence, even relatively small changes in the shares of these crops have a substantial impact in absolute terms.

Table 2: Acreage needed in different scenarios; in 1,000 ha (model 1)

2015	Sce-nario	2030						2050					
		min	1st q	mn	med	3rd q	max	min	1st q	mn	med	3rd q	max
1,033	bl	750	898	938	939	979	1,138	687	825	862	863	899	1,046
	bc	666	804	841	842	878	1,023	583	704	736	737	768	893
	mpc	840	1,000	1,042	1,043	1,085	1,254	783	933	973	973	1,012	1,170
	wc	1,711	1,981	2,057	2,059	2,132	2,417	1,797	2,080	2,161	2,163	2,240	2,533

Simulation model 2 asks for the impact of changes in production (consisting of yields, areas and livestock) and changes in consumption (consisting of feed use and non-feed use) on the trade balance and therefore identifies changing import needs or export possibilities. Thus, this model does not incorporate assumed changes in imports of protein feedstuff. Changes in yields as well as exogenously given acreage and livestock are directly implemented in the model and affect SSRs (in addition to changes in non-feed use). Relative to 2015 (and contrary to results of model 1), changes in average SSRs are quite substantial so that net-import or –export positions change: in the worst case, average SSRs of products that have been net-exported so far (sugar, wheat, pork and milk) fall below 100%. Consequently, these products may become net-imported products and thereby increase food and feed dependencies from other countries. In the best case, net-imported products like cheese, starch crops, coarse grains and soybeans show average SSRs above 100% and, thus, may become net-exported products. Differences between time-specific (2030, 2050) and scenario-specific average SSRs (i.e., the range between average scenario results) are highest in the case of wheat (98 %age points), sugar (92 %age points) and coarse grains (91 %age points). Coarse grains show the highest absolute changes in average imports/exports, relative to 2015: in 2015, some 235,000 tons may be imported according to forecasts. In the best-case scenario in 2050, the simulation results indicate possible exports of about 1.7 million tons on average, but in the worst-case scenario in 2050 necessary imports of about 2.7 million tons on average. Regarding animal products, this range between scenario results is highest in the case of milk: in the best case, there are possible exports of about 219,000 tons on average (in 2030), in the worst case, import needs are up to almost 501,000 tons on average (in 2050).

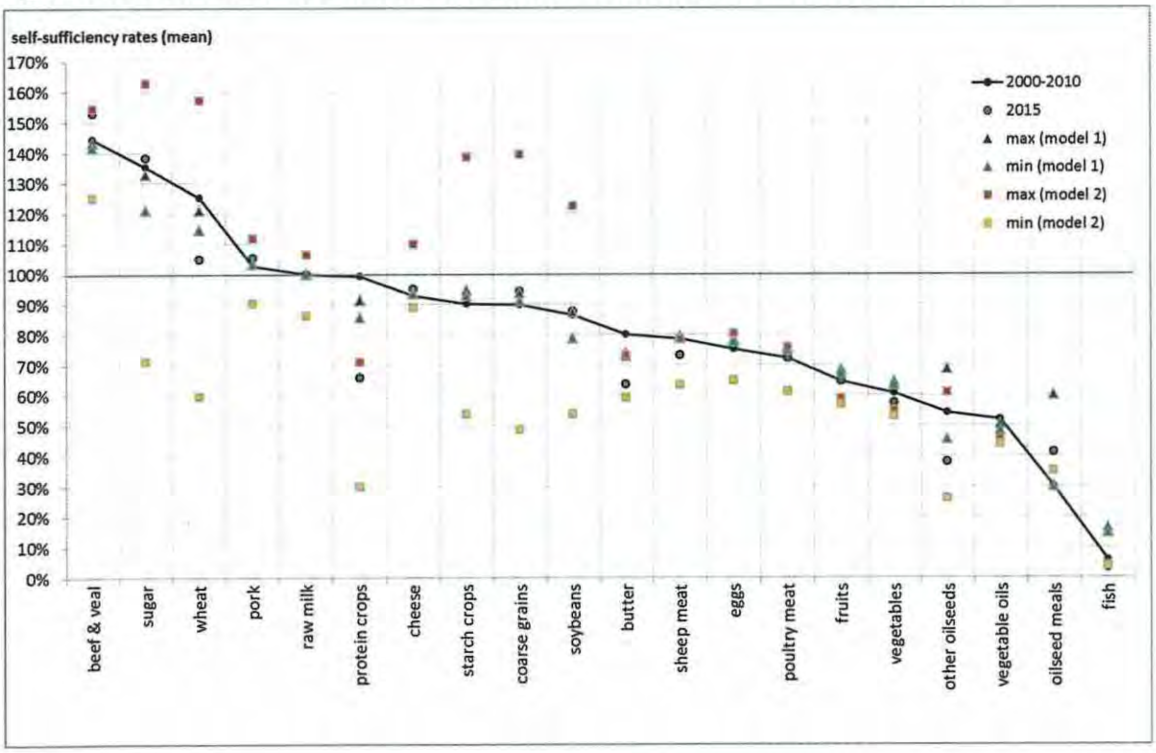
Table 3: SSR (self-sufficiency rates) of crop products (acreage is taken as given) (model 2)

	2000-2010	*diff. to 2015*	2015		2030	*diff. to 2015*	2050	*diff. to 2015*
wheat	125%	*+21%*	105%	baseline	120%	*+16%*	127%	*+22%*
				best-case	134%	*+30%*	157%	*+52%*
				most-probable	109%	*+4%*	113%	*+8%*
				worst-case	61%	*-44%*	60%	*-45%*
coarse grains	90%	*-4%*	94%	baseline	112%	*+18%*	129%	*+35%*
				best-case	118%	*+24%*	139%	*+45%*
				most-probable	102%	*+8%*	115%	*+21%*
				worst-case	50%	*-44%*	49%	*-46%*
soybeans	86%	*+1%*	88%	baseline	84%	*-3%*	107%	*+20%*
				best-case	93%	*+6%*	122%	*+35%*
				most-probable	82%	*-6%*	103%	*+15%*
				worst-case	54%	*-34%*	58%	*-29%*
other oilseeds	54%	*+16%*	38%	baseline	50%	*+12%*	55%	*+17%*
				best-case	54%	*+15%*	61%	*+23%*
				most-probable	47%	*+9%*	51%	*+12%*
				worst-case	28%	*-10%*	26%	*-12%*
oilseed meals	30%	*-11%*	41%	all scenarios	35%	*-6%*	35%	*-6%*
protein crops	99%	*+33%*	66%	baseline	64%	*-2%*	55%	*-11%*
				best-case	71%	*+5%*	63%	*-3%*
				most-probable	61%	*-5%*	51%	*-15%*
				worst-case	38%	*-28%*	30%	*-36%*
vegetable oils	52%	*+8%*	44%	all scenarios	45%	*+2%*	44%	*0%*
sugar	135%	*-3%*	138%	baseline	144%	*+5%*	163%	*+25%*
				best-case	135%	*-3%*	154%	*+16%*
				most-probable	127%	*-11%*	142%	*+3%*
				worst-case	75%	*-63%*	71%	*-67%*
starch crops	90%	*-3%*	94%	baseline	119%	*+26%*	135%	*+41%*
				best-case	121%	*+28%*	138%	*+45%*
				most-probable	108%	*+14%*	120%	*+27%*
				worst-case	56%	*-38%*	54%	*-40%*
fruits	65%	*-2%*	64%	all scenarios	59%	*-6%*	57%	*-8%*
vegetables	61%	*+2%*	57%	all scenarios	55%	*-2%*	53%	*-4%*

Table 4: SSR (self-sufficiency rates) of animal products (acreage is taken as given) (model 2)

	2000-2010	*diff. to 2015*	2015		2030	*diff. to 2015*	2050	*diff. to 2015*
beef & veal	144%	*-9%*	153%	baseline/most prob.	141%	*-12%*	138%	*-15%*
				best-case	154%	*+1%*	152%	*-1%*
				worst-case	127%	*-26%*	125%	*-28%*
sheep meat	79%	*+5%*	73%	baseline/most prob.	71%	*-2%*	70%	*-3%*
				best-case	78%	*+5%*	77%	*+4%*
				worst-case	64%	*-9%*	63%	*-10%*
pork	103%	*-3%*	105%	baseline/most prob.	102%	*-4%*	100%	*-5%*
				best-case	112%	*+6%*	110%	*+4%*
				worst-case	92%	*-14%*	90%	*-15%*
poultry meat	73%	*+1%*	72%	baseline/most prob.	69%	*-3%*	68%	*-4%*
				best-case	76%	*+3%*	74%	*+2%*
				worst-case	62%	*-10%*	61%	*-11%*
eggs	75%	*-1%*	76%	baseline/most prob.	73%	*-3%*	72%	*-4%*
				best-case	80%	*+4%*	79%	*+3%*
				worst-case	66%	*-10%*	65%	*-11%*
fish	6%	*+2%*	3%	all scenarios	4%	*+1%*	4%	*+1%*
raw milk	100%	*0%*	100%	baseline/most prob.	97%	*-3%*	95%	*-5%*
				best-case	106%	*+6%*	105%	*+5%*
				worst-case	87%	*-13%*	86%	*-14%*
butter	80%	*+16%*	64%	baseline/most prob.	67%	*+3%*	66%	*+2%*
				best-case	73%	*+10%*	72%	*+8%*
				worst-case	60%	*-4%*	59%	*-4%*
cheese	93%	*-2%*	95%	baseline/most prob.	100%	*+5%*	98%	*+3%*
				best-case	110%	*+15%*	108%	*+13%*
				worst-case	90%	*-5%*	89%	*-6%*

Figure 2: minimum and maximum average self-sufficiency rates of model 1 and 2



3.4 Summary of results

Currently, Austria is a net exporter of sugar, beef and veal; regarding wheat and pork, production is slightly higher than domestic demand. There are deficiencies in the cases of "other" oil seeds (i.e. non-soybeans), oil seed meals, vegetable oils, fruits, vegetables, poultry meat, eggs, butter and, most extremely, fish. Based on supply balance data (historical data and forecasts up to 2020) and data derived via Monte-Carlo simulations, self-sufficiency rates for Austria in 2030 and 2050 are addressed by means of two simple simulation models. The scenarios employed in the simulation models for 2030 and 2050 can be described as follows:

1. The best-case scenario assumes a relatively high level of agricultural productivity. All possibilities offered by technical progress (including biotechnology) are used. The intensity level of inputs increases relative to 2015. There are no shortages in energy, inputs and imports of feedstuffs. Demand for biofuel and biofibres increases up to 10% of the acreage of the respective crops.

2. The most-probable-case scenario assumes a medium input level and expanded areas farmed extensively (25%). Technical progress and breeding efforts stay at the same extent as today. Shortages in phosphate and high-protein feedstuff supply are also taken into account. Demand for biofuel and biofibres increases up to 12% of the acreage of the respective crops. The scenario assumes that the share of extensive agriculture is higher. The most-probable-case scenario more or less mirrors current political focus.

3. The worst-case scenario assumes a relatively low input level (100% organic agriculture). Shortages in fossil energy, phosphate fertilizers and high-protein feedstuffs are also taken into account. In this scenario, demand for biofuel and biofibres increases up to 40% of the acreage of the respective crops.

Given a set of different assumptions, the largest positive changes in crop yields per hectare (relative to 2015) are due to technical progress. However, the largest negative changes in yields are generally due to lower intensity levels of inputs. Lower intensity levels may be the result of shortages in input supply or due to political presumptions.

The simulation models show that the assumption of a given production (model 2, assuming given areas, livestock and yields) implies higher changes in SSRs relative to 2015 than the assumption of a given trade balance (model 1). The results of model 1 show that SSRs in 2030 and 2050 are close to historical (2000 - 2010) SSRs. However, this does not imply that food security is not a future issue: a constant SSR (+/- 0%) is the result of equal relative changes (in %) in, both, production and consumption. According to the structure of model 1, a high and positive relative change in production (with production being the solution of the model) must be guaranteed by an increase in acreage or livestock. In this sense, model 1 derives a "required" SSR. The assumptions on changes in imports of protein feed, population and changes in per-capita demand for bioenergy in model 1 result in relatively moderate changes in SSRs. Relative to 2015, changes in crop yields in 2030 and 2050 are positive for all crops (except for protein crops). However, in the worst case scenario, crop yields are lower than in 2015 due to more extensive production methods, thereby implying relatively large increases in acreage that are necessary to guarantee the required production. Theoretically and given the model assumptions, the acreage of arable crops considered in model 1 must more than double according to simulation results in the worst-case scenario.

Model 1: acreage (trade balance and consumption is taken as given)

- In the **best-case scenario** the required total acreage to meet present-day food security demands of Austria decreases by -19% (-191,000 ha) in 2030 and by -29% (–297,000 ha) in 2050, relative to 2015. (see Table 2)
- In the **most-probable-case scenario** the required acreage to meet present-day food security demands of Austria increases in 2030 by +1% (+10,000 ha) in 2030 and decreases 2050 by -6% (-60,000 ha) in 2050, relative to 2015. The most-probable-case scenario indicates that more extensive agriculture and more area used for biofuel and fiber production is possible if technical progress is not prohibited. (see Table 2)
- In the **worst-case scenario** the acreage needed to meet present-day food security demands of Austria increases by +99% (+1,025,000 ha) in 2030 and by +109% (+1,128,000 ha) in 2050, relative to 2015. (see Table 2)

Model 2 (taking production/acreage and consumption as given) likewise implies that a constant SSR is the result of equal relative changes in production and consumption. In addition, such a situation also requires relative changes in trade (which is the solution variable of model 2) of an equal size. However, the result of a decreasing SSR for a product with import needs (i.e., SSR below 100%) does not necessarily imply more imports in absolute terms (i.e., in tonnes): for example, if the negative relative change in production is higher than the negative relative change in consumption, the SSR decreases, but import needs may decrease in absolute terms. The assumptions on changes in crop and animal yields, population and changes in bioenergy used in model 2 imply relatively large changes in and ranges of possible SSRs. Products like cheese, starch crops, coarse grains or soybeans may become net-exported products in the best case; products like sugar, wheat, pork and milk may become net-imported products in the worst case, thereby indicating possible future import dependencies that previously (2000 - 2010) did not exist.

Model 2: self-sufficiency rates (production/acreage and consumption is taken as given)

- SSRs increase by up to 45 percentage points for coarse grains and by up to 52 percentage points in 2050 for wheat in the **best-case scenario** (see Table 3). SSR for meat products and milk increase slightly (see Table 4).
- In the **most-probable-case scenario** SSR increases by up to 21 percentage points for coarse grains and by up to 8 percentage points for wheat in 2050. SRR drop by 15 percentage points for protein crops and beef & veal and by around 5 percentage points for other meat products and milk in 2050 (see Table 3 and 4).
- In the **worst-case scenario** SSR drop by up to 46 percentage points for coarse grains and by up to 45 percentage points for wheat in 2050. SRR drop by up to 36 percentage points for protein crops and by up to 67 percentage points for sugar (see Table 3). SSR beef & veal will drop by around 28 percentage points. SSRs for other meat products and milk products will drop between 6 and 15 percentage points until 2050 (see Table 4).

It is important to emphasize that the simple simulation models employed in this project do not "forecast" SSRs for 2030 and 2050. Rather, the simulation models show the possible ranges of results for SSRs due to Monte-Carlo simulations, given a set of assumptions, by leaving economic decisions of agents aside and by taking certain variables as given. Therefore, the results show the impact of assumed changes on certain supply-balance positions in an "if ... then"-manner only.

4. Conclusions and recommendations

4.1 Conclusions

On a global scale, climate change will have a positive impact on agricultural production by 2030 in most regions. Under the selected climate scenario, most crops will benefit by 2030. By 2050 some regions will show negative impacts.

In Austria, climate change will generally have a positive influence on per-hectare yields for most of the crops. If technical progress and a high input level are assumed, yields will increase up to 2050. The exceptions to this are protein crops.

Climate change will cause more extreme weather events (especially heat and drought and heavy rain) affecting agricultural production and yields within a growth period. Regional markets may be disturbed. Volatile prices and import needs for manageable periods will be a consequence.

Self-sufficiency rates (SSR) and acreage needed for food and feed production are strongly influenced by other parameters as:

- Dependency on imports of crude oil, diesel, natural gas; dependency on nitrogen fertilizer produced by natural gas (Haber-Bosch-process)
- Dependency on imports of inputs, particularly phosphates and active components of pesticides
- Dependency on imports of high-protein feedstuffs, particularly soy bean meal and vegetable oils
- Accepting technical progress (e.g. biotechnology) by politics and the population
- Uncontrolled expansion of areas farmed for biofuels and biofibres
- Political presupposition towards a low input agriculture (e.g. 100% organic farming)

The simulation- model developed in this project can be us by to show other scenarios as well. By changing parameters for yield or area used for biofuel different scenarios influenced by the threats can be modelled.

4.2 Recommendations

Based on the findings and results of this project, the following recommendations may assist decision makers in meeting Austria's future food security:

1. **Climate change and agricultural production in Austria**

All specific scientific research on climate change indicates that agriculture has to adapt to it. Following the 5th report of the IPCC on climate change, Austria will have to face more and more extreme weather situations, which will especially influence agricultural production. Yields, sale volumes of farms, prices of agricultural products and farmers' income may fluctuate strongly year by year. Feed and food markets will be more volatile.

Therefore we recommend

- State financed storage of key agricultural products to stabilize markets and guarantee supply in years with low yields.
- Subsidized assurances, either with respect to production or based on the average yearly farm income, to sustain the economic viability of farms (investing power) and farmers' incomes.

- Enhancing research and plant breeding particularly regarding drought and heat tolerant varieties.
- Market support policy that stabilizes prices and farming systems that increase yields.

2. Dependency on imports of crude oil, diesel, natural gas; dependency on nitrogen fertilizer produced by natural gas

Austria is heavily dependent on imports of high strategic importance originating from non-EU countries. These imports include energy (crude oil, natural gas), phosphate fertilizer and protein feedstuffs, especially soy.

The main **crude oil** suppliers to Austria are (in descending order with respect to amount) Kazakhstan, Libya and Nigeria. **Natural gas** is mainly imported from Russia and Norway. Kazakhstan can be expected to be a stable short-term trading partner for oil- and gas exports to Austria and in the subsequent period leading up to 2050. Libya's future development is highly uncertain due to the physical and political devastation caused by the regime change in 2011. Nigeria will remain a highly potent, but also an uncertain exporter of hydrocarbons to Austria until 2015 and most likely beyond that. Russia has no imminent internal or external risk factors in the near future and can continue to be viewed as a stable exporter of crude oil and gas for Austria until 2015; Austria will have to be prepared to face increasing foreign competition for Russian oil and gas. Norway will be able to reliably supply hydrocarbons to Austria until 2050.

Worldwide reserves of petrol as well as natural gas are already limited and prices are relatively high, when compared to output prices of agricultural production. Different economic sectors in Austria are heavily competing with respect to petrol and natural gas based energy use. Most of the competitors have higher values added than agriculture, which finally could result in the situation that agriculture will not have access to affordable and economically justifiable energy.

We recommend

- raising Austria's self-sufficiency rate in the energy sector
- limiting the use of petrol and natural gas based energy to those sectors, where no other energy use is technically or economically possible (e.g. energy for mobility)
- replacing fossil energy (natural gas) with alternative energy sources (wind power, solar energy) for the production of nitrogen fertilizers
- enhancing fertilization efficiency and fostering research to develop methods and/or plants to fix nitrogen by plants (due to the dependency on imports of fossil energy for the production of nitrogen fertilizer)
- increasing the production of biofuels as well as of biogas. Agriculture should be able to produce the energy needed for agricultural production and food logistics. Using bio-waste, which accumulates year by year in Austria and originates from households, gastronomy and the food industry, it should be possible to reduce the demand for area. Austria should foster investments and research to enhance energy efficiency and eventual development of new generations of biofuels
- diversifying suppliers of crude oil and by doing so, minimizing the risk of getting cut off from short-term supply in the short and near future
- assisting in building up stable political institutions in exporting countries Austria is depending on.

3. Dependency on imports of phosphates and other inputs

Concerning phosphate, Morocco (by far the largest phosphate supplier worldwide, accounting for more than 90% of all imports to Austria) will be in a monopolistic position in the 21st century. Austria will have to prepare for how to ensure uninterrupted exports to its agriculture sector from a single dominant exporter threatened by internal and external security threats as well as by demographic, societal and environmental pressure.

We recommend

- limiting the use of phosphor to the minimum demand of soil based crop production
- enhancing recycling of phosphor from any source available, e.g. sewage treatment plants (laundry detergents) or extracts from bones in abattoirs
- enhancing scientific research on the mobilization of phosphates in agricultural soils, even that only postpones the problem
- assisting in the building of stable political institutions and peace-keeping actions in phosphate exporting countries
- ensuring technical and legal facilities to produce vitamins, essential amino acids and pesticides in Europe. Problems relating to the lacking supply of pesticides may be crucial as crop pests and invasive pathogens already have a high impact on yields. Climate change may intensify the risks.

4. Dependency on imports of high-protein feedstuffs

Austria depends on feed imports, especially vegetable oils and soybean meals. The protein component in oil seed meals is essential for Austrian pig and poultry production. In spite of successfully raising the supply rate for oil seed meals by reinforcing domestic oil plant cultivation, the protein supply situation remains crucial. Soy products are particularly important to ensure high quality protein feed for pigs and poultry. Throughout the last decades, there have been strong efforts to increase soybean production, but it seems difficult to achieve the necessary level of production. Planting in more areas is restricted by a lack of varieties adapted to Austrian climate conditions (yield) and difficulties with weeds.

Consequently, the good or at least relevant self-sufficiency levels for pork and poultry meat are more or less superficial and very sensitive to shortages of the protein supply from abroad.

Actual per capita consumption of meats in EU and Austria is double the world level. Enforcement of oil crop cultivation within the last decade and industrial use of cereals in Austria has lowered protein imports, but only gradually.

With SSRs of 9% for soybean, 49% for oil seed meals and 46% for vegetable oils EU-27 exhibits similar shortages in the home production of relevant agricultural products as Austria.

We recommend

- enhancing the cultivation of soy beans for feed production in Central Europe (Austrian protein strategy, "Danube soya")
- enhancing research and debate possible methods and technologies to solve weed control problems in soy cropping
- considering the use of animal offal and meat and bone meal for feeding of non ruminants
- re-evaluating hygiene provisions to facilitate feeding of food waste to animals
- promoting responsible use of meat in human diets. For Austria effects of reducing meat consumption in diets on food security may be limited as around 70% of Austrian farm land can only be used by meat production due to geography (alpine grassland) or climatic or natural limitations (crops grow only in feeding quality crop rotation).

- promoting the consumption of meat less dependent on high quality protein feedstuffs and using feed from grassland and meadows (ruminants)
- assisting in building up stable political institutions in exporting countries Austria is depending on

With regard to soy, Austria should strengthen its relationship with Brazil as soy supplier bearing in mind that its other two main soy suppliers, Argentina and the US, may have problems in meeting Austria's long term demands.

5. Technical progress

We recommend

- intensifying scientific and applied research programs in plant and animal breeding. The final objectives should be to raise yields in crop production as well as to increase the transformation rate in animal production
- informing the public on food security issues and present-day agricultural production methods and enable an unbiased dispute on technologies and measures to enhance productivity.

6. Biofuels und biofibres

The increased use of biofuels and biofibres is an important pillar of the bioeconomy. Fossil energy resources will decrease within the next decade and may end anytime. Prices will rise. Political risks may disturb markets even earlier.

We recommend

- enhancing the use of biofuels and biofibres to moderate prices for fossil energy and to steer demand and supply (in addition to other alternative energy sources)
- preventing an unlimited expansion of areas farmed for biofuels and biofibres, by steering the demand for food, feed, fibers and fuel.

We have to keep in mind that higher farm prices in developing countries increase incomes in agriculture, lead to rising investments, and at the same time favor productivity in the sector. There are still about 1.4 billion people living on less than US$ 1.25 a day. At least 70% of the world's very poor people are rural. 80% of rural households farm to some extent, and typically it is the poorest households that rely most on farming and agricultural labor.[13] 90% of the world's extremely poor are small-scale farmers.[14] Higher agricultural prices, even if they are results of biofuel production, may, sometime in the foreseeable future, reduce poverty and boost investments.[15]

7. Policy presuppositions

Low input agriculture may be more environmental friendly. Extensive low input agricultural production needs more area to produce the same amount of food. Extensive low input agricultural production in Austria is factually an export of virtual area to developing countries. Dependencies grow strongly.

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[13] IFAD, Rural Poverty Report 2011, 5, http://www.ifad.org/rpr2011/index.htm
[14] FAO (2012): Livestock sector development for poverty reduction, Rome; XIII
[15] See pages 6, 14 regearding prices John Dixon and Aidan Gulliver with David Gibbon Principal Editor: Malcolm Hall, http://www.fao.org/docrep/003/y1860e/y1860e00.htm, last visited Dec 2013

High input agriculture may harm the environment and interfere with animal welfare. SSR may be increased significantly.

We recommend

- balancing reasons between political presupposition towards a low input agriculture (e.g. organic farming) and a high input agriculture. Sustainable agricultural intensification (more intense production taking into account environmental aspects) may be a solution
- limiting the consumption of agricultural area by construction of e.g. building, roads or reforestation and other use.

The recommendations are based on the 7 major risks that were derived by expert assessment primarily from WP 1 and 2 "Production and supply" and "Global supply resilience" (= risk analysis first stage).

Monte-Carlo simulations (WP 3 "Risk analysis and scenarios") are based on these risks found by the risk analysis first stage and show potential effects and the range of variation of the risks and challenges (= risk analysis second stage).

Experts found recommendations in the context of risk analysis on the basis of the three model scenarios. Particularly the recommendations number 2, 5, 6, and 7 were sharpened by the results of the Monte-Carlo simulations and expressed as political recommendations.

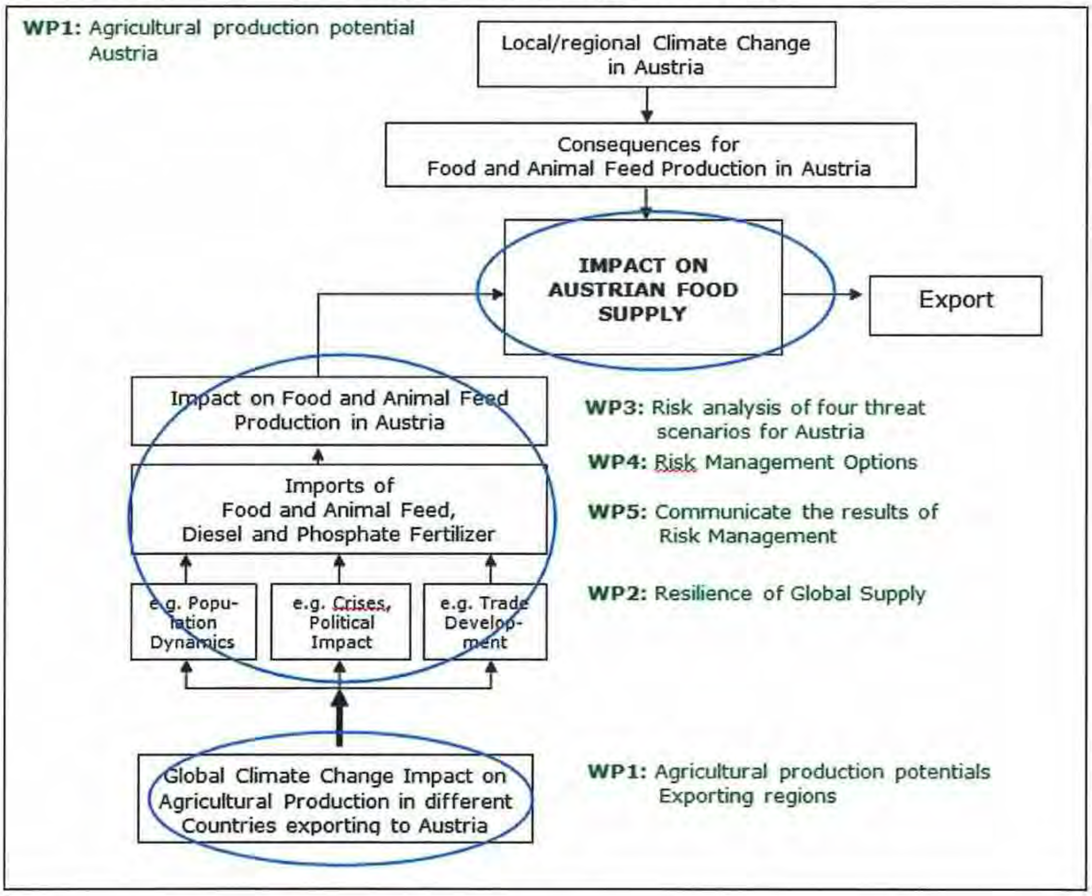
5. Methods

Project results were derived into two stages. The first was comprised of a forecast for production, areas, consumption, trade balances and SSRs, and a risk assessment (NR). The second was based upon a risk assessment using threat scenarios analysed by Monte-Carlo simulations. Based on the assessment of forecasts of production, area, consumption, trade balances and SSR for 2030 and 2050 and a risk assessment (NR) of exporting countries, scenarios were developed in expert workshops.

Agricultural production prognoses, hazards and threats regarding the resilience of food and feed supply as well as the supply with energy and phosphate fertilizer as described in WP 1 and WP 2 were analysed and assessed for this reason. The scenarios were separately calculated with the Monte Carlo simulation in WP 3. With the Monte Carlo simulation input criteria and the calculated consequences of several hazards and threats can be combined to calculate an overall risk, which describes the impact on Austrian food supply and the self-sufficiency rate. The results of the simulations of different scenarios for the 2030s and for the 2050s are evaluated separately against today's demand for food and feed (2015).

Risk management options and recommendations were developed in a concluding expert workshop taking into account results of WP 1 and 2, model results (WP 3) and the general expertise of the experts (WP 4).

Figure 3: Structure of the analysis of security risks caused by climate change



5.1 Methods of Work Package 1:

Methodology

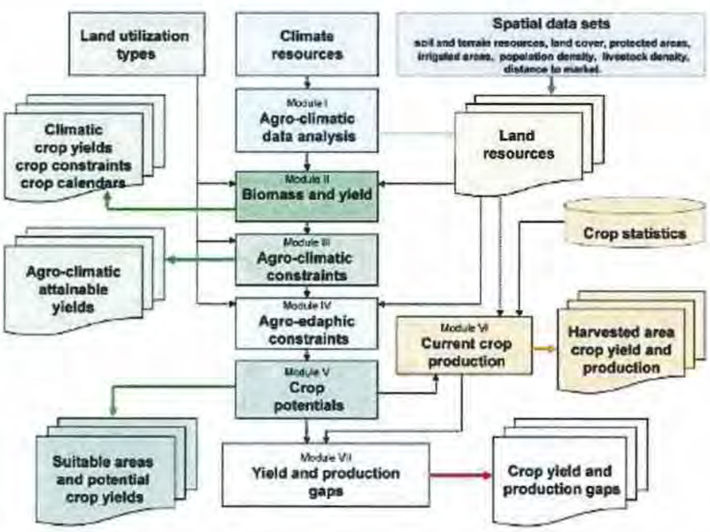
Worldwide agricultural production and demand for 2015, 2030 and 2050 on the basis of agricultural statistics and the forecasts of the Statistics Austria, EUROSTAT, OECD, FAO (FAO-Stat 2009, FAO 2003, FAO 2006) and FEDIOL (a member of primary food processors) and the UN medium population forecast (UN 2007, if available also latest updates will be used) were taken as baseline in WP 1. Relevant studies and useful climate reports were analysed and taken into consideration. A ten year interval (2000 to 2009) for the relevant product groups formed the basis of the assessment of production and demand of food and feed 2015 for EU27 and Austria based on trend analysis and experts opinions. Due to compatibility in data aggregations of various agricultural statistics, product groups are chosen for this study.

The team of BOKU_Met focused their work on the influence of climate change on global yields and those of the EU and Austria. The data used within Work Package 1 is based on the GAEZ (Global Agro-ecological Zones) system. The GAEZ methodology has been developed and refined over more than 30 years by IIASA (International Institute for Applied Systems Analysis) and the FAO (Food and Agriculture Organization) of the United Nations.

GAEZ is an integral part of an advanced modelling framework that combines the FAO/IIASA Global Agro-ecological Zone model and the IIASA World Food System model. The GAEZ approach covers the availability of digital global databases of climatic parameters, topography, soil and terrain, land cover, and population distribution. These data sets have not only enabled revision and improvements to AEZ calculation procedures, but have also allowed crop suitability and land productivity assessments to be extended to temperate and boreal environments. The GAEZ modeling framework has been used for the spatial assessment of biofuel feedstock potential in a global study of biofuels and food security.

GAEZ v3.0 provides one of the most ambitious assessments, which is publicly accessible from the IIASA and FAO Web sites[16].

Figure 4: GAEZ model structure and data integration (IIASA, 2012)



[16] http://www.iiasa.ac.at/Research/LUC/GAEZv3.0/ resp. IIASA/FAO, 2012

The selected criteria for the data were the following:

- agro-ecological suitability and productivity: cultivated, unprotected land
- suitability and potential yields for up to 280 crops/land utilisation types under alternative scenarios
- management for historical, current and future climates
- rain-fed agriculture
- intermediate scenario (medium scenario, better management, partly market orientated, between low and high input scenario)
- CO2-fertilizer effect
- Hadley CM3 A2 scenario
- time horizons: 1961-1990; 2020-2030 and 2030-2050

Three input level selection options were available: high level inputs, intermediate level inputs, and low level inputs. The choice was made for the intermediate-level inputs/improved management scenario. Under the intermediate input, improved management assumption, the farming system is partly market oriented. Production for subsistence plus commercial sale is a management objective. Production is based on improved varieties, on manual labor with hand tools and resp. or animal traction and some mechanization. It is medium labor intensive, uses some fertilizer application as well as chemical pest, disease and weed control, adequate fallows and some conservation measures (Tóth et al., 2012). Regarding the Climate Change Scenario, the Hadley CM3 A2 Scenario was selected. Therefore, the Global Circulation Model used, was HADLEY CM3[17] (Hadley Centre Coupled Model, Version 3) under the IPCC emission scenario A2. The HADLEY CM3 represents a coupled atmosphere-ocean general circulation model (AOGCM) which was developed by the Hadley Centre in the United Kingdom. HadCM3 has been used extensively for climate prediction, detection and attribution and other relevant climate sensitivity studies. Furthermore it was one of the major models used in the IPCC Third and Fourth Assessment Report (Met Office, 2013).

The A2 marker scenario[18] (A2-ASF) was developed using ASF an integrated set of modeling tools that was also used to generate the first and the second sets of IPCC emission scenarios. Overall, the A2-ASF quantification is based on the following assumptions:

- relatively slow demographic transition and relatively slow convergence in regional fertility patterns
- relatively slow convergence in inter-regional GDP per capita differences
- relatively slow end-use and supply-side energy efficiency improvements (compared to other storylines)
- delayed development of renewable energy
- no barriers to the use of nuclear energy

The A2 scenarios out of the four SRES (Special Report on Emissions Scenarios, report by IPCC) scenario families stem from of a more divided world (IPCC, 2000). The A2 scenario family represents a differentiated, heterogeneous world which is characterized by a a) continuously increasing population, b) world of

[17] http://www.ipcc-data.org/sres/hadcm3_info.html

Gordon, C., C. Cooper, C.A. Senior, H.T. Banks, J.M. Gregory, T.C. Johns, J.F.B. Mitchell and R.A. Wood, **2000**. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Clim. Dyn.*, **16**, 147-168.

Pope, V., M.L. Gallani, P.R. Rowntree, R.A. Stratton, **2000**. The impact of new physical parameterizations in the Hadley Centre climate model: HadAM3. *Clim. Dyn.*, **16**, 123-146.

[18] http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=98

independently operating, self-reliant nations and c) regionally oriented economic development. The possible range of the projected global average surface warming until the end of the century is in between 2.0°C to 5.4°C (for further details see IPCC, 2000). The SRES scenarios, however, do not encompass the full range of possible futures, which means that emissions may change less or more than the scenarios imply.

After selecting the criteria and choosing the items and the regions resp. country, the changing rates for each item had to be calculated. Changing rates of the year 2015 were based on the calculations in relation to 1975 (for the period 1961-1990) and the projections for 2020-2030 (with 2025 as reference year). Changing rates for 2030 are based on the year 2015. The spectral changing rates of the time spans from 2015 to 2030 and 2030 to 2055 were finally calculated for the world regions (USA, Europe, Asia, Africa, Australia and South America, subdivided) and Austria.

20 selected crops investigated:

Wheat
Barley
Millet
Oat
Rye
Maize
Wetland rice
Dryland rice
Soy
Rapeseed
Olive Oil
Sunflower
Potatoes
Sweet Potatoes
Cassava
Yam and Cocoyam
Phaseolus bean
Kidney bean
Sugar cane
Sugar beet

Indicator plants for the main world regions

As a next step, indicator plants for the different world regions were defined (Table 5). Data could be determined for the main world regions. Regarding the commodities, where limited or no data was available, indicator plants were chosen. Taking a look at some of the main commodities in focus of the project (cereals, roots and tubers, sugar, pulses and oil) it was recognized that the categories in the data set often were more explicit. Therefore, the most important crops in each region had to be chosen. For instance, in the case of sugar, data was available for sugar cane and sugar beet. The same applied to oil plants, where indicator plants had to be defined for each region. Between grain used for the human consumption and grain for animal feed no differentiation was possible within the data set.

Table 5: Indicator plants for different world regions (author's own compilation)

Regions/ Indicator Plant	Cereals	Roots and tubers	Sugar	Pulses	Oil
North America	wheat maize	potatoes	sugar beet, sugar cane	phaseolus bean	soy, rapeseed, sunflower
Europe, Russia	wheat maize	potatoes	sugar beet	phaseolus bean	soy, rapeseed, sunflower, olive
Pacific OECD	wheat, maize	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar cane	phaseolus bean	soy
Africa, Sub-Saharan Africa	wheat, maize, millet	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar cane	phaseolus bean	soy, sunflower
Latin America	wheat, maize	potatoes, sweet potatoes	sugar beet, sugar cane	phaseolus bean	soy, sunflower
North Africa, Near East	wheat	potatoes	sugar beet	phaseolus bean	olive, soy, sunflower
East Asia	rice, wheat, maize	potatoes, sweet potatoes, cassava	sugar beet, sugar cane	phaseolus bean	soy, sunflower
South- and Southeast Asia	rice, wheat, maize	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar cane	phaseolus bean, kidney bean	soy
Rest of World	rice, wheat, maize, millet	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar beet, sugar cane	phaseolus bean	soy, rapeseed, sunflower, olive
Developed Countries	rice, wheat, maize, millet	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar beet, sugar cane	phaseolus bean	soy, rapeseed, sunflower, olive
Developing Countries	rice, wheat, maize, millet	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar beet, sugar cane	phaseolus bean	soy, rapeseed, sunflower, olive
World	rice, wheat, maize, millet	potatoes, sweet potatoes, cassava, yam and cocoyam	sugar beet, sugar cane	phaseolus bean	soy, rapeseed, sunflower, olive

Within the group of pulses, phaseolus bean, which includes kidney beans and chickpeas, (India as a main grower) were selected. The whole rates and indicators served as the basis for the calculation of scenarios of Work Package 3.

Global Impacts

On global scale, climate change will have a positive impact on agricultural production till 2030 in most of the regions. Most of the crops will benefit till 2030 under the selected scenario. There are some regions where negative impacts can be seen when examined until 2050. For the changing rates of main indicator plants in world regions due to climate change till 2050, see Table 6.

Table 6: Changes of the yield of major indicator plants due climate change in main world regions from 2030 till 2050 (decadal rates of yield change). The changes are significantly positive (green fields), significantly negative (red fields) or not significantly positive or negative (yellow fields) (data base: GAEZ, 2013).

Region/ Indicator Plant	Cereals	Roots and tubers	Sugar	Pulses	Oil
North America	wheat 1.1	potatoes -1.8	sugar beet -4.3	phas.bean -5.8	soy -4.1
 Europe Russia E+R	wheat 0.6 1.1 0.8	potatoes 0.9 0.0 0.4	sugar beet -0.9 0.1 -0.4	phas.bean -4.0 -4.2 -4.1	soy 0.7 5.9 3.3
 Africa Sub-Saharan Africa A+SSA	wheat 4.7 2.3 3.5	potatoes 0.3 2.3 1.3	sug. cane -1.2 -1.0 -1.1	phas.bean -5.0 -4.3 0.4	soy 0.9 -0.6 0.2
Latin America	wheat 2.3	potatoes 2.3	sugar beet 0.1	phas.bean -8.1	soy -0.3
North Africa	wheat -1.6	potatoes -1.6	sugar beet -0.7	phas.bean -2.6	olive 1.4
East Asia	rice -1.6	potatoes -1.6	sugar beet 0.1	phas.bean 0.8	soy 2.4
 South- and South East Asia SA SEA	rice 1.9 0.4 1.2	potatoes 2.2 -2.2 0	sug. cane 1.1 -0.1 0.5	phas.bean -1.2 -1.0 -1.1	soy -2.7 -0.3 -1.5
World	rice -0.3 wheat 1.2	potatoes -0.1	sugar beet -0.8 sug. cane 0.2	phas.bean -3.9	soy -0.4

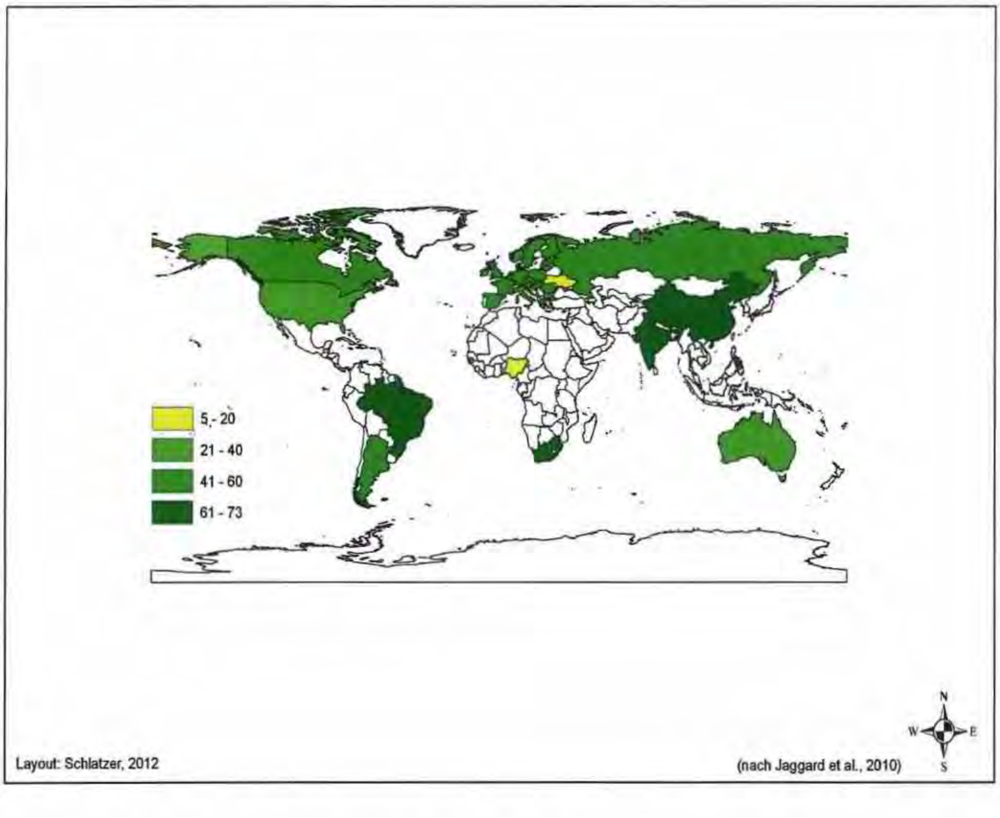
SEA= South East Asia, SSA= Sub-Saharan Africa

The fertilizing effect of CO_2 represents the crucial factor in terms of the higher benefits regarding 2030 compared to 2050. Data for cultivated, unprotected land was taken into account under the Hadley CM3 A2 Scenario. Further criteria for the data set of the suitability and potential yields were a) rain-fed agriculture, b) an intermediate scenario (medium scenario, better management, partly market orientated, between low and high input scenario) and c) CO_2-fertilizer effect (for further details, see methods).

To illustrate the deliverable changing rates, wheat was chosen as an important indicator plant for many regions in Austria, the EU and worldwide. On a global scale, the annual changing rate of the wheat harvest will be 0.06% from 2015 to 2030. By 2050, the annual changing rate of the wheat harvest will be at 0.12%.

Under the chosen conditions resp. scenario, (see chapter of methods) global wheat production will benefit under climate change. According to Jaggard et al. (2010), these changing rates will generally be moderate as prior and follow up studies have shown (see Figure 5).

Figure 5: Changes of yields due to climate change in world regions between 2007 and 2050
Source: Jaggard et.al., 2010



Ertragsänderungen von Weizen (%) aufgrund des Klimawandels im Zeitraum von 2007 bis 2050 (nach Jaggard et al., 2010)
Anmerkungen: Szenario Geringes Wachstum (=+0,7%/a); mit CO2-Effekt (+15%) und O3-Effekt (-9%); maximale Ertragsmöglichkeit von +10%, d.h. bei Weizen von 80 auf 90%)

During the study many studies were cited, collected and analysed. Results, critical points and deliverables for other work packages were discussed within the work package as well as with other work packages and the study team as a whole. Moreover, many graphs (with ARG GIS mapping[19]) were created to show the effects of future climate change on yields in major world regions, including the European Union. Data from Austria was analysed as well. In order to have a comprehensive data set, the FAO GAEZ model was chosen. This made comparisons possible, both between different world regions and on a country level.

[19] Esri's ArcGIS is a geographic information system (GIS) for working with maps and geographic information which is used for: creating and using maps as well as compiling geographic data. For further details see www.arcgis.com

Under the chosen conditions (for further details see methods), the annual changing rate of the wheat harvest is at 0.1% from 2015 to 2030. By 2050, the annual changing rate of the wheat harvest will be at 0.16%. This means the wheat harvest in Austria will benefit more in comparison to the world rates.

Production and demand/consumption[20] data, which was taken out of the studies listed below, was used as a base for the calculations to mirror the development of the ratio between production and demand, production data and demand/consumption data (per capita food consumption in kcal/person/day) were calculated with the following growth factor for the time periods under question.

growth factor $y_n = (1+z/100)^n$ and $(1+z/100) > 1$,

production or demand in year x_n = production or demand in year x_0 multiplied with the growth factor of the respective period, $x_n = x_0 * y_n$

z = yearly yield/consumption growth in percentage

n = number of years of a specific period

x_0 = Production/demand in base year

x_n = Production/demand in year n of a specific period

Austrian data for 2015

Austrian figures (Statistics Austria, 2012a, b)[21][22] for crop specific production and consumption have been aggregated according to data structure of the OECD-FAO-database. Austrian data for 2015 is extracted from forecast series from 2011 to 2020 for the variables production, consumption and cultivation area. These forecasts are conducted by calculating shares of the Austrian data from 2000 to 2010 according to the EU-figures given in the OECD-FAO Agricultural Outlook 2011 (OECD, 2011)[23] for this period. The Austrian data from 2000 to 2010 was transformed into shares of the EU-data (OECD, 2011) for this period. The shares were subjected to a logit transformation which yields values ranging from $-\infty$ to $+\infty$; these values are assumed to follow a linear time trend according to equation (1):

$$logit(s_{it}) = ln(s_{it}/(1-s_{it})) = a_i + b_i t + u_{it}$$

with s_{it} as share of the $product_i$ in $year_t$, and with a_i, and b_i as axis intercept and gradient of the linear trend and u_{it} as error term, respectively. If the shares (s_{it}) are distributed logistically, the error term u_{it} follows a normal distribution. The parameters of the function (a_i and b_i) can be estimated by ordinary least squares. The equation for the estimated and forecasted shares reads:

$$\hat{s}_{it} = 1/(1+e^{\wedge}-(a_i + b_i t))$$

The observed shares in (1) are the ratio between observed values of a region (Austria) to an aggregate region or, where the OECD-forecasts (2010 to 2020) have been lacking, maximum values are used with these maxima assumed to be nearly twice the respective highest value that has been given in the observation. Adjustments have been made in case of unrealistically high or low forecasts. Thus data series from 2000 to 2020 were

[20] These two terms are used interchangeably. All kinds of use are included (food, feed, industrial use, but also waste and losses) With respect to waste and losses also see: Nellemann, C. et alt. (2009), page 30. Industrial use includes bio fuel and biomass use too.

[21] Statistics Austria, (2012a): Agriculture and Forestry, Prices Supply balances. http://www.statistik-austria.at/web_en/statistics/agriculture_and_forestry/prices_balances/index.html, (downloaded 2012)

[22] Statistics Austria, (2012b): Agriculture and Forestry, Cultivated area and yields. http://www.statistik-austria.at/web_en/statistics/agriculture_and_forestry/farm_structure_cultivated_area_yields/index.html, (downloaded 2012)

[23] Statistics Austria (2013) Population forecasts. http://www.statistik.at/web_de/statistiken/bevoelkerung/demographische_prognosen/bevoelkerungsprognosen/, (downloaded 2012)

available for Austria, forming the basis for the simulation models for 2030 and 2050. Crop yields were calculated from the predicted values for production and area. Austrian population data is retrieved from respective forecasts data of Statistics Austria (2013).

EU-27 figures for production, area and consumption for the period 2000 to 2010 time as well as 2015 are based on the OECD-FAO agricultural outlook 2011 or FAO-database. Austrian figures for crop specific production and consumption have been aggregated according to data structure of the OECD-FAO-database. Figures for development of the Austrian population are retrieved from respective forecast data of Statistics Austria (2013).

5.2 Methods of Work Package 2:

The resilience level or national resilience is assessed by using a combination of various indices, based on a wide spectrum of parameters. These parameters describe the current situation in quantitative manner, using arbitrary units. For each country, representing a foreign key supplier of a particular component in the national food production of Austria, the numerical value of a defined index is given. For comparison, also the corresponding value is presented for Austria.

National resilience (NR) levels are assessed using a combination of various indices, based on a wide spectrum of parameters. These parameters describe the current situation in quantitative manner, using arbitrary units.

NR<2: Countries featuring a NR level lower than 2 can be considered highly reliable trading partners. Unforeseen interruptions in supply of food, feed or energy are very unlikely.

NR<4: Describes countries of medium NR. Imports from these countries may be interrupted for limited duration before they resume again normally.

NR≥4: These countries should be viewed as highly vulnerable. In light of the rather large potential negative consequences due to additional stress, the disruption of exports for an undefined time period is more probable than not.

The NR reflects the national self-sufficiency in a particular item (feed, food, energy). NR is defined as the sum of the average value of the political resilience (PR) and the social resilience (SR) and the self-sufficiency index (SSI):

$$NR = \frac{(PR + SR)}{2} + SSI$$

The SSI is defined as:

- SSI = 0 if self-sufficiency rate is >130%
- SSI = 1 if self-sufficiency rate is 100%-130%
- SSI = 2 if self-sufficiency rate is <100%

The country-specific PR is defined as the aggregate of the following indices:

- Governance Index
- Corruption Perception Index
- Failed State Index
- Economic Freedom Index

A PR is determined for each country that is a key supplier of products essential for Austrian food supply. The numerical value assigned ranges from 1 to 5, i.e. resilience equal 1 represents the highest and 5 represents the lowest resilience.

The country-specific social resilience (SR) is defined as the aggregate of the following information:

- Lifestyle
- Education
- Health
- Employment

The SR is determined for each country that is a key supplier of products essential for Austrian food supply. The numerical value assigned ranges from 1 to 5, i.e. resilience equal 1 represents the highest and 5 represents the lowest resilience.

For comparison between countries, the corresponding data are also evaluated for Austria.

5.3 Methods of Work Package 3:

In WP 3 simulation models based on scenarios are developed. In a first step threats identified in WP 1 and WP 2 were evaluated.

Taking into account supply-balance for Austria and global trends (WP1) and possible threats to food security in Austria identified in WP2, risks that would affect agricultural production and food supply in Austria were identified by expert assessment (risk analysis first stage). The results of the assessment were used to develop four additional scenarios (shown in the table above).

- baseline scenario
- best-case scenario
- most-probable case scenario
- worst-case scenario

It is important to note that these denominations of the scenarios ("best case", "worst case", etc.) are made for distinguishing and simplifying purposes only, but they do not aim to judge certain scenario-specific assumptions in a subjective manner.

Table 7: Expert evaluation of identified threats on a scale from 1 (not likely) to 10 (very likely)

	Likelihood	Used for Scenario
Climate Change		
Climate Change regarding model	10	used for all scenarios
Technical progress		
As before	8	most-probable case
Higher than before	6	best-case
Lower than before	6	worst-case
Input level affecting yields		
As before (Medium input level)	10	most-probable case
High input level	6	best-case
Low input level	6	worst-case
Phosphorus fertilizer		
As before (no shortage)	6	best-case
Medium impact of shortage	8	most-probable case
Total impact of shortage	5	worst-case
Demand as before	6	best-case
Medium increase in demand	8	most-probable case
High increase in demand	6	worst-case
Imports of protein feedingstuff		
No import restrictions	5	best-case
Medium import restrictions	8	most-probable case
High import restrictions	5	worst-case

In order to analyse the possible situation of food security in Austria in 2030 and 2050, simple simulation models based on supply balances were developed. The choice of such a methodological approach is due to the fact that a complex topic like the future food security necessitates rather complex and specialized models. The development of respective models (e.g., optimization models, econometric models, combination and conjunction of different models) involves significant lead time and is rather challenging within a project of this dimension. The suggestion to develop (simple) simulation models has already been formulated in the project proposal.

The simulation models are based on the structure of supply balances and simply calculate changes in certain positions due to changes in the numerical level of other positions: The „sources"-side of the (simplified) supply balance distinguishes between the positions production (consisting of yields, areas and livestock, respectively) and the trade balance (including stocks). The "uses"-side of the supply balance is simplified for the purposes of the project and distinguishes between the positions feed use (consisting of livestock and feed-use coefficients) and non-feed use (consisting of population and per-capita non-feed use). The position "feed use" in the database was calculated by deriving feed-use coefficients per animal from feed balances and livestock data of Statistics Austria. Economic considerations (e.g., profit maximization of farmers) are not established in these models since relative prices, costs, etc. are not considered in these models.

According to the results derived from WP 1 and WP 2, the most important threats to food security include the impact of climate change and the availability of P-fertilizer, of imports of protein feeding stuff and of fossil fuels. In order to address all these threats, we develop two different simulation models. The models differ concerning the assumptions, which position of the supply balance is taken as given (i.e., is exogenous). Scenario assumptions (in terms of assumptions on possible changes of the numerical level) are applied on these exogenous variables. Thus, the endogenous variable (i.e., the solution) is different in the two models.

Table 8: Expert evaluation of identified threats on a scale from 1 (not likely) to 10 (very likely) – total likelihood points out of 60

	Threat	baseline scenario	best-case scenario	most-probable case scenario	worst-case scenario
impact of climate change		Yes			
Likelihood			10	10	10
technical progress		as before	higher than before	as before	lower than before
Likelihood			6	8	6
input level affecting yields		as before	high input level	medium input level	low input level
Likelihood			6	10	6
phosphorus fertilizer		no shortage		medium impact of shortage	total impact of shortage
Likelihood			6	8	5
bioenergy		as before	low increase in demand	medium increase in demand	high increase in demand
Likelihood			6	8	6
imports of protein feedingstuff		no import restrictions		medium import restrictions	high import restrictions
Likelihood			5	8	5
Total likelihood (points of 60)			**39**	**52**	**28**

The simulation models are used to analyse different scenarios by simulating the effect of different assumptions (applied on the exogenous variables) on self-sufficiency rates and on endogenous variables.

Assumptions

The following assumptions were considered in the simulation models.

Table 9: Overview of assumptions

	baseline scenario	best-case scenario	most-probable case scenario	worst-case scenario
impact of climate change	yes			
technical progress	as before	higher than before	as before	lower than before
input level affecting yields	as before	high input level	medium input level	low input level
phosphorus fertilizer	no shortage		medium impact of shortage	total impact of shortage
bioenergy	demand as before	low increase in demand	medium increase in demand	high increase in demand
imports of protein feeding stuff	no import restrictions		medium import restrictions	high import restrictions

To account for these scenarios, the exogenous variables of the simulation models are used to employ scenario-specific (baseline, best/most-probable/worst case) and time-specific (2030/2050) assumptions. We make scenario-specific and time-specific assumptions for the following exogenous variables:

- **crop yields**, accounting for the impact of climate change, technical progress, input levels, and the availability of phosphorus fertilizer
- **animal yields**, accounting for technical progress and input levels

For other exogenous variables we only make scenario-specific assumptions (i.e., their numerical levels in 2030 and 2050 are equal):

- **non-feed use per head**, accounting for changes in the demand for bioenergy (wheat, coarse grains, other oilseeds, sugar beet, starch crops)
- **trade balance** (in model 1 only), accounting for the availability of protein feedingstuff (soybeans, other oilseeds, oilseed meals, protein crops)

Assumptions on other exogenous variables like areas/livestock (model 2), feed-use coefficients and population are equal in all scenarios. While there are differences in the **population** between 2030 (about 9 mill. people) and 2050 (about 9.3 mill. people, see Statistics Austria, 2013), **areas/livestock** (model 2 only) and **feed use coefficients** are assumed to be equal in 2030 and 2050. Respective scenario-specific and/or time-specific numerical values of the exogenous variables are based on calculations, on analyses of project partners (e.g., in the case of crop yields per hectare) and/or on discussions within the project team.

Assumptions on changes in crop yields

In the simulation model, crop yields are scenario- and time-specific (i.e., there are eight different yield levels per crop) and account for the impact of climate change and for changes in technical progress, intensity of input levels and fertilization.

Estimation of yield performance (Mechtler, K., AGES):

Progresses in yield performance of agricultural crops are generally a complex matter based on many components. Improvements to the technical equipment for tillage, sowing, harvesting and plant protection purposes, the availability of adequate fertilizers and crop protection products, successes in plant breeding, restrictions in the application of agrochemicals in certain production programs, as well as the know-how and skills of the farmer himself all make up relevant impact factors for a successful plant production. Based on national yield data of Statistics Austria for more than 20 years (1990–2011), annual changes in yields were estimated by time-series regression of the crops in concern. For categories of crops products such as coarse grains weighted means of the included crops species have been calculated, based on their actual areas. Austria can report relatively high annual growth rates in yields of maize, rape and soybean. As the agro technical preconditions have already maintained a well-developed level during the whole period concerned, these yield improvements may be substantially based on progresses in plant breeding. Yield growth rates turn out to be lower for cereal species with certain requirements in quality parameters (bread wheat), which have also to be met by the breeders beside yield performance, and with significant acreage under organic farming (triticale, rye).

The annual rates of change due to technical progress as seen in Table 10 were derived from these regression results. They represent weighted averages of more disaggregated crop products. These annual change rates are less than +1% (of yields in 2015), except for protein crops showing a negative trend.

Differences between crop yields in organic and conventional agriculture serve as a proxy for certain intensities of input levels and were derived from Weigl et al. (s.a). Again, these differences are weighted averages of the respective disaggregated crop products. In the case of protein crops, the difference between the "low-input" yield and the "high-input" yield is highest (-42.3%).

Impact of Phosphorus fertilization (Mechtler, K., Baumgarten, A., AGES):

Phosphorus (P) is important to processes in plant metabolism with energy transfer. It has a positive influence on soil structure and fertility. In assessing the consequences of a mineral lacking P-fertilization it is relevant whether organic fertilizers are available or not. Therefore yield reduction rates were calculated for regions with and without manure application. For the scenarios in the study we used the average of the crop specific yield reduction rates of the two regions, as results need to represent the national level. The main production areas Northeastern Flats and Hills (mean P-input from organic manure 2 kg P/ha) and the Foothill region of the Alps (mean P-input from organic manure 17 kg P/ha) were selected for cultivation areas with and without livestock husbandry. For each region an average annual P-withdrawal per hectare was calculated based on means of the crops specific withdrawals (20 kg P/ha in the Northeastern region and a higher amount of 25 kg P/ha in the Foothill region due to higher yield potential and higher share of maize in crop rotation). Also included was the different actual plant available P-content in the top soil of the arable land (72 mg P-CAL/kg in Northeastern and 49 mg P-CAL/kg in the Foothill region) in the calculation model. Depending on decreasing P-contents in the soil and on Bavarian results of field experiments, the yield reduction rates were calculated by yield functions created with results of AGES-own field trial series (Dersch, 2005) (StMELF, 2011). The yield functions describe the course of the relative yields for the chosen culture type groups at declining P-contents in the soil.

Crop species with higher nutrient withdrawal rates such as potatoes or sugar beets showed stronger yield falls after 15 (2030) or 35 (2050) years. However, all in all the reduction rates turned out to be rather low: 0.4 to 1.9% after 15 years and 1.1 to 4.6% yield losses after 35 years in case of organic fertilization and with 0.0 to 3.7% (15 years) and 1.2 to 9.8% (35 years) without manuring, respectively. The variation is given by the crop species included. It should be stressed that after 15 respectively 35 years of abstinence of mineral P-fertilization the plant available P-contents will decrease considerably, especially in the Northeastern areas up to 54 (after 15 years) and up to 32 mg P-CAL/kg (after 35 years). The decrease of P-soil contents in the Foothill region will be less distinct up to 41 and 33 mg P-CAL/kg due the higher organic P-input.

Table 10 shows the impact on crop yields in 2030 and 2050 if P-fertilization is stopped in 2015 and provides an overview of the data input which was used to calculate scenario-specific yields.

Table 10: General assumptions on changes in crop yields

	climate change incl. CO_2 fertilization[24]		technical progress[25]	input level[26]	phosphorus fertilizer[27]	
	decadal rates of change in%		*decadal rates of change in%*	*difference of "low-input" yields, rel. to "high-input" yields*	*rel. change in%*	
	2015-30	*2030-50*			*2030/15*	*2050/15*
wheat	1.03%	1.58%	0.25%	-33.0%	-1.17%	-4.43%
coarse grains	1.48%	1.32%	0.82%	-37.9%	-2.78%	-7.20%
soybeans	2.18%	6.22%	1.00%	-30.0%	-2.78%	-7.20%
other oilseeds	0.50%	0.12%	0.75%	-30.0%	-2.78%	-7.20%
protein crops	-1.59%	-4.94%	-0.13%	-42.3%	-2.78%	-7.20%
sugar	0.56%	0.36%	0.98%	-10.0	-2.78%	-7.20%
starch crops	9.79%	1.48%	0.96%	-33.0%	-2.78%	-7.20%

Increased yield losses caused by plant diseases and pests were not considered as these effects can be tackled by new technologies and plant protection measures in the best case and largely in the most probable case scenario and are consumed by the already lower yields of organic farming.

CO_2 fertilization effect on crop yields

The "fertilization" effect of increasing atmospheric CO_2 on crop yield is accounted in GAEZ by the CO_2 yield-adjustment factor (f_{CO_2}). Crop species respond differently to CO_2 depending on physiological characteristics such as photosynthetic pathway (e.g. C3 or C4 plants). The local environment also influences the impact that CO_2 has on crop growth. Realization of the fertilization effect of CO_2 is adjusted when sub-optimum growth conditions are indicated by the suitability classification for a LUT in a given grid-cell. Under very suitable conditions it is assumed that a fertilization effect of two-thirds that derived from laboratory experiments could be realized in 46 farmers' fields. On average this results in about half of the CO_2 fertilization effect measured in laboratory experiments to be applied in GAEZ, as is broadly consistent with results reported in free-air CO_2 enrichment (FACE) experiments.In GAEZ various scenarios were simulated as published by IPCC in the special reports on emission scenarios (SRES) and quantified by different climate modelling groups. GAEZ runs were performed with different CO_2 concentrations for each scenario for three future time periods (2020s, 2050s and 2080s).[28]

[24] Climate change – Hadley CM3 A2 scenario IIASA/FAO (2012): Global Agroecological Zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO, Rome, Italy. http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/docs/GAEZ_Model_Documentation.pdf

[25] analysis of plant variety approval AGES

[26] analysis of plant variety approval AGES, Input level – organic vs. conventional farms (Grüner Bericht 2013, Tab. 2.4.7, http://www.agraroekonomik.at/index.php?id=gruenerbericht)

[27] 1) Aktuelle pflanzenverfügbare P-Gehalte auf Ackerland im Nordöstl. Flach- und Hügelland und Alpenvorland aus: Baumgarten A., G. Dersch, J. Hösch, H. Spiegel, A. Freudenschuß u. P. Strauss: Bodenschutz durch umweltgerechte Landwirtschaft. AGES, März 2011. 2) Mittlerer Tierbesatz im Nordosten und im Alpenvorland: INVEKOS-Daten; 3) Berechnung des P-Anfall durch Wirtschaftsdünger: BMLFUW: Richtlinien für die sachgerechte Düngung, 6. Auflage 2006; 4) Veränderungen der P-CAL-Gehalte durch P-Düngung bzw. P-Entzug sowie Ertragseffekte in Abhängigkeit vom CAL-Gehalt: Georg Dersch: Bodenuntersuchungen und Nährstoffbilanzen als Grundlagen für ein nachhaltiges Nährstoffmanagement in Marktfruchtbetrieben im Osten Österreichs. Agrozucker/Agrostärke 4, 34 - 42, 2005.; H. Spiegel, T. Lindenthal, M. Mazorek, A. Planer, B. Freyer und A. Köchl: Ergebnisse von drei 40-jährigen P-Dauerversuchen in Österreich. 1.Mitteilung: Auswirkungen ausgewählter P-Düngerformen und -mengen auf den Ertrag und die P- CAL/DL-Gehalte im Boden. Die Bodenkultur 52, 3-17, 2001. Scheffer/Schachtschabel: Lehrbuch der Bodenkunde, 15. Auflage, Heidelberg 2002, S. 284-285.

[28] http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/docs/GAEZ_Model_Documentation.pdf p 45-47, .20.06.2014

Relative changes of crop yields due to climate change are calculated within the project (see chapter 2). For the simulation models, data on changes in yields of certain specific crops were aggregated into product categories according to the database of the simulation models.[29] Table 6 shows that all crop yields increase from 2030 to 2050 due to climate change, except for the case of protein crops.

Table 10 summarizes the scenario-specific assumptions on crop yields, which are based on discussions within the project team.

In the **baseline scenario**, only the impact of climate change and technical progress is accounted for. Annual rates of change due to technical progress are set equal to those presented in Table 10.

The **best-case scenario** accounts for the impact of climate change, a higher annual growth rate of crop yields (1%) than in the baseline scenario due to technical progress[30], a high intensity of input levels (i.e., yields are assumed to be equal to yields of conventional agriculture) and no shortage of phosphorous fertilizers.

The **most-probable case scenario** accounts for the impact of climate change, a technical progress equal to the baseline scenario, an intermediate intensity level of inputs (i.e., 25% of the crops show yields that can be observed in organic agriculture), and 50% less phosphorus fertilizer (i.e., the relative change in yields due to shortage in phosphorus fertilizer as of 2015 – see Table 10 – is weighted by 0.50).

The **worst-case scenario** accounts for the impact of climate change, a relatively low annual growth rate due to technical progress (0.1%; protein crops: -0.13% as in Table 10), a low intensity of inputs (i.e., yields are set equal to those of organic agriculture) and no phosphorus fertilization as of 2015 (see Table 10).

Scenario- and time-specific crop yields were calculated in four sequential steps (i.e., each assumption was employed on the resulting crop yield of the previous step):

1. impact of climate change
2. technical progress
3. intensity of input level
4. decline in phosphorus fertilizer.

The resulting crop yields in absolute values for each scenario and year are presented in Table 12.

[29] This applies to the product categories „coarse grains", „other oilseeds" and "protein crops". The respective relative changes are weighted averages (with acreage in 2015 due to technical progress used as weights; see next paragraph).
[30] In the case of soybeans, this annual growth rate is set at 1.3%, which is the growth rate as derived from the estimations. In the case of protein crops, the growth rate was set at 0%.

Table 11: scenario-specific assumptions on crop yields

	Baseline scenario	Best-case scenario	Most-probable case scenario	Worst-case scenario
climate change	see Table 10	see Table 10	see Table 10	see Table 10
technical progress	see Table 10	+1% of 2015 per year[1]	see Table 10	+0.1% of 2015 per year[2]
input level *(weight of organic / conventional yields)*	-	0.00 / 1.00	0.25 / 0.75	1.00 / 0.00
phosphorus fertilizer *(weight of differences in yields (with/without P-fertilizer))*	-	-	0.50	1.00

[1] exceptions: soybean (+1.31%, which is the annual rate of change according to regression results), protein crops (+/- 0.00%)
[2] exception: protein crops (-0.13%; see Table 10)

Table 12: scenario-specific crop yields (in t/ha and as an index 2015=100)

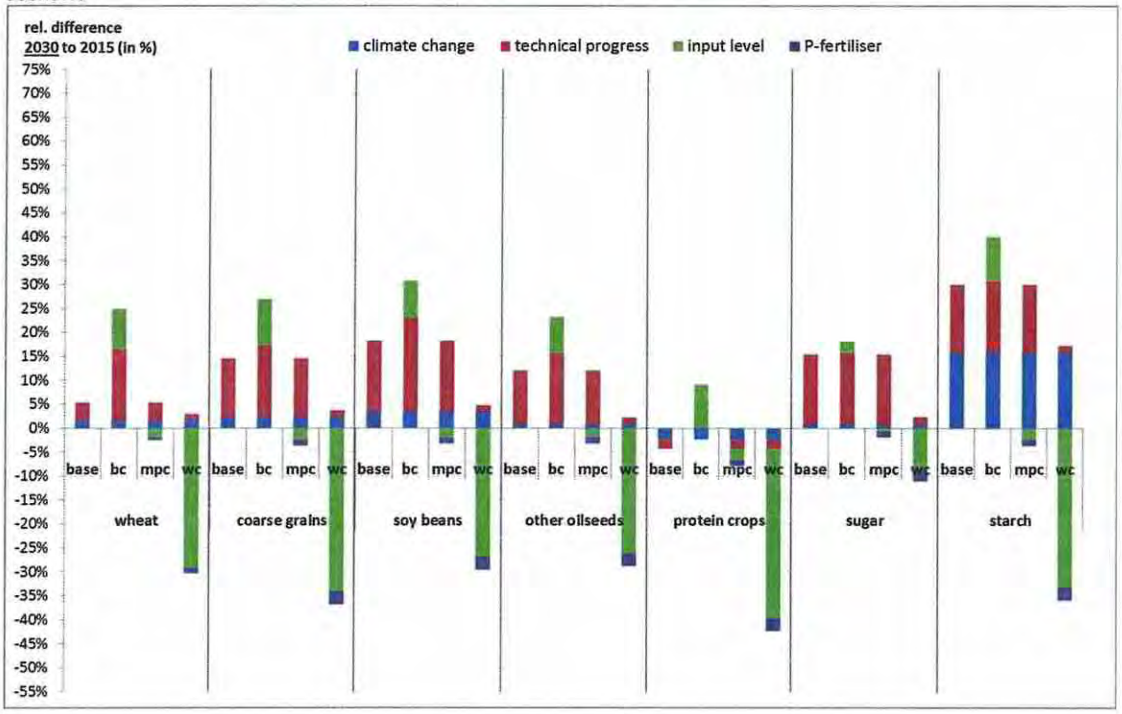
		Baseline scenario		Best-case scenario		Most-probable case scenario		Worst-case scenario	
	2015	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
t/ha									
wheat	5.3	5.6	6.1	6.7	8.0	5.5	5.8	3.9	3.9
coarse grains	7.9	9.0	10.5	10.0	11.9	8.7	10.0	5.3	5.2
soybeans	2.8	3.4	4.3	3.7	4.9	3.3	4.1	2.1	2.3
other oilseeds	2.4	2.6	3.0	2.9	3.4	2.6	2.9	1.7	1.7
protein crops	2.0	1.9	1.7	2.2	1.9	1.9	1.6	1.2	0.9
sugar*	10.2	11.7	13.8	12.0	14.2	11.5	13.4	9.3	9.1
starch crops	33.1	43.0	50.5	46.3	54.6	41.8	48.4	26.9	26.7
index									
wheat	100	105	114	125	150	103	109	73	73
coarse grains	100	115	134	127	151	111	127	67	66
soybeans	100	118	152	131	173	115	146	75	83
other oilseeds	100	112	127	123	145	109	122	73	71
protein crops	100	96	84	107	97	92	78	58	46
sugar	100	115	136	118	139	114	131	91	89
starch crops	100	130	153	140	165	126	146	81	81

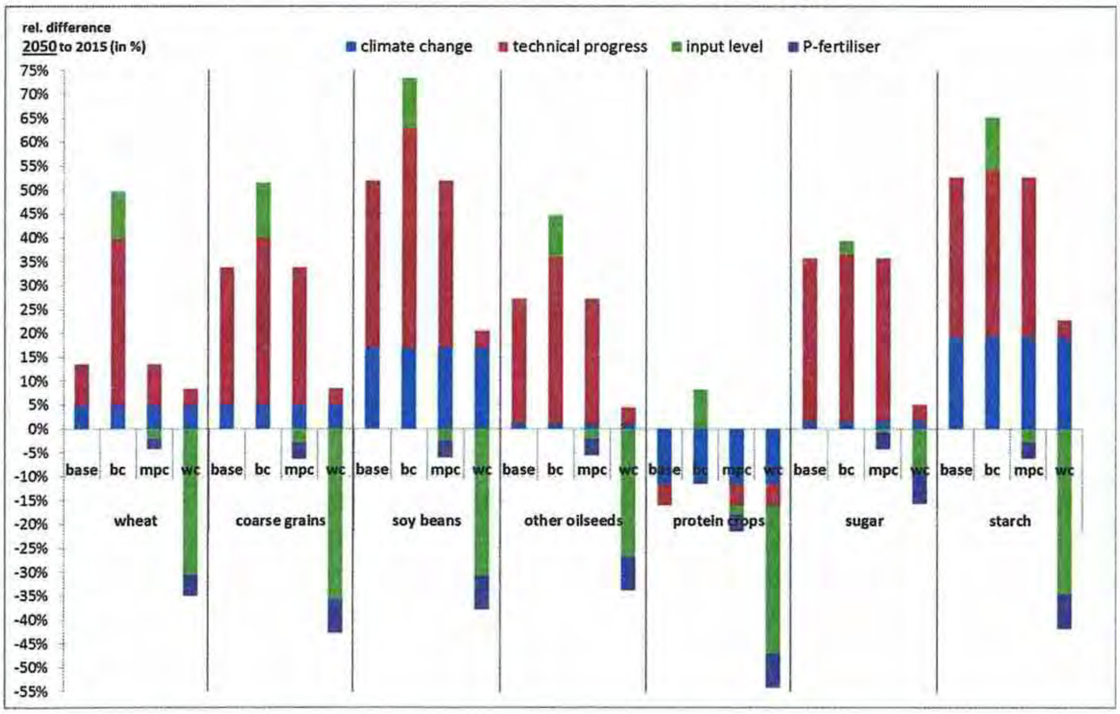
* in raw sugar equivalent

Compared to 2015, crop yields (apart from protein crops) are higher in the baseline scenario, in the best-case scenario and in the most-probable case scenario. In addition, crop yields increase over time (2015/2030/2050). In the worst-case scenario, however, the impact of low intensities of input levels as well as that of no phosphorus fertilization as of 2015 generally outweigh technical progress and the (generally positive) impact of climate change so that, first, yields are lower compared to 2015 and, second, they are lower in 2050 compared to 2030 in most cases. Figure 6 shows that the largest positive changes in yields are due to technical progress, whereas the largest negative changes in yields are generally due to lower intensity levels of inputs. Both, positive and negative changes increase over time (from 2030 to 2050).

Figure 6: impact of scenario-specific changes on crop yields (in% of 2015)

Note: base = baseline scenario; bc = best-case scenario; mpc = most-probable case scenario; wc = worst-case scenario





Assumptions on other changes

Other assumptions in the simulation model include assumptions of changes in animal yields, changes in imports of protein feedingstuff as well as changes in bioenergy use (see Table 13). In all scenarios, technical progress is assumed to increase animal yields each year by 0.1% of 2015. Based on the resulting yields due to technical progress, different assumptions on the intensity of input levels are assumed to result in an increase (decrease) in animal yields by 10% in the best-case (worst-case) scenario, relative to 2015.

Table 13: other scenario specific assumptions

	Baseline scenario	Best-case scenario	Most-probable case scenario	Worst-case scenario
animal yields				
technical progress	0.1% of 2015 per year	0.1% of 2015 per year	0.1% of 2015 per year	0.1% of 2015 per year
intensity level	-	+10% of 2015	-	-10% of 2015
imports of protein feedingstuff (model 1)	-	-	-10%*	-30%*
per-capita demand for bioenergy	*bioenergy use of 4% of area*	*increase* based on bioenergy use of 10% of area*	*increase* based on bioenergy use of 12% of area*	*increase* based on bioenergy use of 40% of area*
wheat	-	+8.9%	+11.8%	+53.1%
coarse grains	-	+14.1%	+18.8%	+84.8%
other oilseeds	-	+3.0%	+4.0%	+18.1%
sugar	-	+8.5%	+11.4%	+51.1%
starch crops	-	+5.5%	+7.4%	+33.2%

* relative to results of Monte-Carlo simulations (see chapters 6.3.5, 6.4. and Annex 14.1 of the full report)

Shortages in imports of protein feedingstuff (i.e., soybeans, other oilseeds, oilseed meals, protein crops) are accounted for in the most probable-case scenario and in the worst-case scenario. In the most-probable (worst) case scenario, imports are assumed to decrease by 10% (30%) relative to the levels according to Monte-Carlo simulations (see chapters 6.3.5, 6.4. and Annex 14.1). Since trade balances are taken as given in model 1 only, this scenario assumption is not implemented in model 2.

A possible increase in the demand for bioenergy is accounted for by changes in the non-feed use per head of wheat, coarse grains, other oilseeds, sugar beets and starch crops. These changes are based on expert assessments within the project team on the bioenergy use in terms of certain shares of the mean area from 2008 to 2010 of the respective crop. The respective production for bioenergy use was equated with changes in the non-feed use per head of the respective crops.

Monte-Carlo simulations

Applying these four scenarios for the years 2030 and 2050 and for two different models results in 16 different outcomes for each product.

Figure 7: Overview on model-, time- and scenario-specific calculations

Note: 1, 2 ... model 1 and model 2

In both models per-capita demand for non-feed use is exogenous, thereby accounting for a given food demand of the Austrian population. The difference between the models is following: **model 1** analyses the impact of changes in consumption and trade on production. Thus, the solution to the model is the necessary level of production given certain assumptions on demand (including bioenergy use) and trade (including imports of protein feeding stuff) so that the requirements of a supply balance are fulfilled. In this model, changes in yields (including the impacts of climate change and P-fertilization) are implemented in order to derive necessary changes in acreage and livestock that guarantee the required production level. The animal sector is modeled in the first place since livestock is endogenous and directly affects the feed use (and thus total use) of certain crop products. It is important to note that assumptions on imports of protein feeding stuff are implemented only in this model. However, assumed changes in crop yields do not directly affect SSRs of the respective crop products.

Contrary to this, **model 2** analyses the impact of changes in production and consumption on trade. In this model, the solutions are necessary imports or possible exports so that the requirements of a supply balance are fulfilled. Hence, contrary to model 1, acreage and livestock are taken as given. In this model, assumed changes in yields directly enter the calculation of production and directly affect SSRs. However, since trade is endogenous in model 2, the assumptions on imports of protein feeding stuff are not implemented.

According to the time frame of the agricultural outlook of the OECD, the supply-balance data for Austria was forecasted up to only 2020. Due to uncertainties on the numerical level in 2030 and 2050, we employ **Monte-Carlo simulations** to generate possible values of certain variables that are assumed to be exogenously given in the simulation models (per-capita non-feed use in both the models, trade balances in model 1 and areas and livestock in model 2).

Assuming a triangle distribution (here: minimum, mean and maximum), the Monte-Carlo simulations are based on the respective time series from 2000 to 2020. We draw 1,000 values by chance for each variable and product, which allows generating a possible range of input data for 2030 and 2050, based on a certain probability function. Scenario-specific assumptions (bioenergy use, imports of protein feeding stuff) were employed on these data. Applying all data and scenario assumptions in the simulation models implies that each model delivers 1,000 results for each product, year (2030, 2050) and scenario (baseline, best-case, most-probable case, worst-case).

As was shown in the previous chapters, we assume either specific levels of exogenous variables (regarding yields and population) or specific relative changes of exogenous variables (i.e., imports of protein feedingstuff, per-head non-feed use of bioenergy crops) for the simulation of scenarios in 2030 and 2050.

For some exogenous variables we account for uncertainties in scenario data for 2030 and 2050 and perform Monte-Carlo simulations (i.e., stochastic simulations). This applies to the following variables:

- **(non-feed) use per head** (model 1 and 2)
- **trade balances** (model 1) and
- **areas/livestock** (model 2).[31]

The numerical values of these variables are treated as random numbers. We assumed a triangle distribution (here: minimum, mean and maximum of the time series according to the database from 2000 to 2020; see chapter 4.1) and made 1,000 independent draws of random values for each variable and respective product. Assuming a triangular distribution, a random variable *x* has the following probability density function (see, e.g., Mayrhofer, 2010, and references therein):

$$f(x) = \begin{cases} \dfrac{2(x-a)}{(c-a)(b-a)} & for\, a \leq x \leq c \\ \dfrac{2(x-b)}{(c-b)(b-a)} & for\, c < x \leq b \\ 0\ otherwise \end{cases}$$

with *a* = minimum, *b* = maximum; *c* is the most probable value (i.e., in our case, the mean of the time series 2000-2020). Thus, we generated a range of possible data which is based on a probability distribution. This data serves as data input for the simulation models (see full report). All data input generated by Monte-Carlo simulations was employed simultaneously in the simulation models and, hence, generated 1,000 different model solutions (i.e., self-sufficiency rates) for each product, scenario and year (2030 and 2050).

Some exogenous variables of the Monte-Carlo simulations are subject to scenario-specific assumptions for certain crops (see also chapters 6.3.3 and 6.3.4. of the full report):

In the case of model 1, we assume changes in **trade balances** in the case of protein feedingstuff (soybeans, other oilseeds, oilseed meals, protein crops). Each value drawn by Monte-Carlo simulations (1,000 values for trade balances of each crop) was decreased by 10% (most-probable case scenario) and 30% (worst-case scenario), respectively; the resulting values are the data input for model 1.

The drawn values of the Monte-Carlo simulations for the **non-feed use per head** were altered in the cases of bioenergy crops according to Table 13. The resulting data serves as input in both model 1 and model 2.

The only exogenous variables of the Monte-Carlo simulations which are not subject to scenario-specific assumption are **areas and livestock**, respectively (i.e., the generated values are used for all scenarios and years). This is only relevant for model 2, where areas and livestock are taken as given.

In the simulation models, each product category (e.g., "wheat", "coarse grains", etc.) is simulated separately. The link between the crop sector and the animal sector is established via the feed use of certain crops per animal. In both models, the following variables are exogenous (i.e., taken as given) for 2030 and 2050:

- population of Austria (forecasts according to Statistics Austria, 2013)
- non-feed use per head (in kg per head)

[31] Since "yields" (in terms of t/ha or kg/head) are not available for the product categories oilseed meals, vegetable oils, fruits, vegetables, and fish, we employ Monte-Carlo simulation on the variable "production" for these categories.

- crop-specific feed use per animal (in kg per head)
- yields of crops (in tons per hectare) and animals (in kg per head)

Model 1:

In model 1, the animal sector and the crop sector are simulated in two successive steps: the animal sector is modelled first. In a second step, the resulting livestock numbers of the first step enter the crop sector via its respective feed use.

Step 1 (animal sector): Total non-feed use (i.e., human consumption) is the result of the assumed level of non-feed use per head in 2030 and 2050 and population forecasts for 2030 and 2050. In the case of animal products, this non-feed use is equal to the national (i.e., total) use (apart from the case of milk, which is also used as animal feed). Taking the trade balance in 2030 and 2050 as given, the difference between a given national use and a given trade balance is the required animal production to meet the demand for animal products. Assuming certain animal yields (per head) in 2030 and 2050 gives the required level of livestock for animal production.

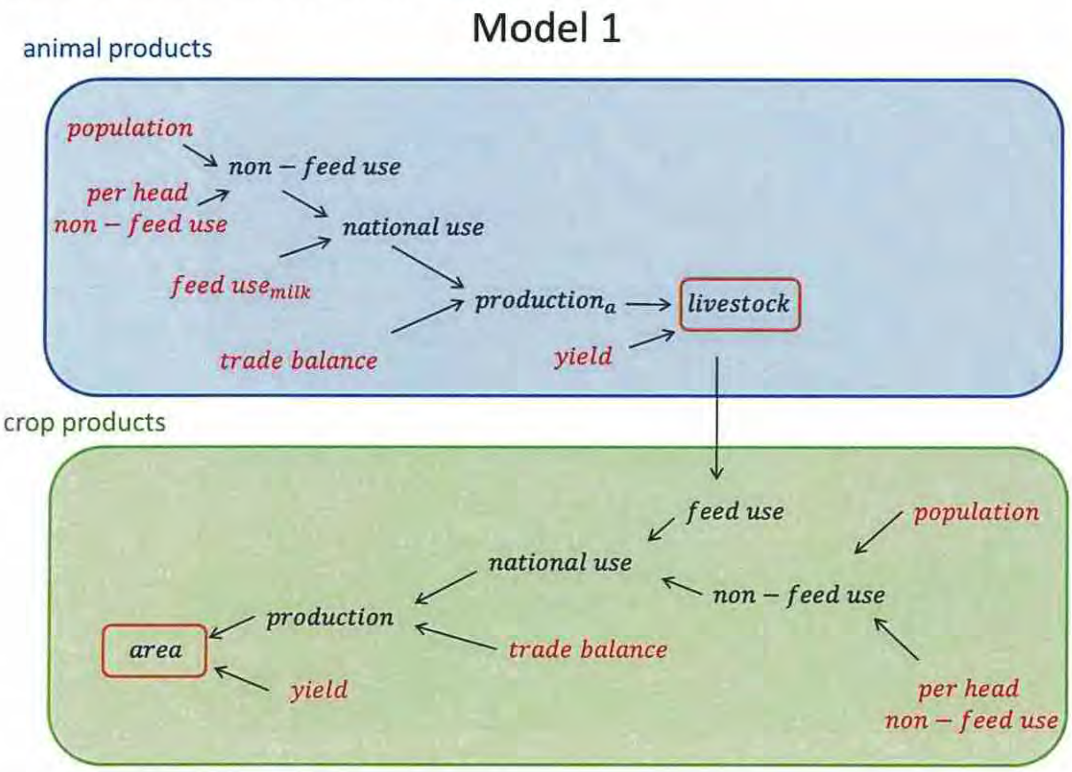
Step 2 (crop sector): The resulting number of livestock in step 1 determines the feed use of certain crops. Thus, national use of crop products is the sum of feed use and a given non-feed use. Again, taking the trade balance regarding crop products in 2030 and 2050 as given, production of crop products is determined by the national use and the trade balance. Assuming certain levels of crop yields (per hectare) in 2030 and 2050 gives the corresponding acreage of crop products required to meet production needs.

According to the structure of model 1, the following research questions can be assessed:

- What is the impact of changes in demand and trade balances on production and, thus, on self-sufficiency?
- Given demand and trade balances for animal products as well as animal yields, how does the number of livestock need to change to guarantee the required animal production? How does the feed use of crop products change?
- Given demand, trade balances and yields of crop products, how does the acreage need to change to guarantee the required production? What is the impact of changes in yields on acreage?

Figure 8: structure of the simulation models for 2030 and 2050, model 1

Note: exogenous (i.e., given) variables are indicated in red types.



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Model 2:

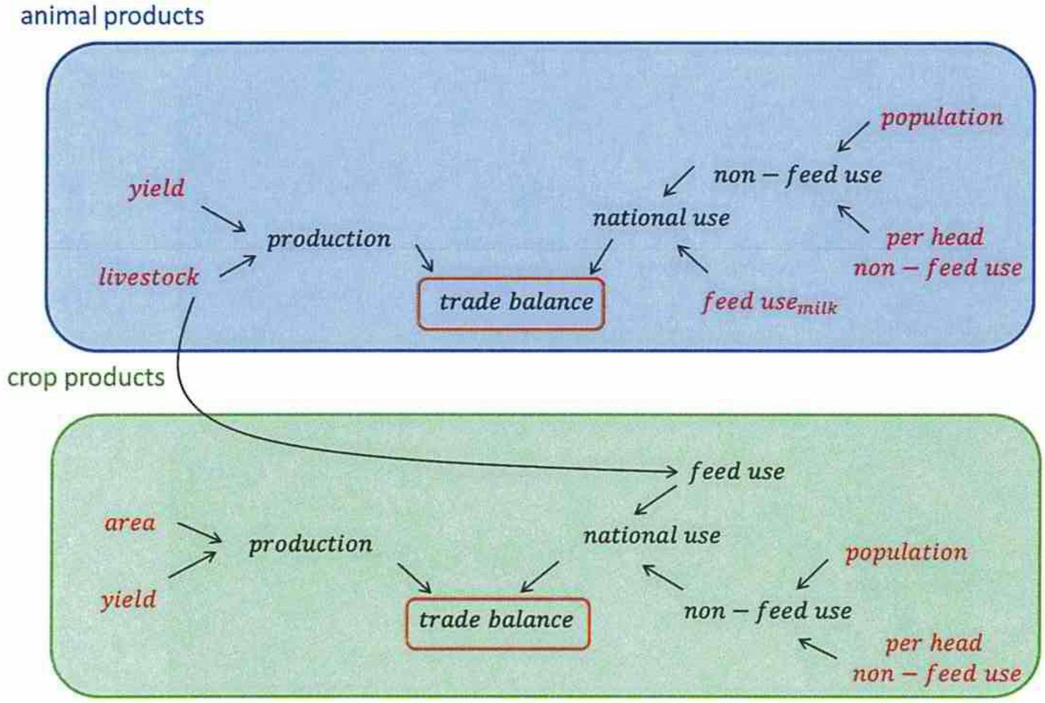
Since livestock and acreage in model 2 are taken as given in 2030 and 2050 (i.e., both variables are "known" in advance) the animal and the crop sector can be simulated simultaneously. On the demand side (feed and non-feed use, i.e., national use), model 2 is similar to model 1. Contrary to model 1, production is determined by yields in 2030 and 2050 and by the exogenously given areas and livestock in 2030 and 2050. The difference between production and national use is the resulting trade balance (i.e., necessary imports or possible exports).

The structure of model 2 allows assessing the following research questions:

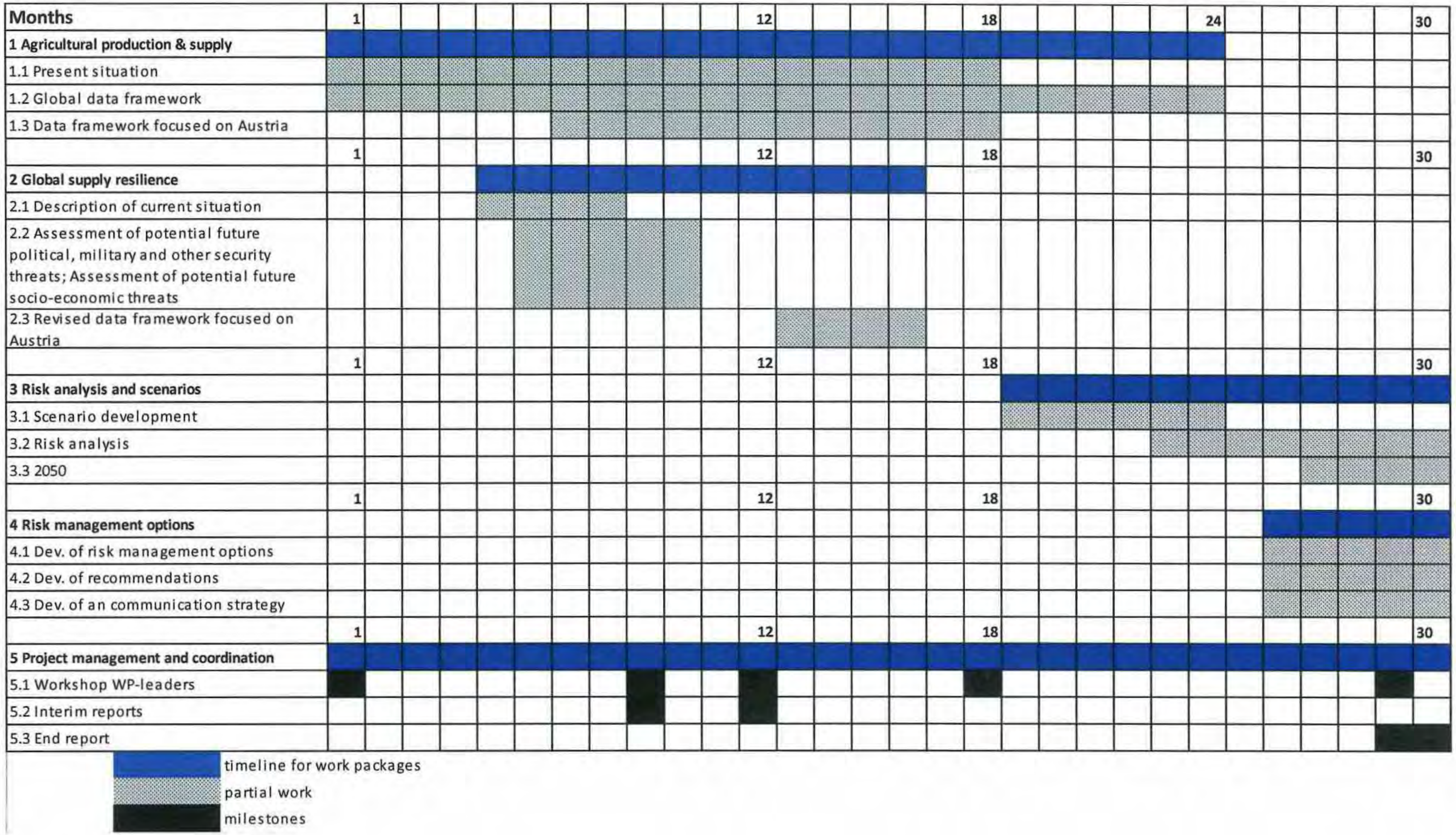
- What are the impacts of changes in crop and animal yields on production?
- What are the impacts of changes in demand and production on trade balances? What is the necessary level of imports or the possible level of exports? Which self-sufficiency rates can be achieved?

Figure 9: structure of the simulation models for 2030 and 2050, model 2

Note: exogenous (i.e., given) variables are indicated in red types.



6. Work and time plan



7. Publications and Dissemination

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Mechtler, K. (2011): Food Security - 2nd Project meeting, WP 1-Results, Data and SSF-Rates for Austria 2015, version 1; Presentation on 07 October 2011 at AMA, Vienna

Mechtler, K. (2012): Food Security – 4th Project meeting, WP1-Results, Agricultural Data for Austria in 2015, version 2; Presentation on 26 April 2012 at AGES, Vienna

Mechtler, K. (2013): Food Security - Methods and Results of WP1-Food Security-Project - Databases and Results for 2015; Presentation on 03 March 2013 at AWI, Vienna

Mechtler, K. (2013): Food Security - Methods and Results of WP1-Food Security-Project - Yield progress in agricultural crops; Presentation on 26 July 2013 at BOKU, Vienna

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All Food Security workshop presentations, working papers and reports are available in the office of the Austrian Association for Agricultural Research, www.oevaf.at.

Dissemination activities will start and force up after the finalization of the end report.