SUSTAINABLE GLOBAL WHEAT SUPPLY SCENARIOS UNDER FUTURE CLIMATE CHANGE IMPACTS
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ABSTRACT: Climate change is predicted to have impacts on agricultural productivity which, coupled with growth in population, will make sustainably feeding the world extremely challenging. While some parts of the world are expected to benefit from moderate climate-change related temperature increases and elevated atmospheric CO₂ concentrations, others are likely to face worsening agricultural production conditions. Even those regions benefiting from changing average conditions are likely to face more frequent extreme weather events which make agricultural production and food supply more volatile than it already is. This paper uses the example of wheat, as one of the most important staple crops worldwide to explore climate change issues relevant to supply and demand. Published data on current and projected wheat yields under different adaptation strategies are used to analyse the extent to which global production can be increased to match projected demands. A set of wheat supply scenarios was developed which shows that the increasing demand can only be provided by northern hemisphere producers narrowing their yield gaps, utilising climate change benefits and increasing production levels to supply southern hemisphere consumers. Even then there are significant risks associated with food security and resilience which could jeopardise the ability to service the future global wheat demand.

Keywords – wheat demand and supply trends, yield gaps, climate change impacts, adaptation, wheat supply scenario
1. INTRODUCTION

Wheat is one of the most important global crops. In 2009, around 680 Mt wheat was produced worldwide making up about 30% of the global cereal production (FAO, 2011\textsuperscript{a}). Wheat products are a main source for energy and protein in many societies (Mitchell and Lawlor, 2000; FAO, 2002; Röder, 2008; UK Agriculture, 2010; HGCA, 2010). Wheat is also used as animal feed, making it an important input to meat and milk production (Mitchell and Lawlor, 2000). With a growing population, development, increasing wealth, urbanisation, changing lifestyles and globalisation of taste, the demand for wheat is constantly increasing.

From a climate change perspective virtually no other economic sector is as exposed to natural influences as agriculture. Even though wheat is grown worldwide in many different climates, its optimal growing environment is in temperate environments (FAO, 2002; Röder, 2008; Gooding, 2009). With moderate temperatures and a sufficient supply of water, nutrients and pesticides, wheat can generate high yields of over 10 t/ha, but with changing environmental conditions, global wheat production faces significant impacts and new challenges.

According to the Intergovernmental Panel on Climate Change (IPCC) scenarios, temperature increase, higher atmospheric CO\textsubscript{2} concentration and longer growing periods are expected to favour agricultural production in higher latitudes within the next forty years, while climate change impacts will have a greater negative influence on production in lower latitudes (IPCC, 2007). However, limited resources (especially water and fertile land), soil erosion and pressures from plant pathogens, pests and weeds will also affect production in regions that are likely to be favoured by climate change (Olesen et al., 2010). Extreme events and unpredictable weather conditions will also add to these pressures, suggesting that climate change is unlikely to impact agriculture as isolated events but rather as a wide set of impacts affecting not only plant physiology, but the whole growing system and environment of the plant. With increasing volatility on one side and a growing demand on the other, adaptation strategies will be necessary to limit harmful impacts and make use of possible opportunities to guarantee sufficient wheat supply at a stable and reasonable price to ensure food security.

Despite the potential of agriculture to capture carbon through photosynthesis, it contributes significantly to global climate change due to emissions of several greenhouse gases (GHGs). Agriculture generates about 14% of the total global GHG emissions mainly in the form of methane from enteric fermentation and rice production, and nitrous oxide from fertilising and fertiliser production (IPCC, 2007; DECC, 2010; Defra, 2010). This means that agriculture has to adapt to changing environment and production conditions, and at the same time mitigate its emissions as much as possible. Both require a rethinking of agricultural practices, technologies, economic actions, decision making, supply & demand and consumer behaviour.

The scale of ongoing changes in global and local food production is multi-faceted and complex. This paper therefore looks at projected global wheat demands, the main producers and international trade streams and whether the global wheat supply can be increased and sustained utilising the positive impacts of climate change to support increased yields.

2. GLOBAL WHEAT PRODUCTION AND DEMAND TRENDS

Currently about 680 Mt of wheat is produced worldwide with an average yield of about 3 t/ha. The main producers (EU, China, India, the Russian Federation, USA, Canada, Australia, Ukraine) produce about 80% of the total global wheat (FAO, 2011\textsuperscript{a}). According to FAO (2006) the global demand will increase to about 900 Mt by 2050, about two thirds of this is projected for food use and one third for other uses such as feed. These assumptions are based
on the projections of population growth, improved calorie intake in food insecure regions and changing social structures and diets (FAO, 2006).

According to the UN medium variant the population is expected to grow to approximately 9 billion by 2050 (UN, 2004; UN, 2011) with the largest growth in Africa and Asia with an increase of about 1 billion people each. These are also the regions with very strong urbanisation and structural and lifestyle changes. While in Africa and Asia currently about 40% and 43% of the population, respectively, lives in urban areas, this will increase to 62% and 67% by 2050 (UN, 2004). The global average per capita food consumption is also expected to rise from about 2950 to 3130 kcal/capita/day until 2050 (FAO, 2006). Nonetheless, even then there still will be a significant level of undernourishment with food consumption under 2500 kcal/person/day especially in sub-Saharan Africa.

While the global cereal demand per capita is slowly growing, the increasing ‘hunger’ for wheat seems unstoppable. Worldwide diets not only substitute starchy foods with energy-rich foods such as livestock products, oils and sugar, but also switch from traditional staples like roots, tubers and coarse grains to wheat (FAO, 2006; Röder, 2008). This trend arises because wheat, especially in the form of bread, has been the staple of the (middle and upper class) urban population for many centuries (Barlösius, 1999; Fenton, 1997; Tannahill, 1988). Moreover, the demand for feed wheat increases with a rising consumption of meat. Increasing meat consumption follows the same patterns as wheat consumption and can be understood as a combined dietary dynamic (Barlösius, 1999). Thus, the increasing demand for wheat, combined with high population growth, improved food consumption and changing social structures and diets will result in higher wheat demands for direct human consumption and also to provide animal feed for dairy and meat production.

The highest increases in the wheat consumption rate are expected for Africa and Asia which are, in most cases, already wheat net importers (FAO, 2011a). China and India take special positions as they together account for 38% of the world population (FAO, 2006). Both countries produce about 115 Mt (China) and about 80 Mt of wheat (India) per annum, which is nearly 30% of the global wheat production and makes them the top two wheat producers. They mainly produce for domestic use and their wheat trade varies from year to year but the amounts wheat imported and exported are almost insignificant compared to the amounts of wheat produced. According to FAO (2006) China as well as India have become almost self-sufficient in wheat and are modest net exporters in some years after being net importers in the past. But it is likely that both countries will in future become net importers again (FAO, 2006; World Grain, 2011). The projections of the wheat demand for China are very uncertain but expected to grow mainly because of an increasing urbanisation and meat consumption (FAO, 2006). Moreover, wheat is an irrigated crop in China and the availability of irrigation water might be the limiting factor for its future domestic supply. For India the wheat demand is expected to increase mainly because of population growth and a shift from other cereals to wheat (FAO, 2006; World Grain, 2011). Therefore future global wheat demand is expected to increase as a result of population trends and changing diets, especially in Africa and Asia, creating new global wheat demands and will require an increased wheat production and wheat trade by the main wheat producing and exporting countries.

3. POTENTIAL WHEAT PRODUCTION AND YIELD GAPS

The average global wheat yield is about 3 t/ha (FAO, 2011a). Comparing the yield of the main production areas shows that yields differ strongly between regions. In France, Germany and the UK (the main wheat producers in the EU) average yields are around 8 t/ha. The EU in total has an average yield of about 5.4 t/ha. Looking at the last 10 years of wheat yields of the European main producers it can be recognised that yields are growing very slowly or even
stagnating (FAO, 2011a). Brisson et al. (2010) and Peltonen-Sainio et al. (2009) found that this development is not caused by reaching the genetic plateau. They note there is still potential for breeding to improve yields, but that agricultural management and economic factors have had negative impacts. One reason may be a reduction in use of fertilisers (especially nitrogen) and pesticides due to environmental policies and increasing cost (Peltonen-Sainio et al., 2009). Another reason may be modification of crop rotation from legumes to oilseed rape as the preferred breaking crop as the later restores soil fertility less than legumes (Brisson et al., 2010).

The yields of other main producing countries are significantly lower with about 3 t/ha in the USA, Canada and Ukraine and even less in the Russian Federation (2.3 t/ha) and Australia (1.6 t/ha) (FAO, 2011a). China and India as the top wheat producers, but growing wheat mainly for domestic use, achieve yields of about 4.7 t/ha and 2.8 t/ha (FAO, 2011a). The success of the wheat production of China and India is essential to cover their domestic demand and to which extent their future wheat import requirements will put pressure on global supply.

While the main European wheat producers and Canada already achieve yields which (almost) equal possible yields or are close to it, wheat exporters such as the USA, Australia, the Russian Federation and the Ukraine could, according to their actual agro-ecological potential, at least double their yields (Bruinsma, 2009). The low yields in these countries can be explained by economics as enough land is available and the volume of wheat can be produced on large areas with lower inputs (cost) resulting in lower yields. The yield optimum of wheat is a function of the price for inputs, especially nitrogen fertiliser, and the market price of wheat (Sylvester-Bradley et al. 2008). Hence low yields in regions with large production areas available are a consequence of agricultural economics. Since sufficient land is available at present, there is no incentive to increase yield. But wheat main producing countries are at the limit to expand arable land and a higher supply can only be achieved in these regions by yield improvement (Bruinsma, 2009). This shows that only a few main producers are receiving possible wheat yields while other produce far below their ecological potential. This also means that there is an ecological prospect to improve wheat yields significantly in many main producing regions but only with increasing inputs and cost.

Overall there are wide variations in global yields achieved, which can only partly be attributed to biophysical constraints. If sufficient demand developed, at a minimum market price, agricultural economics would likely incentivise increases in yields via changes in agronomy in key producer countries and possibly by arable land shifts. While others have considered the extent to which achievable yield improvements could satisfy increased demand projections, this has not taken any detailed account of climate change impacts and adaptation nor has it drawn out inferences for global trade patterns in any detail.

4. OBJECTIVES OF THIS WORK: EXAMINING THE CHALLENGES OF MEETING THE INCREASING GLOBAL WHEAT DEMAND

According to the IPCC (2007) environmental and climatic conditions for growing agricultural products will worsen in lower latitudes (Africa and some parts of Asia) and wheat production will be at best much more inefficient or at worst impossible in these areas. For higher latitudes (northern Europe, northern America, northern Asia) yield improvements for wheat of 8-25% by 2050 are expected under the B1 emission scenario (IPCC, 2007). Additionally Zhang and Cai (2011) assume that in main producing regions like the USA, the Russian Federation and China more land will become suitable for agriculture under the B1 emission scenario while in lower latitudes (e.g. Africa, South America, India) arable land might be lost due to climate change. Hence, regions with the highest growth rates in wheat demand are also
likely to be negatively affected by climate change impacts while the main producing regions with moderate population growth are likely to be favoured. In other words wheat is not produced in the regions with the highest demand growth but needs to be imported. These are also regions with populations already vulnerable to food shortage and so climate change impacts are likely to aggravate the conditions of their livelihoods. It becomes clear that food demand trends and future crop yields cannot be isolated from climate change issues. To get a complete picture production, demand and climate change data needs to be simultaneously synthesised.

Above it has been shown that several wheat main producing countries have the potential to expand their production significantly and that these are also the future regions where wheat production is possible under climate change impacts. One way of bridging this production-consumption gap is for the main producers and exporters (e.g. USA, EU, Australia, Canada) to responsibly increase and stabilise their wheat production, in order to provide sufficient amounts of wheat of a specific quality at a stable and reasonable price worldwide. While the Russian Federation and Ukraine can also be regarded as important wheat producers and exporters due to the availability of resources and climate change benefits, insufficient infrastructures and low productivity currently still constrict an optimal production. The availability and quality of land in these regions makes increased production viable, but the infrastructure would have to be significantly improved to facilitate substantial increases in exports.

But even in these countries where yields and arable land are expected to increase, climate change impacts are likely to make agriculture and wheat production more unpredictable. Extreme weather events and resource limitations (including water and fertile land) make the socio-economically and environmentally responsible and efficient use of inputs increasingly important, in all production areas. Recent events in the Russian Federation, Ukraine (drought and wildfires), Australia (flooding), extremely wet seeding seasons in the USA and spring droughts in Central Europe are leading to severe disruptions in the worldwide wheat supply causing strong price rises and underline the seriousness of extreme events. Drought affects all growing stages of the wheat plant. Even though the plant prefers drier to wetter conditions, long dry spells in combination with high temperature restrain biomass production, fertility and grain development of the plant (Mitchell and Lawlor, 2000; Lawlor, 2005; Richter and Semenov, 2005; Spiertz et al., 2006; DaMattta et al., 2010; Peltonen-Sainio et al., 2010). Heavy rains, hailstorms or strong winds can cause stem breakage. Wet weather conditions and water logging increase the pressure of fungi and rot which can be foliar, stem and root based diseases. Climate change projections therefore may point to a potential increase in yields in certain producer regions, but this may be offset by increased vulnerability to more frequent extreme weather events and more prevalent pests and disease. Our existing knowledge of the potential impact of these effects is limited, but it seems likely it could contribute to increased uncertainty, risk and vulnerability in future wheat supply chains.

The data and evidence presented above on global production and demand trends, yield trends and gaps and climate change adaptation predict an increasing global demand for wheat (due to improved food intake, population and economic growth and socio-economic change) at a time when the agricultural sector is likely to face very significant climate change impacts. The global community has been struggling for many decades to improve food security, but with very limited reduction in the numbers of people experiencing malnutrition and hunger (FAO, 2011c). Climate change impacts will significantly exacerbate the difficulty of this task and demand and supply trends would indicate that key producers should increase their production in response, but this neglects the impact of climate change on agriculture. It is
important to consider the extent to which wheat production can adapt to climate change impacts and how resilient the resultant practices and supply chains will be.

This work takes into account the impacts of climate change adaptation strategies on yield and production potential to consider the socio-economic consequences for main producers and global trade. By developing a set of wheat supply scenarios this paper will combine the named issues of an increasing wheat demand and climate change impacts on wheat production and its consequences on food supply and the adaptation of agricultural production. Analysing these scenarios allows us to evaluate the extent to which regions with increasing wheat demand will increasingly depend on the main producer countries and the extent to which wheat production will be influenced by climate change impacts and constraints on where production will be possible as well as on the familiar market economics.

5. WHEAT SUPPLY SCENARIOS

5.1. Methodology

Combining published data on wheat production, yields, yield trends and gaps, projected demands and climate change impacts a set of wheat supply scenarios was developed to examine the possible global wheat supply today and in 2050. The baseline for the scenarios is the global wheat production of the ten main wheat producers in 2009. It was assumed that the top-10 producers, already providing 70% of the total global wheat, will also be the major global wheat producers within the next 40 years. Moreover, some of the main producers are assumed to benefit from climate change impacts until 2050 regarding yield and arable land improvement (IPCC, 2007; Zhang and Cai, 2011) and according to the research of Bruinsma (2009) have the potential to significantly improve their yields. By contrast many net importing countries are likely to face severe negative climate change impacts which can lead to interruptions and reduced availability in their agricultural and food systems, resulting in an even higher dependency on imports. The data the scenarios are based on were generated from the FAO database (FAO, 2011a) and then combined with the region specific projections of the IPCC (2007) and results of Zhang and Cai (2011) detailing how climate change may impact agricultural production (wheat) and land availability and suitability. Additionally we evaluated the quantities of wheat could potentially be produced if the main producing countries utilised their full agro-environmental potential to narrow their yield gaps (Bruinsma, 2009). No explicit account was taken of economic and political issues or consequent greenhouse gas emission impacts.

5.2. Wheat supply scenarios

On the basis of currently utilised areas for wheat production and possible yields the USA, the Russian Federation, Ukraine and Australia could, according to Bruinsma (2009), potentially double their yields, while European producers and Canada are already achieving yields up to the agro-ecological potential. According to the IPCC (2007), agricultural production in these areas, as well as in northern and central Europe, is likely to be favoured by climate change until 2050 under the B1 emission scenario (IPCC, 2007). In Europe, the Russian Federation and Ukraine wheat yield improvements of 25% are projected, in North America 20%, while in Australia benefits in some regions are likely to be offset by yield reductions in other regions. Projections for India and China are uncertain (IPCC, 2007). Zhang and Cai (2011) also showed that more land will be suitable for growing crops under the B1 emission scenario. In North America about 15%, in the Russian Federation even about 37-50%, in
China about 26%, while in Australia improvements in some areas will be set off by increasing vulnerability and unsuitable land in others. For northern and central Europe no changes are expected and in India available land is likely to be reduced (Zhang and Cai, 2011).

In the context of closing yield gaps and yield improvements and land use benefits from climate change, this research takes a closer look at potential wheat yields and future supply. Three sets of wheat supply scenarios have been considered (Table 1). Each scenario contains two production options: (a) the current global production; and (b) production in 2050. Scenario 1a assumes the current global wheat production, with its yield gaps, using production numbers from 2009, while scenario 1b projects wheat production in 2050, changing yields according to the IPCC B1-scenario in 2050 using additionally available crop land according to Zhang and Cai (2011) under the B1-IPCC scenario. Scenario 2 assumes that existing yield gaps of the main producing countries are halved compared to today’s production (2a) and projected production to 2050 (changing yield and land availability) (2b). The third scenario set assumes that the yield gaps in the main producing countries are closed (3a) and again projects wheat production to 2050 according to changing yields and land availability (3b).

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<tr>
<th>Scenario 1a</th>
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<th>Scenario 2a</th>
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<th>Scenario 3a</th>
<th>Scenario3b</th>
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<tr>
<td>Wheat production in 2009; Top-10 producers</td>
<td>Wheat production in 2050; Top-10 producers</td>
<td>Current wheat production and closing yield gaps by half; Top-10 producers</td>
<td>Wheat production in 2050 closing yield gaps by half; Top-10 producers</td>
<td>Current wheat production closing yield gaps; Top-10 producers</td>
<td>Wheat production in 2050 closing yield gaps; Top-10 producers</td>
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*Table 1. Wheat supply scenarios*

The results of the three scenarios are illustrated in Figure 1. They focus on the ten major wheat producers, China, India, USA, Russian Federation, France, Canada, Germany, Australia, Ukraine and UK, which currently produce about 465 Mt annually, making up 70% of the total global supply.

Under scenario 1 the main producing countries could, according to climate change projections, increase their annual production by approximately 163 Mt, from 465 Mt in 2009 to about 628 Mt in 2050.

Under scenario 2 yield gaps in the main producing countries, which are not making use of their agro-ecological potential, will halve, leading to an increase in current annual production of 103 Mt. This means that the main wheat producers could produce about 568 Mt of wheat instead of 465 Mt annually under current conditions. As a result of the effects of climate change, the production then could rise in 2050 to 738 Mt in the major wheat producing countries.

Under scenario 3, yield gaps are closed and the global supply would increase by 193 Mt to 658 Mt. The major increases in production come from the USA, Australia, the Russian Federation and the Ukraine, as these have the largest yield gaps currently, while Europe and Canada contribute no increase as they are currently close to their maximum potential yields. This shows that the ten major wheat producers could already produce today's total wheat supply by making full use of their agro-ecological potential. Incorporating production from other wheat producers, the current wheat production could reach around 875 Mt. Including climate change impacts, the wheat production of the ten main wheat producers could increase to about 860 Mt in 2050 which comes close to the projected global wheat demand of 900 Mt.
in 2050. This could be sufficient if the rest of the global wheat production stays the same or even decreases in countries with negative climate change impacts in low latitudes, which are already net importers.

![Wheat supply scenarios for the 10 main producing countries](image)

**Figure 1.** Wheat supply scenarios for the 10 main producing countries

### 5.3. Discussion

Scenario 1 (a/b) and 2 (a/b) show that the global wheat supply will only be sufficient if additional to the ten main producing countries other countries contribute to the production. In scenario 3, with the assumption that the main wheat producing countries close their yield gaps and make full use of favourable climate change impacts, the ten main producers come very close to providing the global demand under current and future conditions. This would require substantial investment and changes in practice, including increased fertiliser use. The scenarios neglect the wheat production in other countries where little data is available about yield gaps and climate change impacts of smaller wheat producing regions. However, even though it is likely that wheat yields and production in some northern regions improve, many other regions in lower latitudes which currently produce wheat will face negative effects on wheat with significant yield reductions or wheat being impossible to grow (IPCC, 2007; Brown, 2008; Olesen et al., 2010). Therefore this limitation is not considered likely to have a major impact on the global supply balance.

It could be argued that Scenario 3 is too optimistic and both economically and ecologically unlikely as these calculations do not include any socio-economic or political factors such as markets, economic development, land tenure, resource availability, prices for production factors and food/agricultural/trade policies or environmental impacts like precipitation, land degradation, pests or maintenance of soil fertility and plant available nutrients. Narrowing or closing the yield gap as well as adapting to climate change and utilising positive impacts from moderate temperature increase and elevating atmospherically CO₂ concentration (Mitchell and Lawlor, 2000) will require increased input of production factors like nitrogen fertiliser and investment (Röder et al., 2011). Irrigation is particularly likely to become an issue as currently wheat is a rainfed crop in most main producing countries (excluding China) and the occurrence of uneven and unpredictable precipitation is more likely under future climate change scenarios. This may result in requirements for
irrigation in order to maintain yields and production resilience even in temperate regions, such as northern Europe. China is one of the few countries, where wheat is routinely an irrigated crop. According to Brown (2011a) ground water tables have significantly fallen in the wheat production areas due to pumping to irrigate wheat. This is also reported form other world regions like the Middle East where countries formerly self-sufficient in wheat increasingly depend on imports as unsustainable irrigated grain production lead to the depletion of ground water resources and limits the production of wheat and makes it more inefficient (Brown, 2011b).

Increasingly there is a trend to embrace organic farming and the use of cover crops and intercropping seem to be adequate instruments to increase yields and build resilience on small scale level and for subsistence farming in Africa and Asia (FAO, 2011b), these methods do not necessarily contribute to yield improvement in industrial agriculture where even higher yields need to be maintained or established and efficiency is not only an income issue for the farmers but also for global wheat prices. Nonetheless, methods like intermediate cover crops, crop rotations including legumes and best fertiliser and tillage practices and crop and resource management could lead to higher sustainability in large scale agriculture without decreasing yields.

The FAO projects global wheat yields to increase to an average of 3.75 t/ha until 2050 (Bruinsma, 2009). This projection is based on historical trends without regarding climate change impacts. Considering increasing crop land in main producing countries according to Zhang and Cai (2011) 870 Mt could be produced globally under optimal conditions and overlooking interruptions, which still is lower than projected demands. This number does also not include crop land losses in other regions. Even though most of the main producing countries seem to benefit from climate change impacts until 2050, these projections have a high uncertainty. Especially with the prospect of an increasing occurrence of extreme weather events and risk of plant diseases and weeds, these numbers seem very optimistic if not unrealistic. Droughts, uneven precipitation and floods in the last few years in main wheat producing countries showed how easily the production system can be affected, resulting in significant impacts for the global supply and already volatile food prices.

The demand for wheat might also be regulated through the price. As it is likely that food prices will stay high and increase even further, the wheat demand may be lower than projected and people might switch to other crops. It is also uncertain how large climate change impacts will be on agricultural systems in lower latitudes and on other staples and the food security of many. Increasingly harsh conditions for subsistence farming would generate higher demands for and dependency on market crops such as wheat. Without clear and fair international political actions and legislations for producer on all scales and for consumer it is likely that the high numbers of people suffering food insecurity will not decrease but increase the vulnerability of many.

CONCLUSIONS

The demand for wheat is constantly increasing due to population growth, urbanisation and structural changes of societies. According to global climate change projections, wheat production in regions in higher latitudes is likely to be favoured, while yields in lower latitudes are likely to decrease and production might even be impossible. Especially in regions with increasing demands, production will be very limited and a greater number of countries will rely on a few main producers. This means that producers in the northern hemisphere will have to take a greater responsibility for supplying southern hemisphere consumers, because of possible climate change impact benefits and in terms of better suitable agro-ecological conditions and higher efficiency and productivity in growing wheat.
different wheat production scenarios showed that there is a high potential to increase the global wheat supply significantly. With this and the outlook of a continuously increasing demand worldwide, it is essential that main wheat producers utilise their production potential and maximise their yields not mainly following economic interests but food sufficiency concerns to maintain and sustain the global food supply. Even though for northern regions favourable agricultural conditions are expected until 2050, the main producing countries are also vulnerable to climate change impacts. For example, extreme weather events can interrupt large areas of wheat production, as current flooding in east Australia and droughts in the Russian Federation have shown. Sustainable and resilient practices, not only technological but also social, economic and political, that maintain or even improve yields without depleting resources to guarantee a sufficient global wheat supply in the long term will be necessary, not only with the outlook until 2050, but also with keeping in mind that climate change projections and impacts after 2050 are very uncertain.

The issues of food security and demand and climate change impacts are still in most cases treated as separate problems. This work showed that they are closely interlinked and require an interdisciplinary approach that combines socio-economic and environmental concerns. This work also demonstrates that adapting to climate change in the main wheat producing countries should not just happen for the own economic interest but because of a responsible behaviour and awareness to improve and secure the global food supply especially in regions which are already and will be hit hardest from climate change. With severe climate change impacts in vulnerable areas where people mainly depend on subsistence farming, the high volatility of the global market for food and agricultural commodities and steadily increasing food prices a stable and just global food supply is necessary.

To understand the complexity of food production, demand trends and climate change impacts better, further work in the areas of input requirements such as irrigation and fertiliser, production methods, land use and risk management is needed. Even though local approaches are crucial to deal with regional production characteristics and demand within their socio-economic, political and cultural environment these approaches need to be seen within the dynamics of a holistic global food system and a changing global climate.

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