Modelling robust crop production portfolios to assess agricultural vulnerability to climate change

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Paper prepared for presentation at the EAAE 2014 Congress
'Agri-Food and Rural Innovations for Healthier Societies'

August 26 to 29, 2014
Ljubljana, Slovenia

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Abstract
Agricultural vulnerability is assessed by (i) modelling climate change impacts on crop yields and gross margins, (ii) identifying crop production portfolios for adaptation, and (iii) analyzing the effect of agricultural policies and risk aversion on adaptive capacity. We combine, spatially explicit, a statistical climate change model, the bio-physical process model EPIC and a portfolio optimization model. Under climate change, optimal portfolios include higher shares of intensive crop managements which increase crop yields and gross margins by 2-3%. Abolishment of decoupled but higher agri-environmental payments would reduce nitrogen fertilizer inputs by 23-33%, but also crop yields and gross margins by 18-37%.
Keywords: climate change impact, adaptation, agricultural vulnerability, portfolio optimization, agri-environmental policies

1 Introduction

Climate change is expected to affect the agricultural sector in many respects (Parry et al., 2007) and thus influences agricultural vulnerability (Fellmann, 2012). The latter can be interpreted in various ways as there exists a plurality of definitions, concepts and methodologies to assess vulnerability (Hinkel, 2011). Some definitions differentiate between external or bio-physical and inherent or social vulnerability and address their relation (Brooks, 2003; Turner et al., 2003; Eakin and Luers, 2006). Bio-physical vulnerability is often expressed in terms of exposure, i.e. the nature and degree to which a system is subject to climate change, and sensitivity, i.e. the degree to which systems are affected positively or negatively by climate change, which together describe the extent of potential climate change impacts. In contrast, social vulnerability usually describes a state that exists within a system before it encounters a hazardous event and may be determined by factors such as poverty and inequality. An interaction between external hazards and social vulnerability produces an outcome, which is often measured in terms of physical, human or economic damage or harm (Brooks, 2003). Vulnerability is thus commonly perceived as a '*measure of future harm*' (Hinkel, 2011). To develop such a measure, Hinkel (2011) suggests to apply forward-looking, observable indicators. For the social subsystem indicating variables could include gross domestic product (GDP), farm income or other forms of social and physical capital which represent the adaptive capacity of a system. Thereby, adaptive capacity does not address adaptation measures as such but refers to potential adjustments in resources, technology or behavior and is also influenced by socio-economic factors such as institutions, governance, and generic factors such as education, income level, or health (Adger, 2006; Smit and Wandel, 2006). Bio-physical vulnerability is typically addressed by simulation based approaches (e.g. Iglesias et al., 2011). Complex simulation based models or integrated assessment models are employed to simulate possible future states of a vulnerable system which are then evaluated based on harm indicators (Hinkel, 2011). Such harm indicators are often defined in cooperation with stakeholders in order to increase the practical relevance of the results (e.g. Mitter et al., 2014).

Agricultural vulnerability can thus be approximated by bio-physical vulnerability, i.e. bio-physical harm indicators resulting from simulation-based approaches, as well as indicators for social vulnerability such as farmers' annual gross margins. Bio-physical vulnerability to climate change varies considerably between countries and regions (O'Brien et al., 2004; Ionescu et al., 2009). According to Metzger et al. (2005), Austria belongs to three agro-environmental regions, alpine south, continental, and pannonian where considerable differences in climate change impacts are expected (Trnka et al., 2011). While cropland in the alpine region (i.e. the western parts of Austria) is expected to benefit from increasing temperatures and CO_2 fertilization because sufficient water supply during the growing season is available, cropland in the pannonian region (i.e. the north-eastern parts of Austria) is likely to suffer from increasing temperatures due to water limitations (Thaler et al., 2012; Schönhart et al., 2014). However, favorable topographical and soil conditions in the pannonian region as well as the availability of freshwater for irrigation may reduce agricultural vulnerability. Furthermore, agri-environmental policies are considered suitable to increase regional adaptive capacity. Aggregated results over all Austrian NUTS-3 regions suggest that gross margins increase if policy-induced adaptation measures are considered (Schönhart et al., 2014). However, bio-physical vulnerability and the ability to adapt have not yet been assessed on high spatial resolution in Austria. In addition to that, quantitative research on the impact of policy scenarios and farmers' risk preferences for optimal production choices is needed in order to strengthen their adaptive capacity (Bezabih and Sarr, 2012).

This article presents an assessment of agricultural vulnerability exemplified on Austrian cropland. The aim of our analysis is threefold: Firstly, we assess the impacts of regional climate change scenarios on level and variability of crop yields and gross margins in Austria. Crop yields and gross margins serve as indicating variables for bio-physical and social vulnerability, respectively. Secondly, we identify viable adaptation measures by modelling optimal crop production portfolios. These portfolios aim at reducing climate-induced variability in gross margins for different levels of risk aversion. We recognize that climate change is a highly uncertain phenomenon and consider, therefore, a broad range of climate change scenarios for the period 2010-2040. Thirdly, we assess the effect of risk aversion and agricultural policy scenarios on the choice of robust crop production portfolios. This allows us to approximate the effect of changes in the adaptive capacity on agricultural vulnerability.

The article is structured as follows. In section 2, we describe the integrated agricultural vulnerability assessment framework. In section 3, we present and discuss robust crop production portfolios under climate and policy change as well as the effect of risk aversion on portfolio choices, and in section 4 we draw conclusions.

2 Integrated Agricultural Vulnerability Assessment Framework

Figure 1 shows the integrated agricultural vulnerability assessment framework applied on the entire cropland area at 1 km pixel resolution. It consists of a statistical climate change model for Austria (ACLiReM, Austrian Climate Change Model using Linear Regression; Strauss et al., 2013); a crop rotation model (CropRota; Schönhart et al., 2011); a bio-physical process model (EPIC, Environmental Policy Integrated Climate; Williams, 1995); crop gross margin calculations; and a mean-standard deviation portfolio optimization model.

2.1 Statistical Climate Change Model for Austria (ACLiReM)

ACLiReM generates, based on daily weather station data from 1975 to 2007, a set of climate change data with spatial and temporal resolution of 1 km and 1 day (Strauss et al., 2012; Strauss et al., 2013). For our analysis, five regional climate change scenarios are generated for the period 2010-2040. Each scenario consists of a rising trend in temperature (+0.05 °C per year), and considers varying assumptions on precipitation sums and distributions. Either, mean annual precipitation sums (i) remain the same as in the past; (ii) decrease or (iii) increase by ~0,67% per year, resulting in a decrease or increase of 20% in 2040 compared to the historical period; or 20% of the seasonal precipitation distributions shift(iv) from summer to winter, and (v) vice versa, while the mean annual precipitation sums remain at the same level as the historical values. We employ these five climate change scenarios because they cover the currently expected spectrum of climate projections until 2040 in Austria. At the same time, the simultaneous use of five scenarios in one analysis reflects the prevailing uncertainty about future developments.

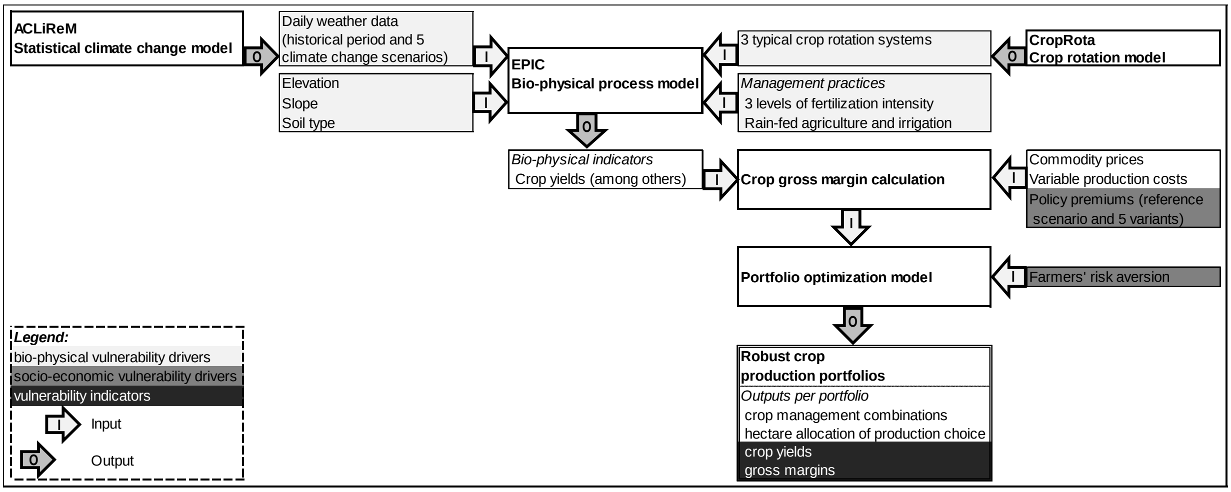

Figure 1.The integrated agricultural vulnerability assessment framework.

2.2 Crop Rotation Model (CropRota)

CropRota is based on historically observed crop shares and additional agronomic data in Austria. It is applied to compute typical crop rotations as well as their relative shares at municipality level over a 31 year period (Schönhart et al., 2011). CropRota has derived up to 22 different crop rotations per municipality. Typically, crop rotations consist of one (monoculture) to six annually sequential crops. The derived crop rotations and shares at municipality level are then proportionally assigned to the observed shares of cropland at pixel level. This assignment procedure is repeatedly performed to generate three alternative crop rotation systems (CRS1-CRS3) at pixel level. The consideration of three alternative CRS per cropland pixel allows acknowledgement of continuous crop production optimization without major system changes.

2.3 Bio-physical Process Model (EPIC)

EPIC simulates bio-physical processes which respond to daily weather, topographic information, soil types, crop characteristics, crop management, and atmospheric CO_2 concentration (Williams, 1995). It is applied to simulate annual dry matter crop yields and environmental outcomes for alternative crop management practices. The simulations are performed for the Austrian cropland on a 1 km pixel resolution. Each pixel includes a combination of homogenous bio-physical characteristics (homogeneous response units, HRUs) on elevation, slope, and soil type and thus allows accounting for the natural heterogeneity in crop production and emissions (Schmid, 2006). In total, there are 40,244 cropland pixels in Austria that sum up to a total area of ~1.27 mil ha. The simulations are performed for a historical period (1975-2005) and for five climate change scenarios in the future period (2010-2040). We consider different crop management practices including three crop rotation systems (CRS1-CRS3, see chapter 2.2), three levels of fertilization intensities (high, moderate, low), and optional irrigation. The three levels of fertilization rates represent legal standards and policy guidelines. Irrigation is only combined with high fertilization intensity and is allowed for all simulated crops. In the historical period (1975-2005), we consider only one crop rotation system (CRS1) in combination with three fertilization intensities and irrigation, i.e. four different crop management practices. In the future period (2010-2040), we (i) consider the same crop management practices as in the historical period to assess the effect of climate change. This scenario is referred to as ‘future1’, and (ii) add additional crop rotation systems (CRS2-3) to allow for a broader portfolio. We thus consider 12 different crop management practices. This is referred to as ‘future 2’.

2.4 Crop Gross Margin Calculations

Annual gross margins by cropland pixel, crop management practice, and climate change scenario are calculated according to Equation 1:

$$\pi_{i,m,s} = \sum_{c} (y_{i,c,m,s} * p_c - k_{c,m} + d_m) \qquad \forall\, i, m, s \qquad (1)$$

where π are annual gross margins in €/ha, y are the simulated annual crop yields in t/ha, p the average commodity prices in €/t, k the average variable production costs in €/ha, and d the agricultural policy premiums in €/ha. The index i denotes cropland pixels in Austria (I = 40,244), c the crops in sequence of the three crop rotations, m represents alternative crop management practices including crop rotations, fertilization rates, and irrigation (M = 12), s represents states of nature and is the product of $T*k$, where T represents the years of simulation (T=30) in each climate scenario and k a constant representing the number of climate scenarios. In the historical scenario k=1, and in the future period k=5. Thus, in the historical period s results in 30 states of nature and in the future period in 150 states of nature. Commodity prices represent the mean of the period 2010-2012 as reported by Statistics Austria. Variable production costs include purchases of seeds, pesticides, fertilizers, fuel, irrigation water, and electricity, costs of repair, insurances as well as labor costs and are taken from the standard gross margin catalogue and from other data sources. Additionally, we consider agricultural policy premiums such as a uniform decoupled payment (DP) and agri-environmental premiums (ÖPUL) for reduced fertilization (i.e. moderate fertilization rate in EPIC) and low fertilization (i.e. abandonment of commercial nitrogen fertilizer) levels.

We investigate six policy scenarios to cover current premium levels as well as potential developments: (i) DP100%-ÖPUL100% is the reference scenario and considers 290 €/ha of a uniform DP, and ÖPUL premiums for moderate (50 €/ha) and low fertilization levels (115 €/ha) according to the current Austrian Rural Development Programme, (ii) DP0%-ÖPUL100% assumes that DP is abolished and ÖPUL premiums remain the same as in the reference scenario, (iii) DP0%-ÖPUL0% assumes that all agricultural policy premiums are abolished, (iv) DP100%-ÖPUL0% assumes that DP remains the same as in the reference scenario but the ÖPUL premiums are abolished, (v) DP0%-ÖPUL200% assumes that DP is abolished but ÖPUL premiums are doubled compared to the reference scenario, and (vi) DP0%-ÖPUL300% assumes that DP is abolished but ÖPUL premiums are increased threefold compared to the reference scenario. Analyzing these six contrasting policy scenarios allows us to estimate the effect of institutional interventions on the adaptive capacity.

2.5 Portfolio Optimization Model

We apply portfolio optimization to identify combinations of crop management practices which reduce adverse climate change impacts and capitalize on potential opportunities arising with climate change using a mean-standard deviation model (similar to mean-variance model; Markowitz, 1952). The mean-standard deviation model assumes that the farmers’ choices under risk can be described by a function over the mean and the standard deviation which is weighted by a risk aversion parameter. Besides the standard deviation or variance, several other risk measures have been considered in the recent literature, creating a family of models (Mansini et al., 2014), such as lower partial moment (LPM), value at risk (VaR) or conditional value at risk (CVaR). VaR assesses the probability and magnitude of extreme losses during a certain period. The CVaR measures the expected amount of loss conditional on the fact that the VaR threshold is exceeded, and depicts situations of extreme risk (Rockafeller and Uryasev, 2002). CVaR had a great impact on new developments of risk models in finance and banking as extreme risk measure for small tolerance levels (Mansini et al., 2014). The mean-variance approach has been widely used in agriculture (OECD, 2009). For instance, Barkley et al. (2010) apply mean-variance analysis to optimize the selection of wheat varieties in Kansas. Roche and McQuinn (2004) use mean-variance portfolio optimization to investigate farmers' optimal land allocation choices considering agricultural policy change, and Strauss et al. (2011) optimize crop production portfolios for selected crops using a mean-variance approach.

We employ a non-linear mean-standard deviation model to determine optimal crop production portfolios for different levels of risk aversion. The model maximizes a weighted sum of expected gross margins discounted by the standard deviation using a risk aversion parameter (Freund, 1956). We gradually increase the level of the risk aversion parameters (θ) in the objective function and assume that for θ=0 a farmer would be indifferent to risk (risk neutral), whereas θ=1.0 can be interpreted as low, θ=2.0 as moderate, and θ=2.5 as high risk aversion. Risk neutrality is supposed to lead to specialization in one crop management practice, which provides the highest expected utility, i.e. inserting θ=0 in Equation 2, the non-linear term of the objective function cancels out.

The mean-standard deviation model is defined in Equation 2 and separately solved for the historical and future period, each 1 km pixel *i,* and risk aversion parameter level θ*.* The future period includes five climate change scenarios. Due to high uncertainty, the climate change scenarios are assumed to occur equally likely and are thus equally weighted in the model. Note that cropland endowment within a pixel varies regionally and is highest in the eastern and north-eastern parts of Austria where relative shares of cropland mostly exceed 50%.

$$\max_x Z_i = \sum_{m,s} x_{i,m}\, E(\pi_{i,m,s}) - \theta[\frac{1}{S}\sum_{m,s}(\pi_{i,m,s} - E(\pi_{i,m,s}))^2]^{\frac{1}{2}} \qquad \forall\, i$$

$$s.t. \sum_{m,s}\left(A_{i,m,s}\, x_{i,m}\right) = b_i \qquad \forall\, i \qquad (2)$$

where Z is the objective function value that is to be maximized, x is the portfolio variable representing the share of crop management practices *m,* in the portfolio of each cropland pixel *i;* π denotes gross margins (see Equation 1); E refers to the expected value of alternative annual outcomes in the historical and future period, respectively; θ is the risk aversion parameter; A the Leontief production function, which converts land resources and other inputs into crop commodities,; and b denotes the total cropland area in pixel *i*. The optimization is subject to the condition that the portfolio shares of crop management practices have to sum up to 100%.

3 Results

3.1 Robust Crop Production Portfolios under Climate Change

We assess the effects of climate change, adaptation measures, and risk aversion on the composition of optimal crop production portfolios as well as the implications for agricultural vulnerability, i.e. changes in crop yields and gross margins. The identified crop production portfolios capture the trade-off between expected gross margins, their climate-induced variability, and risk aversion and aim to reducing agricultural vulnerability. Frequency distributions of chosen portfolios at pixel level are shown in Table 1 for the historical and the future period and four levels of risk aversion. The columns 'historical' and 'future1' refer to crop production portfolios which consist of maximum four management practices. Portfolios presented in column ‘future2’ consider additional crop rotation systems (CRS2-3) (see section 2.3). As we are interested in the crop fertilization intensities and irrigation we add up the portfolio results for CRS1-3 in ‘future2’ for reasons of clarity.

In the historical period, moderate fertilization intensity is found most often (i.e. on 51% of all pixels) in optimal crop production portfolios when risk aversion is not accounted for, followed by high (18%) and low fertilization (18%). With moderate and high risk aversion, portfolios including low fertilization intensity are chosen most often – either as single strategies (16%) or as part of crop production portfolios, in which it is most often combined with moderate intensity (14%). This indicates that risk aversion could lead to decreasing total agricultural production if the current cropland area remains constant.

Accounting for climate change and the same crop management practices (i.e. ‘future1’), we find that the proportion of portfolios including irrigation nearly doubles (from 13% to 22%) with risk neutrality. Reduced fertilization intensity prevails (40%) though the proportion is considerably smaller than in the historical period. It is followed by high fertilization intensity which increases from 18% in the past to 30% under climate change. With increasing risk aversion, portfolios with low fertilization rates are hardly present as a single management measure in a portfolio, but in combination with irrigation (15% with moderate and 17% with high risk aversion). Portfolios including irrigation and high fertilization intensity play a more important role than in the historical period regardless of the risk aversion level.

Table 1. Portfolio shares (in %) for the historical and the future period (future1, future2) and four risk aversion parameter levels (RAP).

RAP	θ=0.0 risk neutral			θ=1.0 low risk aversion			θ=2.0 moderate risk aversion			θ=2.5 high risk aversion		
period	historical	future1	future2	historical	future1	future2	historical	future1	future2	historical	future1	future2
# of CRS	CRS1	CRS1	CRS1-3	CRS1	CRS1	CRS1-3	CRS1	CRS1	CRS1-3	CRS1	CRS1	CRS1-3
crop management combination												
i	13	22	26	9	16	**19**	7	13	**16**	7	12	**15**
ih	0	0	0	2	4	5	3	6	6	3	6	6
ihm	0	0	0	1	1	5	1	1	9	1	2	9
ihml	0	0	0	0	0	1	0	0	3	0	1	5
ihl	0	0	0	0	1	1	1	3	2	1	4	3
im	0	0	0	6	7	10	5	6	9	5	6	8
iml	0	0	0	1	1	2	3	3	5	3	3	6
il	0	0	0	5	7	5	10	**15**	10	10	**17**	12
h	18	30	27	11	16	11	7	10	5	7	8	4
hm	0	0	0	7	10	17	7	10	13	7	8	11
hml	0	0	0	1	1	3	3	3	6	3	4	7
hl	0	0	0	5	5	1	10	8	2	10	10	2
m	**51**	**40**	**41**	**26**	**22**	14	13	11	5	13	8	3
ml	0	0	0	10	4	5	14	8	6	14	8	6
l	18	8	6	15	4	2	**16**	3	2	**16**	3	1

Note1: In ‘historical’ and ‘future1’ we consider only one crop rotation system (CRS1) derived from historical land use. In ‘future2’ we consider additional crop rotation systems (CRS2-3) in the crop production portfolios but do not make them explicit. Crop management measures considered in the portfolios: high fertilization rates on irrigated cropland (i), high (h), moderate (m), and low (l) fertilization intensity on rain-fed cropland. Portfolios with the highest share are indicated **in bold.**

Allowing for more adaptation measures, i.e. additional CRS in the future period (‘future2’ in Table 1), we find that, similar to ’future1’, portfolios with only moderate fertilization intensity prevail (41%) with risk neutrality followed by portfolios with high fertilization intensity (27%) and irrigation (26%). Compared to the historical period and ‘future1’, the proportions of portfolios including irrigation, high or moderate fertilization intensities are notably higher for all risk aversion levels, while the share of portfolios with high, moderate or low fertilization intensities as single management strategies decrease. With increasing level of risk aversion the share of portfolios containing only irrigation declines from 26% with risk neutrality to 15% with high risk aversion. This happens mainly because diversification increases and the proportion of portfolios including three or even four managements increases as well.

Implications of portfolio choices on average Austrian crop yields and expected gross margins are presented in Table 2. To discern the pure climate change impact, we assign the optimal portfolio shares, i.e. management combinations of the historical period to future climate conditions. At national level, we find that climate change (i.e. increase in temperature and CO_2 levels) results in slight increases of total crop production of 2% and of expected gross margins of 3% compared to the historical period. These positive effects increase if we allow for further adaptation measures, i.e. average levels of production increase by 14-15% and average gross margins by 10-18%, depending on the level of risk aversion. In comparison to risk neutrality, increasing level of risk aversion leads to declines in total crop production of about 3% in the historical and the future period whereas gross margins decrease between 4% (past) and 11% (future). This may result from increasing diversification of portfolios towards an inclusion of less intensive management practices in scenarios with high risk aversion. It is also confirmed by portfolio theory proposing that lower levels of expected gross margins have to be accepted for lower levels of risk. Though the relative impact of risk aversion on gross margins is higher in the future, gross margins are still expected to exceed past levels. However, the presented numbers refer to the national average and vary spatially. Crop production levels, benefits of adaptation measures, and thus gross margins vary across traditional crop production regions, which differ, for instance, in soil, topographic, and climate conditions. The spread across regions also reflects the differences in regional agricultural vulnerability to climate change.

Table 2. Average annual dry matter (DM) crop yields in t/ha and expected gross margins in €/ha and standard deviations (stdev) by levels of risk aversion parameters (RAP) and the historical (1975-2005) and the future period (2010-2040).

RAP	**θ=0**	**θ=1.0**	**θ=2.0**	**θ=2.5**	**θ=0**	**θ=1.0**	**θ=2.0**	**θ=2.5**
period	**DM crop yield in t/ha (stdev)**				**gross margin in €/ha (stdev)**			
historical (CRS1)	6.8 (2.62)	6.8 (2.62)	6.7 (2.58)	6.6 (2.57)	486 (198)	480 (186)	469 (178)	465 (175)
pure CC effect (CRS1)	6.9 (2.63)	6.9 (2.64)	6.8 (2.60)	6.7 (2.59)	499 (197)	494 (190)	482 (185)	477 (184)
future (CRS1-CRS3)	7.8 (2.56)	7.8 (2.63)	7.6 (2.65)	7.6 (2.65)	575 (204)	544 (136)	518 (118)	511 (115)

Legend: CRS (crop rotation system), CC (Climate Change)

3.2 Robust Crop Production Portfolios under Climate and Policy Change

Portfolio shares of optimal crop production portfolios of the future period are shown in Table 3 for four levels of risk aversion and six policy scenarios. We consider changes in levels of risk aversion to approximate individual adaptive capacity and changes in levels of DP and ÖPUL premiums to approximate institutional adaptive capacity. DP enter the portfolio optimization model as a constant so that the crop management shares in the optimal portfolios are the same for DP100%-ÖPUL100% and DP0%-ÖPUL100%. In case of risk neutrality, the abolishment of ÖPUL premiums leads to intensification, i.e. the shares of rain-fed and irrigated portfolios with high fertilization intensity increase to 54% and 36%, respectively. On the contrary, the share of intensively fertilized portfolios amounts to 27% (rain-fed) and 26% (irrigated) with ÖPUL premiums of 100%, and declines to zero with ÖPUL premiums of 300%. If ÖPUL premiums exceed 100%, the share of portfolios which include irrigation in combination with high or moderate fertilization intensity decline to less than 5% regardless of the risk aversion level. However, with increasing risk aversion irrigation is increasingly adopted in portfolios, which is mainly complemented with low fertilization management practices.

Raising ÖPUL premiums to 200% and 300% unsurprisingly increases the share of low (to 33% and 68%) and moderate fertilization (to 57% and 31%) intensity under risk neutrality. Similar trends can be observed for all levels of risk aversion. For instance, the share of portfolios with only low fertilization intensity increases from 1% (in case of no payments) to 40% (with 300% ÖPUL premiums) with low risk aversion and from 1% to 16% with high risk aversion. Portfolios combining moderate and low fertilization intensities prevail with ÖPUL200% (21-23%) and ÖPUL300% (39-42%) for moderate and high risk aversion levels. The results highlight the fact that portfolio diversification increases with increasing risk aversion despite of the allocation of high ÖPUL premiums. This indicates that – even with rising ÖPUL premiums – the shares of portfolios which include a combination of crop management measures and not only focus on low and reduced fertilization increases.

Table 3. Portfolio shares (in %) for six policy scenarios and four risk aversion parameter levels (RAP).

RAP		θ=0.0 risk neutral						θ=1.0 low risk aversion						θ=2.0 moderate risk aversion						θ=2.5 high risk aversion					
DP		100%	0%	100%	0%	0%	0%	100%	0%	100%	0%	0%	0%	100%	0%	100%	0%	0%	0%	100%	0%	100%	0%	0%	0%
ÖPUL		100%	0%	0%	100%	200%	300%	100%	0%	0%	100%	200%	300%	100%	0%	0%	100%	200%	300%	100%	0%	0%	100%	200%	300%
crop management combination	i	26	36	36	26	8	0	**19**	31	31	**19**	5	0	**16**	**28**	**28**	**16**	5	0	**15**	26	26	**15**	5	1
	ih	0	0	0	0	0	0	5	19	19	5	0	0	6	27	27	6	0	0	6	**27**	**27**	6	1	0
	ihm	0	0	0	0	0	0	5	3	3	5	1	0	9	7	7	9	2	0	9	8	8	9	3	0
	ihml	0	0	0	0	0	0	1	0	0	1	0	0	3	1	1	3	2	0	5	2	2	5	4	1
	ihl	0	0	0	0	0	0	1	0	0	1	0	0	2	2	2	2	1	0	3	3	3	3	1	0
	im	0	0	0	0	0	0	10	3	3	10	5	1	9	3	3	9	5	1	8	3	3	8	5	1
	iml	0	0	0	0	0	0	2	0	0	2	5	2	5	1	1	5	9	5	6	1	1	6	11	7
	il	0	0	0	0	0	0	5	0	0	5	13	8	10	2	2	10	19	19	12	3	3	12	**21**	23
	h	27	**54**	**54**	27	2	0	11	**33**	**33**	11	1	0	5	18	18	5	0	0	4	14	14	4	0	0
	hm	0	0	0	0	0	0	17	6	6	17	7	0	13	7	7	13	6	1	11	6	6	11	6	1
	hml	0	0	0	0	0	0	3	0	0	3	4	1	6	1	1	6	9	4	7	2	2	7	11	6
	hl	0	0	0	0	0	1	1	0	0	1	1	0	2	1	1	2	2	1	2	2	2	2	2	2
	m	**41**	8	8	**41**	**57**	31	14	3	3	14	**23**	9	5	1	1	5	9	5	3	1	1	3	6	4
	ml	0	0	0	0	0	0	5	1	1	5	**23**	38	6	1	1	6	**23**	**42**	6	1	1	6	**21**	**39**
	l	6	1	1	6	33	**68**	2	1	1	2	11	**40**	2	1	1	2	5	21	1	1	1	1	4	16

Note: Agricultural policy scenarios consider different levels of decoupled payments (DP) and agri-environmental premiums (ÖPUL). As DP is a constant, the results of DP100%-ÖPUL100% and DP0%-ÖPUL100% are the same. DP100%-ÖPUL100% is the reference scenario. Crop management measures considered in the portfolios: high fertilization rates on irrigated cropland (i), high (h), moderate (m), and low (l) fertilization intensity on rain-fed cropland. Portfolios with the highest share are indicated **in bold.**

Average dry matter crop yields amount to 7.6-7.8 t/ha in the future period with DP100%-ÖPUL100% (reference policy scenario). When ÖPUL premiums are reduced to zero, average crop yields increase to 7.8-8 t/ha (Table 4) which is mainly because the share of portfolios including high fertilization and irrigation increases. This is the case regardless of the presence of DP. Similarly, when ÖPUL premiums remain at the current level (100%), average crop yields are the same for the case with and without DP. This confirms that DP are aimed at increasing the mean income of each farm, but do not guide crop management choices. When DP remain zero, and ÖPUL premiums are increased to 200%, we find an increased adoption of moderate fertilizer application and average crop yields of 6.7-6.9 t/ha, which is a slight decrease compared to the reference policy scenario under climate change. With ÖPUL300%, which induces the adoption of low fertilization intensity in the portfolios, average dry matter crop yield notably declines compared to the reference scenario to between 5.8-6.2 t/ha.

Regarding the difference in crop yields for the various degrees of risk aversion, we find that in all policy scenarios, except for DP0%-ÖPUL200% and DP0%-ÖPUL300%, average crop yields decline with increasing risk aversion. With ÖPUL premiums of 200% and 300% a slight increase of crop yields is observed with increasing risk aversion. This is mainly due to higher diversification of crop production portfolios away from solely reduced and low fertilizer managements towards e.g. the combination of irrigation and low fertilization rates.

The average gross margins are highest in the reference policy scenario for each level of risk aversion. Without any agricultural payments and in case only DP is introduced, mainly irrigation and high fertilization intensity are adopted which support high crop yields and thus returns, but also entail higher costs. When only DP but no ÖPUL premiums are provided, average gross margins are similar as in the reference policy scenario. It seems that higher returns due to intensification can almost offset abolished ÖPUL premiums. The higher variable costs for portfolio management could be compensated by the DP, which then leads to similar average gross margins as the reference policy scenario. Still, average gross margins are slightly higher in the reference policy scenario which could imply that both, farmers and the environment, are better off whereas total crop production outputs decrease between 3-4%. Throughout the policy scenarios, we find that average gross margins decrease with increasing levels of risk aversion.

Table 4. Average annual dry matter (DM) crop yields in t/ha and expected gross margins in €/ha for six policy scenarios and four risk aversion parameter levels (RAP) in the future period (2010-2040).

RAP		θ=0	θ=1.0	θ=2.0	θ=2.5	θ=0	θ=1.0	θ=2.0	θ=2.5
DP	ÖPUL	DM crop yield in t/ha				gross margin in €/ha			
100%	100%	7.8	7.8	7.6	7.6	575	544	518	511
0%	100%	7.8	7.8	7.6	7.6	286	253	229	221
0%	0%	8.0	8.0	7.9	7.8	277	246	223	217
100%	0%	8.0	8.0	7.9	7.8	566	536	514	507
0%	200%	6.7	6.9	7.0	6.9	325	289	260	252
0%	300%	5.8	5.9	6.1	6.2	402	367	333	323

Legend: DP (Decoupled payment), ÖPUL (agri-environmental payments).

In light of these results, the average amount of nitrogen fertilizer application is not surprising. Without ÖPUL premiums, fertilizer inputs increase between 6-8% compared to the reference policy scenario. Increasing ÖPUL premiums result in lower average fertilizer inputs (between -11 and -19% with ÖPUL200% and between -23 and -33% with ÖPUL300%) and likely to lower emissions, but also in lower crop yields. However, the average fertilizer application efficiency, which is defined at national level as the ratio of the average crop yields to the average fertilizer application rates, is highest with ÖPUL300% although average crop yields and nitrogen fertilizer application rates are lowest. The scenario without any payments shows the lowest efficiency levels, together with the scenario where DP are granted but no ÖPUL premiums. Thus, an increase in ÖPUL premiums will likely increase the efficiency of nitrogen fertilizer application if crop production portfolios and regions of application are chosen carefully. This can also decrease negative environmental externalities.

The spatial distribution of crop management choices is shown in Figure 2 for the future period and the reference policy scenario, DP100%-ÖPUL100%. Irrigated cropland dominates in the crop production portfolios. In particular, it is found in the semi-arid regions in north-east Austria for all levels of risk aversion. With increasing risk aversion, irrigated cropland seems to expand geographically towards the south. Rain-fed portfolios including high fertilization rates are rather found in the north-western and south-eastern parts of the country as well as in the alpine foreland. With increasing risk aversion the regional distribution of high fertilization intensity remains similar though the hectare shares in the portfolios are decreasing. This indicates a higher degree of portfolio diversification where high fertilizer application is part of. Higher shares of moderate fertilization intensity are in particular found in less-productive crop production regions, i.e. in the north-western and south-western parts of the country as well as in several inner-alpine valleys. Low fertilization intensity is only found in marginal agricultural production areas assuming current agri-environmental payments. Its share increases slightly with increasing level of risk aversion. It should be noted that such marginal production areas might be abandoned under climate change. However, the current version of the portfolio optimization model does not allow for this option.

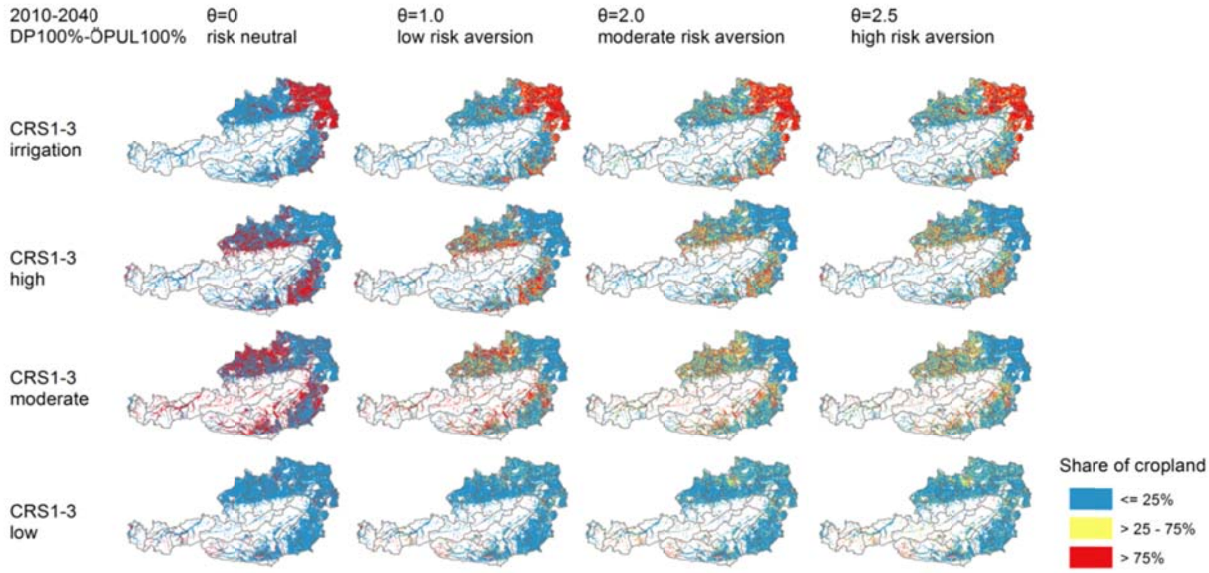

Figure 2. Share of cropland cultivated with different management practices for the future period and the policy scenario DP100%-ÖPUL100% (reference scenario).

4 Discussion and Conclusions

We have developed and applied an integrated agricultural vulnerability assessment framework in order to investigate, spatially explicit, climate change impacts as well as the effects of changes in the adaptive capacity, i.e. changes in risk preferences and agricultural policies on crop production in Austria. We apply a portfolio optimization model to identify optimal crop production portfolios for a historical and a future period, six policy scenarios, and four levels of risk aversion. Using crop yields and gross margins as indicating variables for bio-physical and social vulnerability, the model results suggest to expand high fertilization intensity on rain-fed and irrigated cropland to decrease vulnerability to climate change. This indicates that, under climate change, higher production costs can be compensated with higher crop yields and thus revenues. The need to increasing incentives for adopting irrigation under climate change (due to above-average yield levels and decreasing yield variability) are found in other modelling studies as well (e.g. Heumesser et al., 2012). However, economic benefits of irrigation are sensitive to cultivated crops (Lehmann et al., 2013) and changes in price levels (Finger et al., 2011).

We consider different risk aversion levels and agricultural policy scenarios to approximate changes in agricultural adaptive capacity. We find that increasing risk aversion typically results in increasing portfolio diversification and decreasing crop yields which is confirmed by empirical studies (e.g. Bezabih and Sarr, 2012). In particular, low fertilization intensity and irrigation seem to gain in importance with increasing risk aversion. Crop production portfolios are dominated by highly intensive fertilization measures (rain-fed and irrigated) if ÖPUL premiums are abolished in the climate change scenario. It becomes apparent that higher returns due to higher crop yields can almost offset abolished ÖPUL premiums. Assuming the abolishment of DP but higher ÖPUL premiums, we observe a decline in crop yields and gross margins but also in nitrogen fertilizer input. This result points to observed trade-offs between agricultural production, farm net-returns, and environmental impacts. However, it remains unclear whether higher ÖPUL premiums, which lead to extensification on investigated cropland areas and thus improve environmental quality, could maintain the nationally required crop production level, i.e. to maintain the historical level of crop production. To maintain these levels, irrigated, intensively cultivated cropland would be important and ÖPUL premiums should not exceed a twofold increase compared to current premium levels. Spatial analyses show that crop management choices are driven by heterogeneities in soil, topographic, and climate conditions and some crop production regions are better suited for extensification or intensification. Therefore, introducing spatially targeted agri-environmental programs, which strengthen adaptive capacity and also increase environmental quality without compromising on aggregate food production according to the bio-physical suitability of cropland, instead of equal supports across cropland could be considered. Further, targeted governmental supports for introducing irrigation systems to further support adaptive capacity could be considered.

Our integrated vulnerability assessment framework allows considering a broad range of aspects affecting agricultural vulnerability, i.e. soil, topographic, and climate conditions, different adaptation measures and levels of risk aversion as well as policy scenarios. However, several aspects have yet to be explored. We currently disregard that input and output prices as well as market constraints might change in the future. Though being discussed controversially (see e.g. Hampicke, 2011), several authors prefer this approach due to various reasons. For instance, such a quasi-static analysis does not require scenarios on the development of the economy over the next decades. This may be difficult as price projections are usually available for the next ten years (e.g. OECD/FAO, 2013) and not for several decades and are contingent on assumptions for certain development pathways. Keeping input and output prices constant also allows for separating climate change and policy effects from price or market effects and thus facilitates the interpretation of the results (Ciscar et al., 2011).

Another aspect yet to be explored is the uncertainty about changes in frequency and magnitude of extreme weather events as well as their effects on bio-physical and economic outcomes – an issue that is typically raised by agricultural stakeholders such as extension experts (Mitter et al., 2014). Though relevant for climate change impact assessments and crop production choices we are only able to consider extreme events that are represented by observed daily weather data. In the portfolio optimization model we use the standard deviation to incorporate the spread of the distribution of expected gross margins. A detailed economic analysis of extreme events – which are typically characterized by low probabilities of occurrence and high (costly) impacts (Weitzman, 2009; Dietz, 2011) – would require focusing on the tail of the distribution (Kunreuther et al., 2013). Accordingly, alternative risk measures such as the Value at Risk (VaR) and the Conditional Value at Risk (CVaR) could be applied in the portfolio optimization model to meet this demand and to derive robust results.

Further, the assumptions about farmers' risk preferences need to be interpreted with caution. We focus on four risk aversion levels, and implicitly assume constant absolute risk aversion (CARA) preferences, i.e. preferences amongst risky alternatives remain unchanged if initial wealth changes (Chavas, 2004). Though empirical evidence is mixed, decreasing absolute risk aversion (DARA) preference, i.e. increasing wealth improves the ability to manage risks, is rather intuitive. However, the mean-standard deviation framework assumes that the farmers' risk aversion can be described by a function over the mean and the standard deviation using a risk aversion parameter. It is straightforward, easily computable, and frequently applied in the context of agriculture (e.g. Roche and McQuinn, 2004; Strauss et al., 2011; Barkley et al., 2010).

In order to inform policy making processes, additional indicators related to employment, sales or changes in the value chain could be investigated as well. However, we are not able to consider these aspects in the current modelling framework. Our analysis is driven by agronomic practices and bio-physical processes which allow us to quantify the effects of optimal crop management choices on crop yields, gross margins, and environmental effects.

Finally, we are aware of further methodologies suitable for coming up with robust climate change adaptation measures in agriculture. There is also a need to investigate this issue from a farm management perspective which requires including detailed aspects on farm characteristics such as farm type, size, and financial management, individual farmer's behaviour, and fixed cost components in the analysis. Farmers are challenged to understand and assess opportunities and threats arising with climate change. Regardless of their attitudes towards managing risks and uncertainties, they require information and support (e.g. from extension experts, insurance agencies or financial service providers) in order to assess vulnerability and realize the potential of adaptive capacity (Ruben and Pender, 2004). Investigations at farm level should therefore consider aspects of risk and uncertainty communication which could be facilitated with a participatory research design.

Acknowledgement

This research has been supported by the projects CC2BBE (Vulnerability of a bio-based economy to global climate change impacts) funded by the Austrian Climate and Energy fund within ACRP and MACSUR (Modelling European Agriculture with Climate Change for Food Security), a FACCE JPI knowledge hub (http:/www.macsur.eu) and the Federal Ministry of Agriculture, Forestry, Environment and Water Management of Austria (Contract No. 100875), and has been prepared in the framework of the Doctoral School of Sustainable Development (dokNE) of the University of Natural Resources and Life Sciences, Vienna.

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